Autoassembly of cage structures
5*. Synthesis, stereochemistry and cyclization of α,α′-dihydroxy-α,α′-dimethyladipic acid derivatives

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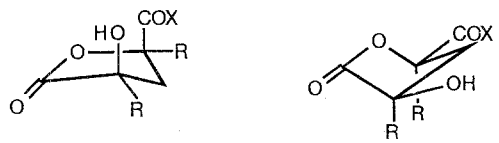
The *d,l*-(**1a**) and *meso*-forms (**1b**) of α,α′-dihydroxy-α,α′-dimethyladipic acid, dilactone (**3**), diiminodilactone (**4**), and lactonolactam (**5**) were obtained by the reaction of acetonylacetone with KCN and HCl. The transformations of **1** to the esters **2**, dilactone **3** to **1a**, and diiminodilactone **4** to dilactone **3** were studied. It was shown that **3** can be readily obtained from **1a** by thermolysis, acid catalysis, and DCC action as well as by acid catalyzed cyclization of **2a**, while dilactone **3** can be obtained from **1b** and **2b** in negligible yield only under drastic conditions, obviously, due to the partial epimirization of the *meso*-forms. The mild thermolysis of **1b** leads to *trans*-lactonoacid (**6**), from which the ester **7** has been obtained. The effective acid catalyzed cyclization of amides **8** and **9** to **3**, lactamoamide **12** to **5**, and amide **14** to model lactone **13** was found. The NMR spectra of the products were studied, and a ^{1}H NMR test was suggested for identification of *d,l*- and *meso*-forms **1** and **2**. The stereochemistry of monolactones **6**, **7**, **9**, **10a**, **10b**, **11**, and dilactone **3** was established. The differences in the chemical behavior of α,α′-dihydroxyglutaric and adipic acids were explained by the significant reduction of the non-bonded interactions of the substituents in the corresponding monolactones during the transfer from 1,3- to 1,4-substituted systems.

Key words: acetonylacetone, its biscyanohydrine, *meso*-α,α′-dihydroxy-α,α′-dimethyladipic acid, its dimethyl ester, monolactone, and methyl ester of the latter, *d,l*-α,α′-dihydroxy-α,α′-dimethyladipic acid, its dimethyl ester, *N,N′*-dibenzil- and *N,N′*-di-α-phenylethylamides, monolactone, *N*-*tert*-butyl- and *N*-α-phenylethylamides, dilactone, diiminodilactone, lactonolactam, lactonization of δ-hydroxycarboxylic acids, their esters and amides; ^{1}H NMR test for *d,l- and meso*-form identification, conformation of substituted valerolactones.

The formation of bicyclic dilactones («autoassembly») from derivatives of α,α′-dihydroxyglutaric acid is a configurationally and conformationally controlled reaction.[2] This reaction proceeds only in the case of *d,l*-, but not *meso*-forms, and only when the α,α′-substituents R are more bulky than COX and OH, since in the intermediate monocycles the COX and *cis*-OH groups are close enough to allow final cyclization in conformation **A**, but not in **B**.



A **B**

X = OH, OR
R = H, Alk

Thus, dilactones can be readily obtained from *d,l*-α,α′-dihydroxy-α,α′-dialkylglutaric acids (**A**, R = Me, Et, Bu^t) and their derivatives in high yields,[3,4] but *d,l*-α,α′-dihydroxyglutaric acid (**B**, R = H) gives no dilactone even under drastic conditions.[2] On the other hand, it is known that dilactones smoothly arise from *d,l*-forms of both α,α′-dihydroxy-α,α′-dimethyladipic (DDA)[5–9] and α,α′-dihydroxyadipic[6,10] acids. To find the reasons for this difference, the preparation, stereochemistry, and cyclization of DDA (**1**), its methyl ester (**2**), and some DDA derivatives have been studied in the present work.

Isomeric DDA were obtained* by the Zelinsky reaction[11] of acetonylacetone (AA) with KCN and HCl taking into account the changes in this procedure suggested in Refs. 5 and 6. The results of the reaction are known to depend significantly on the conditions and on the method of treatment: together with DDA, mono-

*For report 4 see Ref. 1.

**For the previous report see Ref. 9

***Bis-cyanohydrine of acetylacetone exists in the form of the product of a similar monocyclization, *i.e.*, iminolactononitrile of *meso*-α,α'-dihydroxy-α,α'-dimethylglutaric acid.[3]

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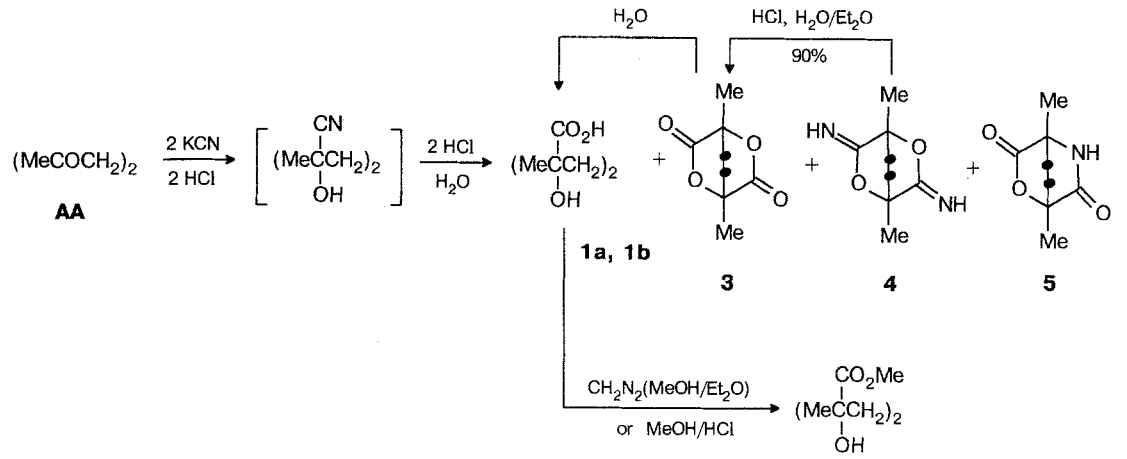
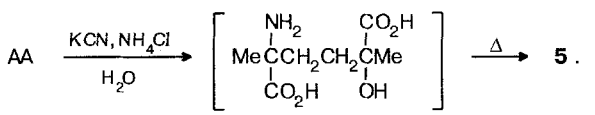
Scheme 1



d,l-**2a**, *meso*- **2b**

lactones[5] and dilactone[5–8] are obtained, and in an excess of NH_4Cl monoaminonitrile[11,12] and the products of its subsequent conversions are formed. Earlier, in all of the cases it was suggested that acetonylacetone biscyanohydrine is initially formed, and this substance was described as an unstable solid or *semi*-crystal,[5–7] but it was not characterized. We isolated DDA as the *d,l*- (**1a**) and *meso*- (**1b**) forms (when synthesis is repeated many times, only **1b** is obtained and **1a** is formed in only one case), and as dilactone **3**, diiminodilactone **4**, and lactonolactam **5** (**4** and **5** have not been described earlier). Compound **4** seems to be a product of double Pinner cyclization of *d,l*-biscyanohydrine of acetonylacetone,** and dilactone **3** is obtained as a result of the partial hydrolysis of diiminodilactone **4**. Possibly, the formation of acid **1b** occurs due to the complete hydrolysis of acetonylacetone *meso*-biscyanohydrine derivatives, which are not capable of double cyclization. We also obtained DDA **1a** by hydrolysis of dilactone **3** (Scheme 1).

It is possible to describe the formation of lactonolactam **5** either as the result of a single Chapman rearrangement and the partial hydrolysis of **4**, or as the result of the cyclization of the α-hydroxy-α'-amino substituted DDA that arises according to the following scheme (*cf.* Refs. 11, 12):



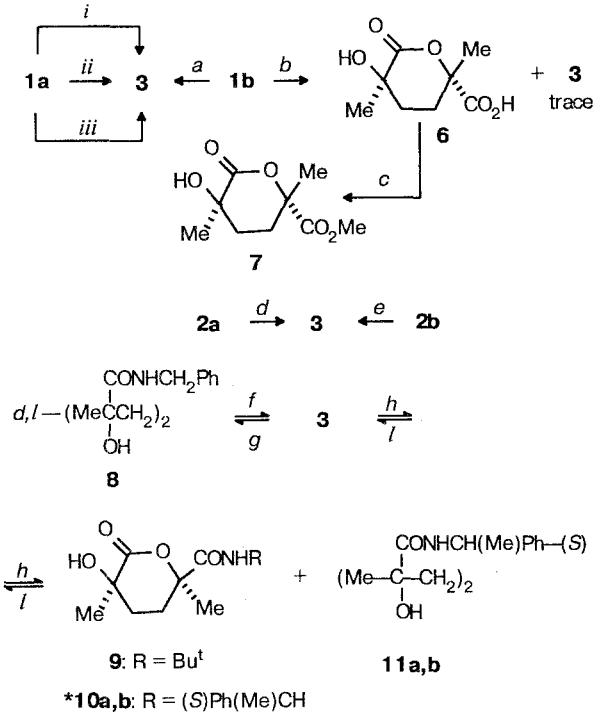
Earlier, the configuration of *d,l*-DDA has been unequivocally proved by separation of antipodes,[6] but it is difficult to distinguish the *d,l*- and *meso*-forms by their melting points[5–8,11] (according to our data, m.p. of **1a** is 193—220 °C and that of **1b** is 212—220 °C). Therefore, the data[5] about interconversion of **1a** and **1b** refluxed in water or in a weak HCl solution seem to be doubtful (it was assumed[6] that a mixture of **1a** and **1b** was considered by Fittig[5] as the *meso*-form). Therefore to identify the isomers, we developed a ^1H NMR test based on the greater geminal non-equivalence of the methylene protons of the *meso*-form (*cf.* Ref. 13): the spectrum widths of **1a** and **1b** were 70 and 190 Hz, respectively (400 MHz in CD_3OD) (Table 1). In addition, according to the ^1H NMR spectra in D_2O/KOD, the potassium salt of acid **1a** is identical to the known *d,l*-form obtained from lactone **3**. Using this ^1H NMR test, we showed that under these conditions[5] (1h reflux in a mixture of water and concentrated HCl, 2:1 in volume), acid **1a** only yields a mixture of **3**:**1a** (7:3), but not **1b**, and **1b** under the same conditions does not change when refluxed for 3h. We also showed that, contrary to the data reported earlier,[7] DDA are easily esterificated, when they are for a short time stored in MeOH with dry HCl, or when their methanol solutions are treated with a CH_2N_2 solution in ether. Unlike DDA, their esters (**2a** and **2b**) have distinct melting points that differ by 60 °C (see Experimental), and yet, like DDA, the width of the methylene proton resonance is considerably greater for the *meso*-form (**2b**, Table 1).

As expected, dilactone **3** is smoothly formed from *d,l*-DDA **1a** by thermolysis and treatment with a HCl solution in Et_2O[5–8] or with dicyclohexylcarbodiimide (DCC). We have advanced a still more effective synthesis for **3** from derivatives of **1**, *viz.*, diester **2a**, diamide (**8**), and lactonoamide (**9**) (Scheme 2).

When the *meso*-forms of **1b** and **2b** are used, dilactone **3** can be obtained only under drastic conditions and in negligible yield, due, apparently to the preceding partial epimirization. Milder thermolysis of **1b** mainly yields *trans*-lactonoacid (**6**), from which ester **7** was obtained.

It should be pointed out that dilactone **3** affords only diamide **8** even when treated with a deficient amount of benzylamine, but in the reactions with sterically hindered amines, monoamides **9** and **10** are exclusively (or

Scheme 2



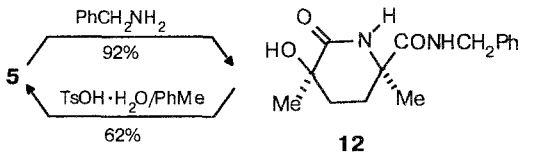
Reagents and conditions (yield): *a.* Δ (< 10%); *b.* 140–170 °C/15 Torr (46.5%); *c.* CH_2N_2, Et_2O/MeOH (62%); *d.* TsOH · H_2O/PhMe, 110°C, 12 h (92%); *e.* TsOH · H_2O/PhMe, 110°C, 19 h (< 5%); *f.* $PhCH_2NH_2$ (42.5%); *g.* TsOH · H_2O/PhMe, (90%); *h.* RNH_2 (R = Bu^t, 32%); *l.* TsOH · H_2O/PhMe, (R = Bu^t, 91%); *i.* *t* > 200°C/1 Torr (40%); *ii.* HCl/Et_2O (21%); *iii.* DCC/C_5H_5N (43%).

*A mixture of diastereomers; the data about their separation, cyclization to dilactone **3**, and hyroptical properties will be reported in a special paper.

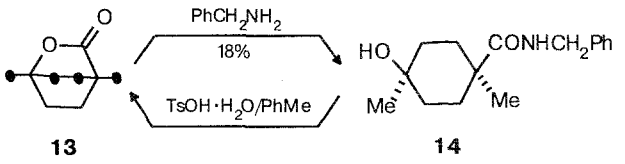
mainly) obtained. In the case of (*S*)-α–phenylethylamine, the minor diamide **11** in a diastereomerically pure state was isolated. Lactonolactam **5** is less reactive than dilactone **3**. The latter readily gives an acid reaction in an aqueous solution and undergoes conversion to the *d,l*-DDA salt in an ethanol alkaline solution, while lactonolactam **5** does not change when stored for 1 h at 20 °C in water or in an ethanol alkaline solution, is crystallized from boiling water, and is insensitive toward the action of HCl in ether. These facts exclude the monoiminodilactone structure for **5** (comp. Ref. 3). The reaction of **5** with an excess of benzylamine leads to the opening of the lactonic cycle to yield only lactamoamide **12**, which, similar to lactonoamides **9** and **10**, transforms to lactonolactam **5** *via* smooth acid catalyzed cyclization (Scheme 3).

Under analogous conditions, amide **14** obtained from model lactone **13** [14] undergoes cyclization to give **13** (Scheme 4).

Scheme 3

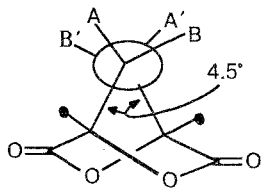


Scheme 4



Therefore, lactonization of δ-hydroxyamides has a general character. The structure of the compounds synthesized was confirmed by IR, ^1H NMR, and ^{13}C NMR spectroscopy, by mass-spectra, and by elemental analysis data (see Table 1 and Experimental).

The structure of dilactone **3** was confirmed by X-ray analysis.* Its molecule is twisted, and the dihedral angle CCH_2CH_2C is 4.5°.



The vicinal coupling constants values for the protons of **3** are in accordance with the Carplus dependence (Table 1). In the ^1H NMR spectra of monolactones **6**, **7**, **9**, and **10a,b** (Table 2), the characteristic signals of the four-spin system of the protons 3a, 3e, 4a, and 4e are present. The long-range coupling constants ^4J detected by the up-field signals of the methyl protons of **9**, **10a,b** and of the OH group of compound **7** indicate[15] the *pseudo*-axial orientation of these substituents. The absence of ^4J for all the other groups indicates the *cis*-orientation of the methyl groups in monolactones **9**, **10a,b** and their *trans*-(*e,e*) orientation in ester **7**. To unequivocally assign the ^1H and ^{13}C signals and to find the primary orientation of the substituents at the C-2 and C-5 atoms in monolactones **6**, **7**, **9**, and **10a,b**, ^{13}C NMR spectra with selective proton decoupling were used. Thus, in the ^{13}C NMR spectrum of **10a** the signal

*Results of X-ray analysis for compound **3** will be published separately.

Table 1. Spectral parameters of the *d,l*- and *meso*-forms of compounds **1—5**, **8**

Compound	^{1}H NMR[a] δ, ppm		NMR ^{13}C[b] (δ, ppm, *J*/Hz)				IR ν/cm^{-1}
	Me	$C(CH_2)_2C(A^1AB^1B)$ (signal linewidth/Hz)	Me	CH_2	—C—	C=O (C=N)	C=O (C=N)
1a	1.38	1.76 (70)	26.40 ^1J = 128.2	35.69 ^1J = 129.4 ^2J = 3.7	75.00 ^2J = 2.4	179.28	1745
1b	1.38	1.56 1.96 (190)	—	—	—	—	—
2a[c]	1.35	1.65 1.76 (95)	26.28 ^1J = 126.9	35.69 ^1J = 129.4 ^2J = 3.7	75.43 ^2J = 4.9	177.74	1740
	1.29[d]	1.75 2.00 (115)					
2b[e]	1.35	1.50 1.90 (185)	26.10 ^1J = 127.6	35.43 ^1J = 130.4 ^2J = 4.2	75.33 ^2J = 4.2	177.64	1740
	1.30[d]	1.63 2.07 (202)	—	—	—	—	—
3	1.58	2.11 2.25[f] (88)	19.01 ^1J = 129.4	29.55 t.q ^1J = 135.5 $^2J_{CH(CH_2)}$ = 4.2 $^3J_{CH(Me)}$ = 4.2	80.14 t.q $^2J_{CH(CH_2)}$ = 4.9 $^2J_{CH(Me)}$ = 1.4	168.69 d.d.q $^3J_{CH\text{-}anti}$ = 8.3 $^3J_{CH\text{-}sin}$ =4.2 $^3J_{CH(Me)}$ = 4.2	1795
	1.21[d]	0.88 1.08 (120)					
4[g]	1.57	2.02 2.14 (100)	20.63	31.30	79.25	(167.47)	(1696)
	1.48[d]	1.23 1.33 (110)	—	—	—	—	—
5[g]	1.51	2.04 2.17 (67)	19.51 19.52	35.14	83.39 83.41	174.27 174.33	1735 1755 sh
	1.60	2.03 2.17[h] (56)	—	—	—	—	—
8[i]	1.37	1.72 1.95 (124)	26.96 ^1J = 126.9	33.82 ^1J = 128.3	75.17 ^2J = 2.4	176.50 ^2J = 5.5	1675

[a] In CD_3OD. [b] **1**, **2** in CD_3OD, **3**, **4**, **8** in $CDCl_3$, **5** in C_6D_6.
[c] δ MeO 3.71, δ ^{13}C(MeO) 52.69 (^1J = 147.7). [d] In C_6D_6.
[e] δ MeO 3.72, δ ^{13}C(MeO) 52.70 (^1J = 147.0).
[f] Iterative analysis of the AA^1BB^1 spectrum by the PANIC program afforded the following values: $^2J_{AB}^{hem} = {}^2J_{A^1B^1}{}^{hem} = -14.8$; $^3J_{AB^1}{}^{cis} = {}^3J_{A^1B}{}^{cis} = 11.0$ (ϕ ~ 4.5°); $^3J_{BB^1}{}^{trans} = 6.3$ (ϕ ~ 125°); $^3J_{AA^1}{}^{trans} = 2.8$ (ϕ ~ 115°) (for the numeration of protons see in the text).
[g] ^{13}C NMR spectrum was recorded under conditions of complete decoupling from protons.
[h] In $CDCl_3$, iterative analysis of the AA^1BB^1 spectrum by the PANIC program afforded the following values: Δ ν = 55.82; $^2J_{AB}{}^{hem} = {}^2J_{A^1B^1}{}^{hem} = -13.5$; $^3J_{AB^1}{}^{cis} = 9.9$; $^3J_{A^1B}{}^{cis} = 11.85$; $^3J_{BB^1}{}^{trans} = {}^3J_{AA^1}{}^{trans} = 5.05$ (numeration of protons is the same as for **3**).
[i] δ ^{1}H: 4.37 (CH_AH_BPh, J_{AB} = −14.9, J_{HNCH} = 6.1), 4.89 (OH), 7.28 m (Ph), 7.61 t (NH); δ ^{13}C: 43.15 ($\underline{C}H_2Ph$, ^1J = 138.7), 127.2, 127.38, 128.51 and 138.03 (Ph).

at 171.51 ppm was assigned to the CO group at the C-5 carbon atom on the basis of the change in its multiplicity under conditions of selective decoupling from the methyne proton at the C$\underline{H}$(Me)Ph group. Therefore the second low-field signal at 175.88 ppm corresponds to the C-1 carbon atom. Then, the change in the multiplicity of this signal permitted us to assign the signal in the ^{1}H NMR spectrum at 1.11 ppm to 2-Me, and the signal at 1.36 ppm to 5-Me. On the basis of the value ^4J(2-Me,3a) = 0.6 Hz the signal of 3-H_a was assigned, and further, based on the ^2J and ^3J values, the signals of 3-H_e, 4-H_a and 4-H_e were also assigned. In the ^{13}C spectrum selective decoupling from the methyl protons at 1.11 ppm causes the multiplicity of the signals at 27.36, 32, and 70.24 ppm to become simpler. Judging from the spectrum without decoupling, these signals correspond to primary, secondary and quaternary carbon atoms, respectively, *i.e.*, to 2-Me, C-3, and C-2. Selective decoupling from the methyl protons at C-5 (1.36 ppm) permitted us to assign the signals at 26.11 (5-Me), 29.81 (C-4), and 86.76 ppm (C-5) based on changes in their multiplicity.

For monolactone **7** the signals of the CO groups were assigned by selective decoupling from the protons of the MeO_2C group, and then, similarly to assignment in **10a**, the ^{1}H and ^{13}C signals were assigned by con-

Table 2. Parameters of NMR spectra of monolactones and lactam **12**[a]

Compound	Solvent	δ, ppm							J/Hz						
		2-CH_3	5-CH_3	CH_2				Others	3a3e	4a4e	3a4e	3a4a	3e4a	3e4e	Others
				3a	3e	4a	4e								
6	CD_3OD	1.41	1.60	1.77	1.90	2.19	2.07		−14.7	−14.2	4.15	13.6	3.9	3.9	
7	$CDCl_3$	1.49	1.64	1.70	2.01	2.12	2.11	2.59 HO 3.78 MeO	−14.7	−14.3	3.9	13.5	3.9	3.9	$^4J_{3aHO}$= 1.5
9	CD_3OD	1.42	1.51	2.02	1.80	1.92	2.27	1.35 Bu^t	−12.7	−13.8	3.4	13.6	3.4	3.4	0.7 3a2Me
10a	C_6D_6	1.11	1.36	1.78	1.38	1.32	2.46	1.07 MeCH 5.12 HCMe 6.82 HN Ph[b]	−14.0	−14.4	3.7	13.3	3.7	4.6	0.6 3a2Me 8.0 HNCH 6.9 HCCH
10b	C_6D_6	1.08	1.21	2.01	1.54	1.28	2.55	1.19 MeCH 5.10 HCMe 6.80 HN	−13.9	−14.4	3.8	13.5	3.7	4.8	0.6 3a2Me 7.5 HNCH 7.1 HCCH
12	C_6D_6	1.19	1.36	2.13	1.49	1.55	2.28	4.28 H_A 4.39 H_B (CH_2Ph) 4.98 HO 5.64 HN_{cycl} 7.12 HNCH	−12.5	−12.5	6.5	7.3	6.5	6.5	6.4 HNCH −14.9 H_AH_B

[a] For the numeration of protons see in the text. [b] Overlapped with the signals of the solvent.

secutive selective decoupling from 2-Me and 5-Me. In the case of compound **9**, the signals of the C-2 and C-5 atoms were assigned analogously to compound **10a**, and then the other ^1H and ^{13}C signals were assigned under conditions of selective decoupling from 2-Me and 5-Me.

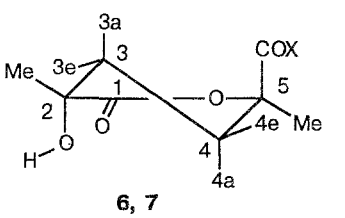
In the monolactones studied, the $^3J_{HH}$ values (Table 3) exclude the boat conformation (the torsion angle of the C(3)—C(4) bond is ~60°)[17] and correspond to the *half-chair* conformation.

This conformation is confirmed rather well by the $^4J_{HH}$ values and the heteronuclear coupling constants $^3J_{CH}$ of the 2-Me and 5-Me carbon atoms (Table 3) according to the Carplus-type angle dependence[17] for the *pseudo-e*-orientation of 2-Me and 5-Me in compounds **6**, **7**, and for the *pseudo-a*-orientation of 2-Me in compounds **9**, **10a,b** (Scheme 5).

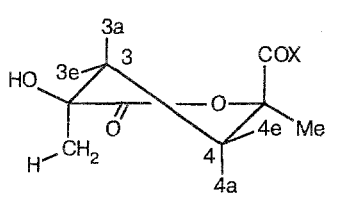
For monolactam **12**, as the $^3J_{HH}$ values and comparison with monolactones **9**, **10a,b** show, the *half-chair* conformation with pseudo-*e*-orientation of the amide group can also be proposed.

Some decrease in $^3J_{CH}$ at torsion angles ~45° compared to the expected values obtained using the Carplus-type dependence[17] should be noted. This phenomenon can be explained both by the effect of electronegative substituents, and by distortions of the torsion angles in the *half-chair* conformation. Thus, the torsion angle at the endocyclic O—CO bond in δ-valerolactone is 5.7°, while in the canonical form it is 0°.[16] The lack of reliable data on the dependence of the coupling constants of carbonyl carbon atoms on the angle (sp^2-hybridization) does not allow us to use the measured $^3J_{CH}$ of C-1 and 5-CO carbon atoms for establishment of the conformation (*cf.* Ref. 17). Nevertheless, a qualitative estimation of the orientation of the 5-COX substituent can be done using the values of these coupling constants: the $^3J_{CH}$ values > 5 Hz indicate that the

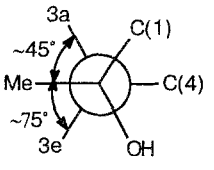
Scheme 5

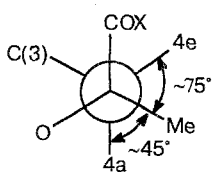


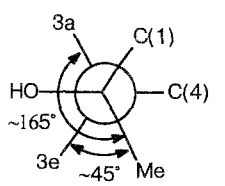
6, 7



9, 10a,b







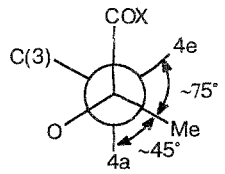


Table 3. Parameters of the ^{13}C NMR spectra of monolactones and monolactam[a]

Compound	δ, ppm *J*/Hz								
	5-CH_3	2-CH_3	4-CH_2	3-CH_2	2-C	5-C	5-CO	1-CO	Others
6[b]	25.22 ^1J = 129.0	26.28 ^1J = 127.6	29.93 ^1J = 131.8 ^3J = 4.2 q (5-CH_3)	33.61 ^1J = 129.0 ^3J = 4.2 q (2-CH_3)	69.85	85.41	175.04	175.29 ^3J = 4.0 q (2-CH_3)	
7[c]	24.54 ^1J = 131.0 q ^3J = 2.8 d (4a) ^3J = 1.4 d (4e)	26.55 ^1J = 128.0 q ^3J = 2.8 d (3a) ^3J = 1.4 d (3e)	28.91 ^1J = 133.2 q ^3J = 3.6 q (5-CH_3)	31.59 ^1J = 129.9 q ^3J = 3.5 q (2-CH_3)	68.77	83.94	172.03 ^3J = 7.3 d (4a) ^3J = 1.8 d (4e) ^3J = 3.8 q (MeO) ^3J = 3.7 q (5-CH_3)	173.3 ^3J = 3.5 q (2-CH_3) ^3J = 5.5 d (3e)	52.56 MeO ^1J = 148.1 q
9[b]	25.8 ^1J = 128.1 q ^3J = 3.3 d (4a)	28.8 ^1J = 128.6 q ^3J = 6.0 d (3a) ^3J = 4.4 d (3e)	33.09 ^1J = 130.8 q	35.02 ^1J = 130.3	71.43	88.68	178.65 ^3J = 6.5 d (4a)	179.5 ^3J = 7.1 d (3e)	27.87 (CH_3)$_3$C ^1J = 128.9 q 52.63 s (CH$_3$)$_3$C
10a[d]	26.11 ^1J = 128.3 q	27.36 ^1J = 128.0 q	29.81 ^1J = 131.5 t	32.32 ^1J = 131.4 t	70.24	86.76	171.51 ^3J = 5.5 d (4a) ^3J = 1.9 d (4e) ^3J = 3.5 q (5-CH_3)	175.88 ^3J = 2.2 d (3a) ^3J = 5.8 d (3e)	22.17 CH_3CH ^1J = 127.3 q 49.43 CHCH$_3$ ^1J = 140.5 d 126.17; 128.77; 129.9; 143.88 Ph[e]
10b[d]	26.03 ^1J = 129.7 q ^3J = 2.8 d (4a)	27.29 ^1J = 128.7 q ^3J = 4.0 d (3a) ^3J = 5.0 d (3e)	29.54 ^1J = 131.8 t	32.55 ^1J = 132.1 t	70.30	86.63	171.27 ^3J = 5.5 d (4a) ^3J = 2.0 d (4e) ^3J = 3.5 q (5-CH_3)	175.70 ^3J = 1.8 d (3a) ^3J = 5.5 d (3e)	22.1 CH_3CH ^1J = 127.9 q 51.37 CHCH$_3$ ^1J = 140.8 d ^2J = 2.8 q Me 126.26; 128.62; 129.6; 143.70 Ph[e]
12[d]	26.51 ^1J = 127.3 q	26.45 ^1J = 127.3 q	36.67 ^1J = 134.2 t	36.51 ^1J = 134.2 t	87.47	87.76	177.69[f]	180.73[f]	43.83 CH_2N ^1J = 137.3 t ^3J = 4.5 t H_o 128.1; 128.23; 129.47; 139.89 Ph[e]

[a] For the numeration of the atoms and configurations see the text. [b] In CD_3OD. [c] In $CDCl_3$, [d] In C_6D_6.
[e] Assigned under conditions of complete decoupling from protons.
[f] Assigned under conditions of decoupling from the protons 2-Me and 5-Me protons.

pseudo-*e*-orientation of 5-COX is favored in monolactones **7**, **10**, **10a,b**.

The results obtained agree with the results of calculations and experimental data, which indicate that δ-valerolactone has the *half-chair* and boat conformations, with a slight difference in energy (0.5—1 kcal/mol) in favor of the former one.[18,19]

The differences in the trend for further cyclization between the five- (**A**, **B** when R = H, Alk) and six-membered lactones studied in Ref. 5—10 and by us, which were regarded in the beginning of this paper, can be explained by significant weakening of the non-bonding interaction of the substituents in 1,4-substituted systems compared to 1,3-substituted systems. Such a difference is observed, for example, in oxidative cyclization of cycloalkenedithiols:[20] bicyclic disulfide forms from *cis*-cyclohexene-3, 6-dithiol under mild conditions and in a high yield, while it cannot be obtained from *cis*-cyclopentene-3,5-dithiol at all.

Experimental

NMR Spectra were obtained on a Bruker WM-400 (^1H 400.13; ^{13}C 100.62 MHz) spectrometer using TMS as internal

standard, EI and CI mass spectra were recorded on a Hitachi M-80A spectrometer at ionizing voltage 20 and 70 eV, and the IR spectra were measured on a UR-20 spectrophotometer for solutions in $CHCl_3$ or in KBr tablets. Melting points were determined on a Boetius RNMK-0.5 table at heating speed 4—5 °C/min. The parameters of the NMR spectra are given in Tables 1—3.

Absolute solvents and freshly prepared and purified reagents were used in the syntheses.

***d,l*-α,α′-Dihydroxy-α,α′-dimethyladipic acid (DDA) (1a).** 13.5 mL of conc. HCl (d = 1.17) was added dropwise for 1 h to a mixture of 10.3 g (158 mmol) of KCN and 9 g (79 mmol) of acetonylacetone (AA) with ice water cooling (4.5—7 °C in a bath), and the reaction mixture was stored for 3 days at 20 °C. Then the mixture, which became dark, was treated with 15 mL of conc. HCl and stored for an additional 3 days at 20 °C. To dissolve the inorganic salts, 100 mL of water were added to the mixture, which partially crystallized. Needle-like crystals were filtered off, washed with EtOH (100 mL) and then with Et_2O (3×30 mL), and dried *in vacuo* to give 0.23 g of colorless prism-like crystals. 0.8 g of the product was additionally isolated from the mother liquor. Total yield of **1a** is 1.03 g (6%); m.p. 193—220 °C (from a MeOH—Et_2O mixture). Found (%): C, 46.66; H, 6.98. $C_8H_{14}O_6$. Calculated (%): C, 46.60; H, 6.80. IR (KBr), ν/cm^{-1}: 1745 v.s (C=O); 2950—3040 (CH_2,CH_3); 3455 (OH). Mass spectrum *m/z* (I_{rel}(%)), EI, 70 эВ): 144 [$M^+ - CO_2 - H_2O$] (33), 143(14), 125(12), 116(33), 115(15), 98(15), 97(14), 93(7), 92(9), 91(5), 59(11), 58(8), 55(7), 46(18), 43(100), 41(10).

All of the mother liquor obtained during isolation of **1a**, as well as the solvents used to wash crystals, were evaporated, and the solid residue was extracted with hot chloroform (6×50 mL). The solvent was evaporated, and the residue was sublimated at 100 °C/1 Torr to give 0.6 g of dilactone **3**, m.p. 98—99 °C. Found (%): C, 56.58; H, 5.90. $C_8H_{10}O_4$. Calculated (%): C, 56.47; H, 5.88. IR ($CHCl_3$), ν/cm^{-1}: 1795 v.s (C=O); 2955—3010 (CH_2,CH_3). Mass spectrum, *m/z* (I_{rel}(%), EI, 70 eV): 171 (0.1), 170 [M^+] (2.4), 126(2.3), 99(7), 98(89), 97(12), 69(7), 59(6), 58(15), 43(100), 41(16).

A solution of 1 g of **3** in 40 mL of water was refluxed for 2.5 h, then activated carbon was added, and reflux was continued for an additional 10 min. Then the solution was filtered and evaporated to give 0.8 g (66 %) of *d,l*-DDA, which was identical to that described above according to the melting point and the ^{1}H NMR spectrum (Table 1).

***Meso*-DDA (1b).** A solution of 10.6 g (93 mmol) of AA in 7 mL of H_2O was added to 13 g (200 mmol) of KCN, and then 20 mL of conc. HCl (*d* = 1.17) was added in small portions at 4 °C (in a bath). The reaction mixture was stored for 3 days at 20 °C, then 25 mL of conc. HCl was added, and the mixture was stored for an additional 10 days at 20 °C. 150 mL of cold water was added to the crystallized mixture, and the insoluble residue was separated, washed with cold water (2×30 mL), with EtOH (15 mL), and with ether (2×15 mL). After drying *in vacuo*, (24 h) 4.8 g of **1b** was obtained, m.p. 210—211 °C. The mother liquors were united, evaporated, and the dry residue was extracted with hot benzene (2×70 mL). After removal of the solvent, the residue was washed with cold ether and dried *in vacuo* to give 2.4 g of white crystals that were identical to lactone **3** according to the melting point and the ^{1}H NMR spectrum (Table 1). The residue after benzene extraction was vacuumed and dissolved in hot water. The precipitated crystals, (0.82 g), were recrystallized from water and were found to be *meso*-DDA according to the ^{1}H NMR spectrum, m.p. 212—220 °C. All of the aqueous mother liquors were united, 100 mL of ether and 80 mL of conc. HCl were added and the mixture was stored for 5 days at 20 °C. Then the ether layer was separated and the water layer was extracted with chloroform. The organic extracts were combined, treated with 5 % solution of $NaHCO_3$ (2×200 mL) and dried over $CaCl_2$. After removal of the solvents, the residue was sublimated at 100 °C/1 Torr. 1.09 g of dilactone **3** was isolated. Altogether, 5.62 g (29 %) of **1b** and 3.3 g (21 %) of **3** were obtained. For **1b**, found (%): C, 46.24; H, 6.66. $C_8H_{14}O_6$. Calculated (%): C, 46.60; H, 6.80. IR (KBr), ν/cm^{-1}: 1750 sh., 1780 v.s (C=O); 2950—3050 (CH_2CH_3), 3475 br (OH).

***d,l*-DDA dimethylate (2a).** An ether solution of CH_2N_2 was added to a solution of 0.3 g (1.46 mmol) of acid **1a** in 10 mL of MeOH at −5÷5 °C until a stable yellow color of the reaction mixture appeared. After 0.5 h, the solvents were distilled off, the remained yellow oil was dissolved in ether and filtered, and the solvent was distilled off again. After recrystallization from petroleum ether (40—70 °C), 0.26 g (76.5 %) of **2a** was isolated, m.p. 65—66 °C. Found (%): C, 51.14; H, 7.45. $C_{10}H_{18}O_6$. Calculated (%): C, 51.28; H, 7.69. IR ($CHCl_3$), ν/cm^{-1}: 1740 v.s (C=O); 2965—3005 (CH_2,CH_3), 3545 (OH).

***Meso*-DDA dimethylate (2b).** Similarly to diester **2a**, 0.45 g (92 %) of **2b** was obtained from the reaction of 0.43 g (2.1 mmol) of **1b** in 20 mL of MeOH and an excess of CH_2N_2 at 20 °C, m.p. 118—120 °C (from Et_2O). Found (%): C, 51.39; H, 7.95. $C_{10}H_{18}O_6$. Calculated (%): C, 51.28; H, 7.69. IR ($CHCl_3$), ν/cm^{-1}: 1740 v.s (C=O); 2960—3020 (CH_2,CH_3), 3545 br (OH).

Dilactone DDA (3). a. 0.12 g (0.58 mmol) of acid **1a** was heated in a distillation flask with an open burner flame *in vacuo* (1 Torr) to give 40 mg (40 %) of **3**, m.p. 98—99 °C (from Et_2O).

b. 0.3 g (1.46 mmol) of DCC was added to a solution of 0.1 g (0.49 mmol) of **1a** in 20 mL of pyridine, and the mixture was stirred for 5 days at 20 °C. The precipitate was filtered off, the solvent was removed, the remaining oil was dissolved in 30 mL of ether, and a flow of dry HCl was bubbled through the solution to bind the remaining pyridine. After the removal of the pecipitate and evaporation of the solvent, the residue was sublimated to afford 35 mg (43 %) of **3**.

c. A mixture of 0.2 g (8.5 mmol) of **2a**, 5 mL of toluene, and 0.1 g of $TsOH \cdot H_2O$ was refluxed for 12 h, then the solvents were distilled off, the dry residue was dissolved in benzene, the obtained solution was filtered, and the solvent was removed. Sublimation of the residue gave 0.14 g (92 %) of **3** as white crystals.

d. A mixture of 70 mg (0.27 mmol) of **9** and 50 mg (0.27 mmol) of $TsOH \cdot H_2O$ in 2 mL of toluene was refluxed for 2 h. Needle-like crystals of $TsOH \cdot H_2NBu^t$ (m.p. 215—217 °C) were filtered off and washed with ether. The filtrate was evaporated, and the dry residue was dissolved in benzene and was evaporated again to give 40 mg (91 %) of **3**.

e. Analogously, 40 mg (90 %) of **3** (m.p. 98—99 °C) was obtained from 0.1 g (0.26 mmol) and 50 mg (0.27 mmol) of $TsOH \cdot H_2O$ in 5 mL of toluene.

Diiminodilactone of DDA (4). 7 mL of concentrated HCl (*d* = 1.15) was added dropwise with stirring to a mixture of 5.5 g (85 mmol) of KCN in 2.8 mL of water and 4.5 g (39 mmol) of AA in 2 mL of water at −20 to 25 °C. The mixture was stored for 24 h at 4 °C, and the precipitate was filtered off and washed with ether. The mother liquor was extracted with ether (3×20 mL), and the extract was evaporated. The oily residue was dried *in vacuo* and extracted with petroleum ether (40—70 °C). Evaporation of this extract gave 2 g of the starting AA. The oil that remained after extraction, was dried *in vacuo* (1 Torr) for 8 h, dissolved in ether and

stored for 3 days at 4 °C. The precipitated crystals (0.1 g) were separated, the filtrate was evaporated, and the residue was dissolved in ether. After cooling, an additional 0.6 g of crystals was isolated. Total yield was 0.7 g (19 % relative to the amount of reacted AA). After sublimation at 100—120 °C (1 Torr), 0.3 g (8 %) of **4** was obtained as white crystals, m.p. 148—155 °C, soluble in $CHCl_3$, MeOH, poorly soluble in ether, and insoluble in petroleum ether. Found (%): C, 57.29; H, 7.13; N, 16.64. $C_8H_{12}N_2O_2$. Calculated (%): C, 57.14; H, 7.14; N, 16.67. IR (KBr), ν/cm^{-1}: 1696 v.s. (HN=C); 2940—2990 (CH_2,CH_3); 3210 v.s., 3390—3410 (NH). Mass spectrum, *m/z* (I_{rel}(%), EI, 20 eV): 168 [M$^+$] (0.5), 140(0.2), 125(15), 68(17), 58(100), 43(18), 41(5).

A mixture of 0.1 g (0.6 mmol) of **4**, 10 mL of ether and 5 mL of concentrated HCl (d = 1.17) was stored for 10 days. Then it was evaporated, and the dry residue was twice sublimated at 100 °C (1 Torr) to give 91 mg (90 %) of **3**.

Lactonolactam (5). 20 mL of conc. HCl (d = 1.17) was added dropwise to a mixture of 10.6 g (93 mmol) of AA and 12 g (185 mmol) of KCN at 0 °C. Spontaneous heating to 10 °C was observed during this procedure. After 3 days, an additional 21 mL of conc. HCl was added to the darkened mixture at 20 °C, and the mixture was stored for 9 days. Then 15 mL more of conc. HCl was added with stirring, and the mixture was stored for 7 days. 50 mL of water was added to the mixture, which strongly darkened, and the precipitated crystals of *meso*-DDA **1b** (4.2 g, 22 %) were isolated. The filtrate was evaporated, and the dry residue was extracted with hot benzene (2×40 mL). After evaporation of the extract, 1 g (6 %) of dilactone **3** was obtained. The residue that was obtained after extraction with benzene, was dried *in vacuo* and washed with acetone (3×50 mL), and with methanol (3×50 mL) to give 6 g of the pink crystals, which were distilled *in vacuo* using an open burner flame (25—30 Torr). The distilled substance (0.9 g) was dissolved in ether and stored for 24 h at 4 °C. The precipitated crystals were filtered and dried *in vacuo* to give 0.8 g of **5** (5.1 % relative to the amount of reacted AA), m.p. 171—173 °C (from water). Found (%): C, 56.84; H, 6.37; N, 8.21. $C_8H_{11}NO_3$. Calculated (%): C, 56.80; H, 6.51; N, 8.28. IR ($CHCl_3$), ν/cm^{-1}: 1735 v.s and 1755 sh. (C=O); 3000—3070 (CH_2,CH_3), 3380 br.s (NH); tabl. KBr: 1650, 1680; 1730 and 1750 (C=O); 2940—2980, 3010 (CH_2,CH_3); 3100—3120 and 3170—3230 (NH). Mass spectrum, *m/z* (I_{rel}(%), EI, 20 eV): 169 [M$^+$] (5), 124(45), 99(8), 98(100), 97(15), 58(10), 43(47) (*cf.* mass spectra of **3** and **4**, CI): 339 [2M$^+$+H], 170 [M$^+$+H].

A mixture of 0.05 g (0.3 mmol) of **5**, 10 mL of ether, and 1 mL of conc. HCl (d = 1.17) was stored for 11 days at 20 °C. After evaporation to dryness *in vacuo* the residue was recrystallized from ether to give starting lactonolactam **5**.

Monolactone of *meso*-DDA (6). 0.8 g (3.88 mmol) of **1b** was ground to a powder, placed into a distilling flask, and heated *in vacuo* (15—20 Torr) for 1.5 h at 140—170 °C in an oil bath. First water was released, which was removed *in vacuo*, then a small amount of **3** was sublimated. The contents of the distilling flask were extracted with boiling ether (15×3 mL), and the solvent was evaporated. The residue was washed with benzene to remove traces of **3** and recrystallized from ether to give 0.34 g (46.5 %) of **6**, m.p. 148—150 °C (*cf.* Ref.[3]). Found (%): C, 51.06; H, 6.38. $C_8H_{12}O_5$. Calculated (%): C, 51.10; H, 6.43. IR (KBr), ν/cm^{-1}: 1730 sh., 1740 and 1745 sh. (C=O). Mass spectrum, *m/z* (CI) : 189 [M$^+$+H]. Compound **6** transforms to *meso*-DDA **1b** (^{1}H NMR) when storing in aqueous CD_3OD for two weeks .

Methyl ester of *meso*-DDA monolactone (7). A solution of 0.3 g (1.6 mmol) of **6** in 5 mL of MeOH was treated with excess CH_2N_2 in ether at 20 °C. After removal of the solvents, the oil residue was crystallized from an ether—*n*-pentane mixture (4 °C) to afford 0.2 g (62 %) of **7** as colorless plate crystals with m.p. 85—87 °C, which are readily soluble in MeOH, $CHCl_3$, poorly soluble in Et_2O, and insoluble in *n*-pentane. Found (%): C, 53.83; H, 7.03. $C_9H_{14}O_5$. Calculated (%): C, 53.47; H, 6.93. IR ($CHCl_3$), ν/cm^{-1}: 1740 and 1755 v.s (C=O); 2950—3050 (CH_2,CH_3); 3560 br (OH). Mass spectrum, *m/z* (CI): 405 [2M$^+$+H], 203 [M$^+$+H]. Compound **7** did not change after 2 months storage in MeOH (^{1}H NMR).

Bis(*d,l*-DDA benzylamide) (8). 0.6 g (5.6 mmol) of benzylamine was added dropwise to 1g (5.88 mmol) of dilactone **3** in 30 mL of ether at 20 °C. After 2 h, an oil was precipitated, which solidified after cooling. Recrystallization from a MeOH—H_2O mixture afforded 0.48 g (42.5 %) of **8** as white needle-like crystals, m.p. 133—135 °C, which are soluble in MeOH, $CHCl_3$, benzene, and insoluble in *n*-pentane, Et_2O and H_2O. Found (%): C, 68.76; H, 7.06; N, 7.45. $C_{22}H_{28}N_2O_4$. Calculated (%): C, 68.75; H, 7.29; N, 7.29. IR ($CHCl_3$), ν/cm^{-1}: 1675 (CO, amide); 1540 (Ar), 3015 (CH_2,CH_3); 3350 br (NH), 3425 (OH). Mass spectrum, *m/z* (I_{rel}(%), EI, 20 eV): 385 (0.25), 384 [M$^+$] (0.65), 351(0.35), 297(0.25), 277(0.5), 233(16), 232(100), 204(5), 125(18), 115(10), 108(10), 107(20), 106(34), 91(42.5), 79(9).

***Tert*-butylamide of *d,l*-DDA monolactone monohydrate (9).** A solution of 0.34 g (4.66 mmol) of *tert*-butylamine in 10 mL of ether was added to a solution of 0.8 g (4.71 mmol) of 3 in 50 mL of ether at 20 °C. The mixture was stored for 10 days to give 0.4 g (32 %) of **9** as prisms, m.p. 158—160 °C, soluble in water, MeOH, poorly soluble in benzene and $CHCl_3$. Found (%): C, 55.09; H, 8.73; N, 5.52. $C_{12}H_{21}NO_4 \cdot H_2O$. Calculated (%): C, 55.17; H, 8.81; N, 5.36. IR (KBr), ν/cm^{-1}: 1630 (CO, amide); 1740 (CO cycl.), 2990 (CH_2,CH_3); 3270 (NH), 3483 (OH). Mass spectrum, *m/z* (CI): 262 [M$^+$+H].

Reaction of dilactone 3 with *S*-(−)-α-phenylethylamine. A solution of 0.36 g (3 mmol) of *S*-(−)-α-phenylethylamine (α-PEA) in 15 mL of Et_2O was added to a solution of 0.52 g (3 mmol) of **3** in 50 mL of Et_2O at 20 °C. After 7 days, CO_2 was bubbled through the solution to remove unreacted α-PEA, and then the ether was evaporated. The residue (0.75 g) was a *semi*-crystalline viscous substance, and, according to the NMR spectrum (see Table 2), it was a mixture of diastereomers of *d,l*-DDA amidolactones **10a,b** in a 1:1 ratio and bis(α-phenylethylamide)(*d,l*-DDA) **11**. The latter was isolated as white needles, m.p. 180—182 °C (from benzene). Found (%): C, 69.89; H, 7.76; N, 6.37. $C_{24}H_{32}N_2O_4$. Calculated (%): C, 69.90; H, 7.77; N, 6.80. ^{1}H NMR (C_6D_6 + CD_3OD), δ: 1.22 (d, $\underline{CH_3}CH$, 3 H, $^3J_{HH}$ = 6.9), 1.45 (s, CH_3, 3 H), 1.91 (m, CH_2—CH_2, 4 H), 5.08 (q, HC, 1 H), 7—7.2 (m, Ph, 5 H). $[\alpha]^{23}_D$ = −94.02° (*c* 0.53, MeOH).

Lactam of 2.5-dimethyl-2-hydroxy-5-aminoadipic acid benzylamide (12). a. A mixture of 0.45 g (2.7 mmol) of lactonolactam **5** and 0.7 g (6.5 mmol) of benzylamine in 20 mL of ether was stored for 6 days at 20 °C, then it was evaporated, and the residue was washed with petroleum ether (40—70 °C) and sublimated at 100 °C/1 Torr to give 0.15 g (20.5 %) of yellowish crystals, m.p. 90—105 °C. After the third sublimation 70 mg (9.5 %) of **12** was isolated as white crystals, m.p. 109—110 °C. Found (%): C, 65.41; H, 7.16; N, 9.83. $C_{15}H_{20}N_2O_3$. Calculated (%): C, 65.22; H, 7.25; N, 10.14. IR ($CHCl_3$), ν/cm^{-1}: 1680 (CO, amide); 1705 (CO), 2990—3065 (CH_2,CH_3); 3415—3455 (NH), 3525 (OH). Mass spectrum,

m/z (I_{rel}(%), EI, 20 eV): 276 [M^+] (5), 233(7), 232(3.3), 143(22), 142(100), 126(7), 125(57), 114(71), 106(10), 98(15), 97(27), 91(58), 86(30), 57(11), 43(35), 18(4).

b. A solution of 0.1 g of **5** in 1 mL of benzylamine was stored for 3 days. After evaporation the residue (yellowish oil) was extracted with boiling Et_2O (3×10 mL). The precipitated white needle-like crystals were isolated and dried *in vacuo* to give 0.15 g (92 %) of **12**.

Reaction of 12 with TsOH · H_2O. A mixture of 40 mg (0.15 mmol) of **12** and 40 mg (0.21 mmol) of TsOH · H_2O in 2 mL of toluene was refluxed for 1.5 h. After isolation of benzylamide salt, the mixture was evaporated, the residue was dissolved in acetone, filtered, evaporated again, and the residue was dried *in vacuo* for 2 h. Sublimation (150 °C/1 Torr) and recrystallization from ether afforded 0.16 mg (62 %) of lactonolactam **5.**

Attempt to carry out the reaction of lactonolactam 5 with *t*-BuNH$_2$. A solution of 90 mg (1.23 mmol) of *t*-BuNH$_2$ was added to a solution of 0.2 g (1.18 mmol) of **5** in 20 mL of Et_2O at 20 °C. After 2 months, the mixture was evaporated to afford starting lactonolactam **5** (^{1}H NMR).

1,4-Dimethyl-4-oxy-4-cyclohexane-1-carboxylic acid benzylamide (14). A solution of 0.3 g of lactone **13** [14] in 2 mL of benzylamine was refluxed for 40 h, evaporated *in vacuo*, and the residue was extracted with boiling *n*-hexane (4×15 mL). The precipitate of colorless glittering crystals was isolated and dried *in vacuo* to give 90 mg (18 %) of **14**, m.p. 97—98 °C. Found (%): C, 73.91; H, 8.70; N, 5.15. $C_{16}H_{23}NO_2$. Calculated (%): C, 73.56; H, 8.81; N, 5.36. IR ($CHCl_3$), ν/cm^{-1}: 1530 (Ph), 1670 (C=O); 2950—3030 (CH_2,CH_3); 3480 (NH, sharp), 3620 (OH, sharp). ^{1}H NMR (C_6D_6), δ: 0.96 (s, 1-CH_3, 3 H), 1.02 (s, 4-CH_3, 3 H), 1.28 (m, 2,6-H_a, 2 H, $^2J_{2a2e(6a6e)} = -13.6$; $^2J_{2a3a(6a5a)} = 10.7$; $^2J_{2a3e(6a5e)} = 4.2$), 1.41 (m, 2,6-H_e, 2 H, $^3J_{2e3a(6e5a)} = 4.2$), 1.19 (m, 2 H, 3,5-H_e, $^2J_{3a3e(5a5e)} = -13.3$), 2.04 (m, 2 H, 3,5-H_a), 4.34 (d, 2 H, CH_2N, $^3J_{HCNH} = 5.9$), 5.63 (br. s, 1 H, HN), 7.05—7.14 (m, 5 H, Ph). ^{13}C NMR (C_6D_6), δ: 22.11 (q, 1-CH_3, $^1J = 126.2$), 29.29 (q, 4-CH_3, $^1J = 126.2$), 31.09 (t, 2,6-CH_2, $^1J = 127.62$), 35.48 (t, 3,5-CH_2, $^1J = 126.3$), 41.59 (s, 1-C), 68.46 (s, 4-C), 127.3, 127.77, 128.75 and 139.93 (m, Ph), 177.76 (m, CO). Mass spectrum, *m/z* (I_{rel}(%), EI, 20 eV): M^+ — absent, 245(16), 244(90), 243(15), 229(30), 216(14), 177(25), 147(7), 138(9), 111(20), 110(35), 109(100), 108(31), 107(31), 96(10), 95(47), 91(82), 81(16), 69(9), 68(28), 67(14), 43(12).

When a mixture of equimole amounts of **14** and TsOH · H_2O in $C_6D_5CD_3$ was refluxed for 1.5 h, the signals of starting compounds disappeared from the ^{1}H NMR spectra and **13** and the TsOH salt of benzylamine were formed.

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References

1. I. V. Vystorop, A. B. Zolotoi, V. M. Anisimov, V. G. Kartzev, and R. G. Kostyanovskii, *Izv. Akad. Nauk, Ser. Khim*, 1992, 1601 [*Bull. Acad. Sci., Div. Chem. Sci.*, 1992, **41**, 1235 (English Transl.)].
2. R. G. Kostyanovskii, I. V. Vystorop, A. E. Aliev, Yu. I. El'natanov, V. N. Voznesenskii, V. I. Zavyalov, and R. A. Karakhanov, *Izv. Akad. Nauk SSSR, Ser. khim*, 1989, 891 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1989, **38**, 801 (English Transl.)].
3. R. G. Kostyanovskii, V. P. Leshchinskaya, Yu. I. El'natanov, A. E. Aliev, and I. I. Chervin, *Izv. Akad. Nauk SSSR, Ser. khim*, 1989, 408 [*Bull. Acad. Sci. USSR*, 1989, **38**, 355 (English Transl.)].
4. I. V. Vystorop, Yu. I. El'natanov, and R. G. Kostyanovskii, *Izv. Akad. Nauk, Ser. Khim*, 1992, 1591. [*Bull. Acad. Sci., Div. Chem. Sci.*, 1992, **41**, 1227 (English Transl.).].
5. R. Fittig, *Lieb. Ann. Chem.*, 1907, **353**, 1.
6. K. Freudenberg, W. F. Bruce, and E. Gauf, *Lieb. Ann. Chem.*, 1934, **510**, 206.
7. J. A. Elvidge, R. P. Linstead, and J. F. Smith, *J. Chem. Soc.*, 1952, 126.
8. G. I. Sabuneeva, *Zhurn. Org. Khim.*, 1965, **1**, 1969.
9. R. G. Kostyanovskii, Yu. I. El'natanov, V. P. Leshchinskaya, and I. I. Chervin, *Izv. Akad. Nauk SSSR, Ser. khim*, 1986, 2637 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1986, **35**, 2420 (English Transl.)].
10. H. R. Le Sueur, *J. Chem. Soc.*, 1908, **93**, 716.
11. N. D. Zelinsky and W. Isajew, Chem. Ber., 1896, **29**, 819; N. D. Zelinsky, *Collection of works*, Moscow, 1954, 307, 325. (in Russian).
12. N. D. Zelinsky and N. Schlezinger, *Chem. Ber.*, 1907, **40**, 2886; N. D. Zelinsky and T. Stadnikov, *Zhurn. Ros. Khim. Ob-va*, 1906, **38**, 722 (in Russian).
13. O. G. Nabiev, M. A. Shakhgeldiev, I. I. Chervin, R. G. and Kostyanovskii, *Dokl. AN SSSR*, 1985, **284**, 872. [*Dokl. Chem.*, 1985 (English Transl.)].
14. A. G. Ismailov, I. D. Sadykhov, M. A. Rustamov, and A. A. Akhmedov, *Azerb. khim. zhurn.*, 1984, № 5, 84 (in Russian).
15. M. Barfield, A. M. Dean, C. J. Fallick, R. J. Spear, S. Starnhell, and P. W. Westermann, *J. Am. Chem. Soc.*, 1975, **97**, 1482.
16. R. Bucourt, in: *Topics in Stereochemistry*, Ed. by E. L. Eliel and N. L. Allinger, Niley Interscience, New York, 1974, **8**, 159.
17. P. E. Hansen, *Progress in NMR Spectroscopy*, Pergamon Press, London, 1981, **14**, 175—296.
18. T. Philip, R. L. Cook, T. B. Mailoy, N. L. Allinger, S. Chang, and Y. Yuh, *J. Am. Chem. Soc.*, 1981, **103**, 2151.
19. J. B. Lambert, M. L. E. Te Vrucht, *Org. Magn. Res.*, 1984, **22**, 613.
20. Th. L. Gilchrist and J. E. Wood, *J. Chem. Soc., Perkin Trans., I*, 1992, 9.

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