

otides in length. In vitro "evolution" was done on this region at 30% mutagenesis, and four more rounds of in vitro selection followed before this second population was cloned. From these sequences, a consensus region was discovered. Certainly though this work is a pioneering achievement in the field, it is an example of how the conventional protocol is significantly more involved than that presented here.

In summary, a novel in vitro selection protocol has been designed to take advantage of a combinatorial library of small size that has multiple copies of every distinct sequence. The method condensed the many days of a typical screening strategy to less than two days. This was a proof-of-concept experiment that showed that the new method succeeds by creating a large number of copies of individual sequences in the initial random pool, consistently reducing the level of nonspecific binding sequences per selection round, and effectively amplifying the few surviving sequences.

Since only the original synthesized sequences were used for all the screenings, the technique should allow for the iterative in vitro selection of modified oligonucleotides that previously could not undergo this powerful process.^[10] Hence, this method should significantly increase the power of the in vitro selection method and is the direction that we are currently investigating.

Experimental Section

The DNA library [4] (31 mg) was labeled at the 5'-end with [γ -³²P]ATP, purified by gel chromatography, and suspended in 300 mL of folding buffer (300 mM KCl, 5 mM MgCl₂, 20 mM Tris, pH 7.5). After cooling down to room temperature following denaturation at 75 °C, the ³²P-labeled DNA was loaded onto an acetate-agarose precolumn (300 μ L), which was attached directly to a 2.5 mM ATP-agarose column (800 μ L, Sigma). The precolumn was washed with 600 μ L of buffer, and the eluted DNA was allowed to equilibrate on the ATP-agarose column for 10 min. The precolumn was discarded after a single use as were all subsequent columns. After equilibration, the ATP-agarose column was washed with 4 mL of folding buffer to elute unbound or weakly bound oligonucleotides. The retained DNA was eluted with 3 mL of the ATP elution buffer (5 mM ATP in folding buffer) and collected in 500 μ L fractions.

In order to perform another round of selection, the ATP had to be removed. Hence, the eluted fractions were collected directly into Microcon-3 microcentrifuge devices (3000 D cutoff, Amicon). After membrane diafiltration, about 98% of the total ATP was removed. The filtered fractions were then pooled, and folding buffer was added until a final volume of 10 mL was attained. The concentration of contaminating ATP concentration was 30 μ M for the DNA sample, which was over 80 times more dilute than that of the 2.5 mM ATP-agarose column. Each cycle of selection started with a new set of stacked affinity columns, i.e. a precolumn attached to a ligand column. The screening cycles for the ATP aptamers are summarized in Table 1.

The rare-DNA PCR was performed as follows: On the last cycle the DNA was eluted from the ATP-agarose column with 3 mL of 10 mM ATP in 20 mM Tris, pH 7.5. This last fraction was precipitated twice from ethanol, and the PCR reagents (50 mM KCl, 8 mM MgSO₄, 10 mM (NH₄)₂SO₄, 20 mM Tris, pH 8.8 at 25 °C, 200 μ M dNTPs, 0.1% Triton X-100, 20 units of Deep Vent (exo-) DNA polymerase, 0.5 μ g 5'-primer, 0.5 μ g 3'-primer) were added. Thermal cycling (94 °C for 45 s; 42 °C for 90 s; 60 °C for 45 s; 45 cycles) was done in a microcentrifuge tube that had first been irradiated with UV light. A positive control containing a dilute solution (~20 000 molecules) of a 52-mer, and a negative control containing no DNA also underwent the same amplification protocol. Gel electrophoresis after amplification showed DNA in all lanes except the negative control.

Received: February 27, 1997 [Z10170IE]
German version: *Angew. Chem.* 1997, 109, 1956–1958

Keywords: aptamers • combinatorial chemistry • in vitro selection • nucleotides • polymerase chain reaction

- [1] L. C. Bock, L. C. Griffin, J. A. Latham, E. H. Vermaas, J. J. Toole, *Nature* 1992, 335, 564–566; J. R. Lorsch, J. W. Szostak, *Biochemistry* 1994, 33, 973–982; D. Smith, G. P. Kirschenheuter, J. Charlton, D. M. Guidot, J. E. Repine, *Chem. Biol.* 1995, 2, 741–750; D. Jelinek, L. S. Green, C. Bell, N. Janjić, *Biochemistry* 1994, 33, 10450–10456; C. Tuerk, S. MacDougall, L. Gold, *Proc. Natl. Acad. Sci. USA* 1992, 89, 6988–6992; C. Tuerk, S. MacDougall-Waugh, *Gene* 1993, 137, 33–39; D. P. Bartel, M. L. Zapp, M. R. Green, J. Szostak, *Cell* 1991, 67, S29; C. T. Lauhon, J. W. Szostak, *J. Am. Chem. Soc.* 1995, 117,

- 1246–1257; P. Burgstaller, M. Famulok, *Angew. Chem.* 1994, 33, 1163–1166; *Angew. Chem. Int. Ed. Engl.* 1994, 33, 1084–1087; M. Famulok, J. W. Szostak, *J. Am. Chem. Soc.* 1992, 114, 3990–3991; M. Famulok, *ibid.* 1994, 116, 1698–1706; J. G. Connell, M. Illangsekare, M. Yarus, *Biochemistry* 1993, 32, 5497; M. Sassanfar, J. W. Szostak, *Nature* 1993, 364, 550–553; a) M. G. Wallis, U. von Ahlsen, R. Schroeder, M. Famulok, *Chem. Biol.* 1995, 2, 543–552; b) R. D. Jenison, S. C. Gill, A. Pardi, B. Polisky, *Science* 1994, 263, 1425–1429; J. F. Milligan, M. D. Matteucci, J. C. Martin, *J. Med. Chem.* 1993, 36, 1923–1937; J. D. Ecker, S. T. Crooke, *Biotechnology* 1995, 13, 351–360.
[2] Some exceptions include 2'-amino- and 2'-fluoro substitutions on sugar (H. Aurup, D. M. Williams, F. Eckstein, *Biochemistry* 1992, 31, 9636–9641) and 1-pentynyl substitution on pyrimidine (J. A. Latham, R. Johnson, J. J. Toole, *Nucleic Acids Res.* 1994, 22, 2817–2822).
[3] D. E. Huizenga, J. W. Szostak, *Biochemistry* 1995, 34, 656–665.
[4] Oligonucleotides were purchased HPLC-purified from Operon. The initial sequence was 5'-GAATTCAGATCTCT-(18N)-GATATCAGGATCCCA-3'. The two primers were 5'-GAATTCAGATCTCT-3' and 5'-TGGGATCCT-GATATC-3'. These sequences incorporated EcoRI and BamHI digestion enzyme restriction sites.
[5] D. M. Coen in *Current Protocols in Molecular Biology* (Eds.: F. M. Ausubel, R. Brent, R. E. Kingston, D. D. Moore, J. G. Seidman, J. A. Smith, K. Struhl), Current Protocols, New York, 1994, Chapter 15.4.
[6] J. P. Katz, E. T. Bodin, D. M. Coen, *J. Virol.* 1990, 64, 1690–1694.
[7] S. A. Kauffman, *The Origins of Order: Self Organization and Selection in Evolution*, Oxford University Press, New York, 1993, Chapter 3.
[8] D. H. Freeman, *Anal. Chem.* 1972, 44, 117–120; B. M. Dunn, I. M. Chaiken, *Proc. Natl. Acad. Sci. USA* 1974, 71, 2382.
[9] J. P. Hummel, W. J. Dreyer, *Biochim. Biophys. Acta* 1962, 63, 530.
[10] Another method for the use of modified nucleotides in the 5'-region of a primer has been described recently: J. Burmeister, G. von Kiedrowski, A. D. Ellington, *Angew. Chem.* 1997, 109, 1379–1381; *Angew. Chem. Int. Ed. Engl.* 1997, 36, 1321–1324.

The Synthesis of Enantiopure ω -Methanoprolines and ω -Methanopipicolinic Acids by a Novel Cyclopropanation Reaction: The "Flattening" of Proline**

Stephen Hanessian,* Ulrich Reinhold, and Gabriella Gentile

Proline occupies a prominent position in the hierarchy of natural amino acid constituents of mammalian proteins.^[1] As part of a peptidic motif, its unique structure results in secondary amide bonds, leading to important conformational and functional consequences.^[2] For example, the well-known *cis-trans* isomerism in prolylamides is associated with vitally important biological phenomena and functions, such as protein folding,^[3] hormone regulation,^[4] recognition,^[5] and transmembrane signaling^[6] to mention a few. The importance of *cis-trans* conformational changes is manifested by the role that peptidyl prolyl isomerases such as the immunophilins play in immunoregulation.^[7] Proline has also figured prominently as a component of therapeutic agents,^[8] in drug design,^[9] and in probing enzyme activity.^[10]

Conformationally constrained analogues of proline have been used extensively in connection with peptidomimetic research.^[11] Although 2,3- and 3,4-methanoprolines have been

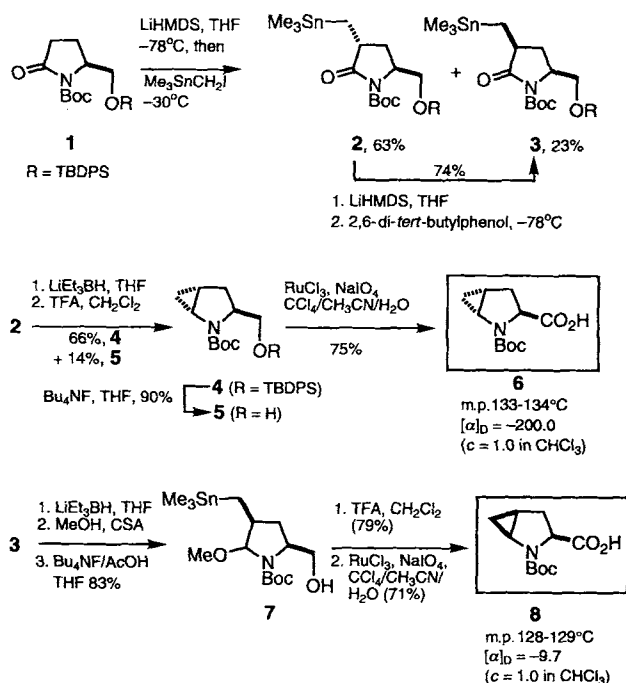
[*] Prof. Dr. S. Hanessian, Dr. U. Reinhold, G. Gentile
Department of Chemistry
Université de Montréal
C. P. 6128, Succ. Centre-ville
Montréal, QC, H3C 3J7 (Canada)
Fax: Int. code + (514) 343-5728

[**] We thank NSERC for generous financial assistance through the Medicinal Chemistry Chair program. We thank Dr. Michel Simard for the X-ray analyses. U. R. acknowledges a DFG Research Fellowship from the Deutsche Forschungsgemeinschaft. G. G. thanks the University of Siena and the Italian C. N. R. for a summer fellowship.

described,^[12, 13] the 4,5-methanoprolines are relatively unexplored.^[14] Furthermore, structural investigations that study the consequences of introducing strain and its effects on the configuration and stability of amide linkages are not available to compare such systems to their proline counterparts.

We describe herein highly stereocontrolled syntheses of the diastereomeric 4,5-methano-L-prolines and 5,6-methano-L-pipecolic acids by a novel intramolecular cyclopropanation reaction of iminium ions and the extension of the methodology to other congeners.^[15, 16]

Treatment of the readily available lactam **1**^[17a] with lithium hexamethyldisilazide (LiHMDS) and Me₃SnCH₂I gave the α -alkylated products **2** ($[\alpha]_D = -15.3$, $c = 0.43$ in CHCl₃) and **3** ($[\alpha]_D = -16.0$, $c = 1.23$ in CHCl₃) in 63% and 23% yields, respectively (Scheme 1). The *syn*-isomer **3** could be easily obtained



Scheme 1. TBDPS = *t*-BuPh₂Si, TFA = trifluoroacetic acid, Boc = *tert*-butoxy-carbonyl, CSA = camphor-10-sulfonic acid.

by treatment of the enolate from **2** with the proton source 2,6-di-*tert*-butylphenol.^[18, 19] Generation of the hemiaminal from **2** and treatment with TFA led to the (4*R*,5*R*)-methanopyrrolidine derivative **4** ($[\alpha]_D = -69.3$, $c = 1.41$ in CHCl₃), which was smoothly deprotected to **5**, and the latter oxidized to give the crystalline (4*R*,5*R*)-methano-*N*-Boc-L-proline in excellent overall yield.

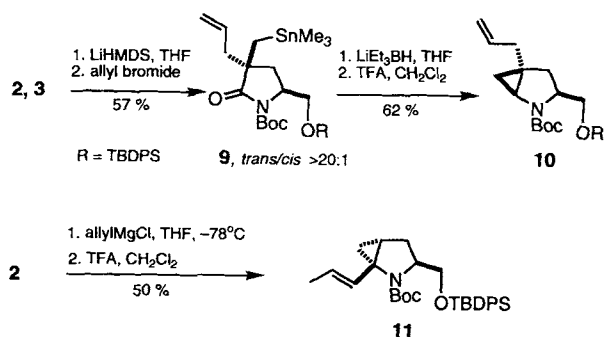
Similar treatment of the *syn*-isomer **3** gave the diastereomeric crystalline acid **8** via its methylaminal derivative **7**. The structures and conformations of **6** and **8** in the solid state were unambiguously confirmed by single-crystal X-ray analysis. Table 1 lists selected torsion angles for compounds **6** and **8**, where considerable "flattening" of the pyrrolidine ring is observed relative to *N*-Boc-L-proline,^[20] particularly in the case of **6**. The flattening of the pyrrolidine ring in **6** is also manifested in the root-mean-square value of 0.003 Å for the C_β and N atoms from the plane defined by C_β, C_γ, C_δ, and N (0.013 Å in **8**). The lowest deviation of 0.018 Å in the case of *N*-Boc proline was found for C_α and C_γ atoms in the plane C_α, N, C_δ, C_γ; in this case C_β was distinctly above the plane (0.521 Å). This differs substantially

Table 1. Selected torsion angles and root-mean-square deviations from fitted atoms in a given plane of X-ray crystal structures, and ¹³C NMR chemical shifts (CDCl₃).

	<i>N</i> -Boc-L-proline [20]	6	8
$\tau(\text{NC}_\alpha)$	-17	-5.6	-14.4
$\tau(\text{C}_\alpha\text{C}_\beta)$	+31	+4.8	+15.3
$\tau(\text{C}_\beta\text{C}_\gamma)$	-35	-2.6	-11.4
$\tau(\text{C}_\gamma\text{C}_\delta)$	+24	-0.7	+2.9
$\tau(\text{C}_\delta\text{N})$	-4	+4.1	+7.6
$\tau(\text{BocNC}_\alpha\text{CO}_2\text{H})$	-72	-64.0	-67.1
rms deviation of fitted atoms	0.018	0.003	0.013
	C _α , N, C _δ , C _γ	C _β , C _γ , C _δ , N	C _β , C _γ , C _δ , N
$\delta(\text{cis/trans})$			
COOH	178.35/176.60	177.7/175.5	179.1/176.1
NC=O	153.95/155.39	157.1/154	155.7/154.1
C _α	58.8	60.8/60.1	59.5/59.1
C _β	30.75/29.53	32.0	31.5/29.1

from **6** and **8**, in which the out-of-plane carbon atom was the one bearing the carboxyl group (0.082 Å and 0.235 Å respectively).

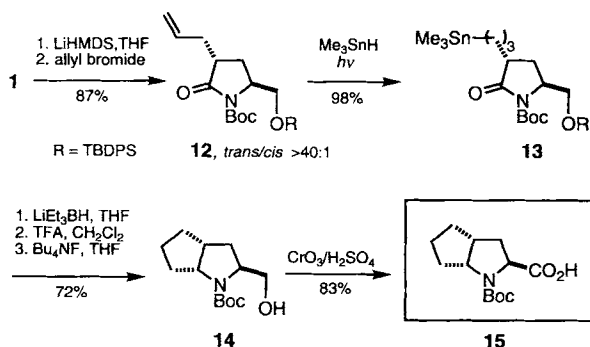
Intermediates **2** and **3** could also be subjected to further stereocontrolled branching leading to the α -C-allyl derivative **9**, which upon controlled reduction and acid-catalyzed destannylation led to the branched 4,5-methano-L-proline precursor **10** ($[\alpha]_D = +4.3^\circ$, $c = 0.72$ in CHCl₃; Scheme 2). Treatment of **2**



Scheme 2.

with allylmagnesium chloride, followed by trifluoroacetic acid (TFA), led to the (*S*)-5-(2-propenyl)-4,5-methano-L-proline derivative **11** ($[\alpha]_D = -27.0$, $c = 0.57$ in CHCl₃) on migration of the double bond. Compounds **10** and **11** represent uniquely functionalized precursors to constrained ω -methanoprolines.

The versatility and generality of the intramolecular carbocyclization reaction with appended trimethylstannylalkyl groups via incipient iminium ions can be demonstrated in the synthesis of bicyclic proline congeners (Scheme 3). These compounds are related to the antihypertensive agent ramipril.^[21] A highly stereoselective allylation of the enolate from **1** gave **12** ($[\alpha]_D = -45.0$, $c = 1.0$ in CHCl₃), which was subjected to a photoinduced trimethylstannylation^[22] to give **13** ($[\alpha]_D = -23.6$,



Scheme 3.

$c = 0.92$ in CHCl_3). Formation of the hemiaminal, followed by acid-catalyzed cyclization and deprotection, led to the bicyclic prolinol derivative **14** ($[\alpha]_D = -97.3$, $c = 1.38$ in CHCl_3). Finally, oxidation under Jones conditions gave the immediate precursor to the *N*-Boc-(4*R*,5*R*)-ramipril diastereomer **15** (m.p. 61–63 °C; $[\alpha]_D = -126.7$, $c = 0.46$ in CHCl_3).

It is also of interest to view compounds **6**, **8**, **10**, and **11** as precursors to constrained analogues or precursors to L-pipecolic acid. The extension of the cyclopropanation reaction to the pipecolic acid series is shown in Scheme 4. Trimethylstannylmethylation of the lithium enolate derived from the readily available **17**^[23] gave the *anti*-isomer **18**. Reduction to the hemiaminal and acid-catalyzed cyclization led to **20** ($[\alpha]_D = -56.0$, $c = 1.02$ in CHCl_3), which was deprotected and oxidized to the crystalline (5*R*,6*S*)-methano-*N*-Boc-L-pipecolic acid **21** (m.p. 138–140 °C; $[\alpha]_D = -105.2$, $c = 1.17$ in CHCl_3). Epimer-

ization of **18** to the *syn*-isomer **19** by diastereoselective protonation, followed by functional group manipulation as described above, led to the crystalline diastereomeric (5*S*,6*S*)-methano-*N*-Boc-pipecolic acid **23** (m.p. 79–81 °C; $[\alpha]_D = -126.7$, $c = 0.40$ in CHCl_3). The structure of crystalline **21** was unambiguously established by X-ray analysis. It is of interest to note that while the proline derivatives **6** and **8** adopt a *cis*-*N*-Boc proline orientation in the solid state (Table 1), the corresponding 4,5-methanopipecolic acid analogue **21** exhibits a *trans* orientation (Scheme 4). The presence of *cis* and *trans* isomers of **6** and **8** in CDCl_3 was evidenced by the corresponding ^{13}C NMR shifts, as in the case of *N*-Boc-L-proline (Table 1).

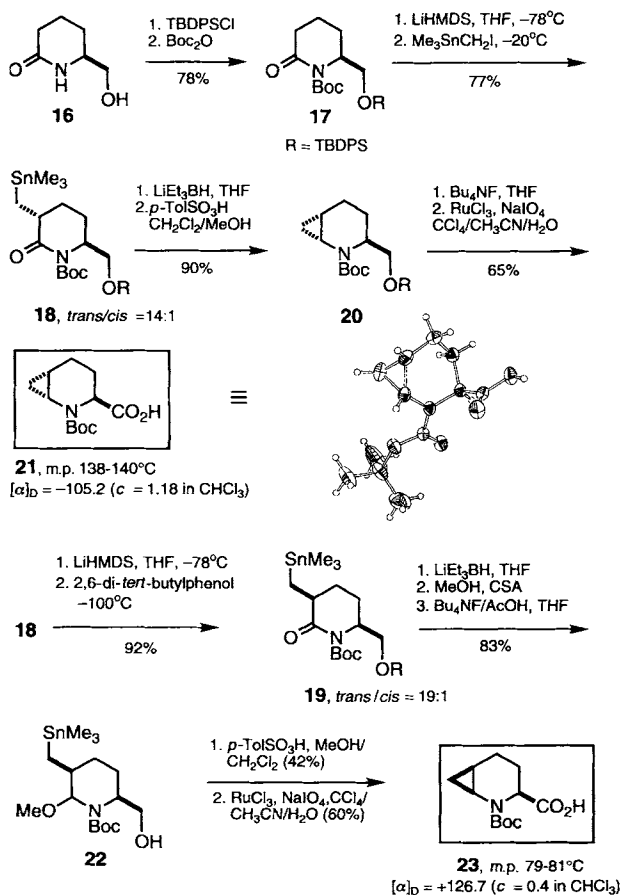
Pipecolic acid is an important constituent of the immunosuppressive agents FK-506^[24] and rapamycin,^[25] in which its α -ketoamide portion is intimately involved in an "active complex" with the target enzyme.^[26] It is also involved in the metabolism of L-lysine, an essential amino acid for mammalian growth and development.^[27] Functionalized pipecolic acids are also considered strained analogues of lysine with applications in drug design and peptidomimetic research,^[28] as well as in the inhibition of L-pipecolate oxidase.^[27]

It is our belief that the replacement of L-proline and L-pipecolic acid by conformationally altered ring variants represented by the methano congeners described in this work could have important consequences in biological recognition, in *cis*–*trans* conformational changes, in the susceptibility of the secondary amide bonds to enzymatic cleavage, and in related processes or phenomena. Studies that address these issues will be reported in due course.

Received: February 4, 1997 [Z 100761E]

German version: *Angew. Chem.* **1997**, *109*, 1953–1956

Keywords: amino acids • asymmetric synthesis • cyclizations • strained molecules



Scheme 4.

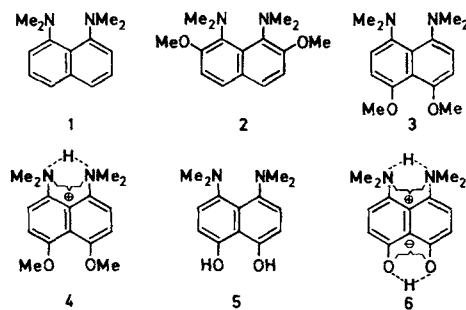
- Example: T. E. Creighton, *Proteins: Structures and Molecular Principles*, W. H. Freeman, New York, **1984**.
- a) C. M. Deber, V. Madison, E. R. Blout, *Acc. Chem. Res.* **1976**, *9*, 106–113; b) E. S. Eberhardt, S. N. Loh, R. T. Raines, *Tetrahedron Lett.* **1993**, *34*, 3055–3059; c) W. A. Houry, H. A. Scheraga, *Biochemistry* **1996**, *35*, 11719–11733.
- a) J. F. Brandts, H. R. Halvorson, M. Brennan, *Biochemistry* **1975**, *14*, 4953–4963; for more recent references see b) K. L. Borden, F. M. Richards, *ibid.* **1990**, *29*, 3071–3077; c) F. L. Texter, D. B. Spencer, R. Rosenstein, C. R. Matthews, *ibid.* **1992**, *31*, 5687–5695; d) K. Lang, F. X. Schmid, *J. Mol. Biol.* **1990**, *212*, 185–196.
- a) K. A. Williams, C. M. Deber, *Biochemistry* **1991**, *30*, 8919–8923; b) J. Wess, S. Nanavati, Z. Vogel, R. Maggio, R. EMBO *J.* **1993**, *12*, 331–338; c) T. M. Suchyna, L. X. Xu, F. Gao, C. R. Fournier, B. J. Nicholson, *Nature* **1993**, *365*, 847–849.
- N. G. J. Richards, M. G. Hinds, D. M. Brennan, M. J. Glennie, J. M. Welsh, J. A. Robinson, *Biochem. Pharmacol.* **1990**, *40*, 119–123.
- a) A. Yaron, F. Naider, F. Crit. Rev. Biochem. Mol. Biol. **1993**, *28*, 31–81; b) R. E. London, J. M. Stewart, J. R. Cann, *Biochem. Pharmacol.* **1990**, *40*, 41–48.
- a) C. J. Andres, T. L. Macdonald, T. D. Ocain, D. Longhi, *J. Org. Chem.* **1993**, *58*, 6609; b) M. K. Rosen, S. L. Schreiber, *Angew. Chem.* **1992**, *104*, 413–439; *Angew. Chem. Int. Ed. Engl.* **1992**, *31*, 384–400; c) G. Fischer, *ibid.* **1994**, *106*, 1479–1501 and **1994**, *33*, 1415–1436.
- D. W. Cushman, H. S. Cheung, E. F. Sabo, M. A. Ondetti, *Biochemistry* **1977**, *16*, 5484–5491.
- M. J. Genin, R. K. Mishra, R. L. Johnson, *J. Med. Chem.* **1993**, *36*, 3481–3483.
- J. T. Yli-Kauhala, J. T. J. A. Ashley, C.-H. L. Lo, J. Coakley, P. Wirsching, K. D. Janda, *J. Am. Chem. Soc.* **1996**, *118*, 5496–5497.
- A. Giannis, T. Kolter, *Angew. Chem.* **1993**, *105*, 1303–1325; *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 1244–1267; M. Kahn, *Synlett*, **1993**, 821–826; *Peptide Secondary Structure Mimetics, Tetrahedron Symposium in-Print*, No. 50 (Ed.: M. Kahn), **1993**, *49*, 3433–3689; J. Gante, *Angew. Chem.* **1994**, *106*, 1780–1802; *Angew. Int. Ed. Engl.* **1994**, *33*, 1699–1720; A. E. P. Adang, P. H. H. Hermkens, J. T. M. Linders, H. C. J. Ottenheijm, C. J. van Staveren, *Recl. Trav. Chim. Pays Bas* **1994**, *113*, 63–78; see also, T. Curran, P. M. McEnaney, *Tetrahedron Lett.* **1995**, *36*, 191–194; G. Müller, M. Gurrath, M. Kurz, H. Kessler, *Proteins: Struct., Funct. and Genet.* **1993**, *15*, 235; S. Hanessian, G. McNaughton-Smith, H.-G. Lombart, W. D. Lubell, *Tetrahedron*, in press.

- [12] Synthesis of racemic and enantiopure 2,3-methanoproline: a) A. Hercouet, B. Bessi res, M. Le Corre, *Tetrahedron: Asymmetry* **1996**, *7*, 1267–1268; b) F. L. Switzer, H. van Halbeek, E. M. Holt, C. H. Stammer, *Tetrahedron* **1989**, *45*, 6091–6100. Recent accounts on 2,3-methanoamino acids: C. H. Stammer, *Tetrahedron* **1990**, *46*, 2231–2254; K. Burgess, K. K. Ho, D. Moyl-Sherman, *Synlett* **1994**, 575–583; K. Burgess, C.-Y. Ke, *J. Org. Chem.* **1996**, *61*, 8627–8631; J. M. Jim nez, R. M. Ortuno, *Tetrahedron: Asymmetry* **1996**, *7*, 3203–3208, and references therein.
- [13] Synthesis of *cis*- and *trans*-3,4-methanoprolines: a) Y. Fujimoto, F. Irrever , J. M. Karle, I. L. Karle, B. Witkop, *J. Am. Chem. Soc.* **1971**, *93*, 3471–3477; recent discussion of cyclopropylpyrrolidines: D. F. Harvey, D. M. Sigano, *J. Org. Chem.* **1996**, *61*, 2268–2272; K. E. Brighty, M. J. Castaldi, *Synlett* **1996**, 1097–1099.
- [14] Synthesis of racemic 4,5-methanoproline amides: a) H. Urbach, R. Henning, R. Becker, DE-A 3,324,263 (Cl. C07D209/2) [*Chem. Abstr.* **1985**, 103: P 54461q]; b) related example involving mixtures of diastereomers: R. Pellicari, L. Arenare, P. De Caprariis, B. Natalin, M. Marinozzi, A. Galli, *J. Chem. Soc. Perkin Trans. 1* **1995**, 1251–1257.
- [15] a) S. Hanessian, U. Reinhold, S. Ninkovic, *Tetrahedron Lett.* **1996**, *37*, 8967–8970; b) S. Hanessian, S. Ninkovic, U. Reinhold, *ibid.* **1996**, *37*, 8971–8974.
- [16] Selected examples of carbocyclizations mediated by alkyltin(IV) intermediates: T. L. Macdonald, C. M. Delahunty, K. Mead, D. E. O'Dell, *Tetrahedron Lett.* **1989**, *30*, 1573–1576; T. L. Macdonald, S. Mahalingam, D. E. O'Dell, *J. Am. Chem. Soc.* **1981**, *103*, 6767–6769; cyclopropane formation from γ -stannyl alcohols: D. D. Davis, H. T. Johnson *ibid.* **1974**, *96*, 7576–7577; H. G. Kuivila, N. M. Scarpa, *ibid.* **1970**, *92*, 6990–6991; N. Isono, M. Mori, *J. Org. Chem.* **1996**, *61*, 7867–7872; cyclopropane formation from β -stannyl ketones: T. Sato, M. Watanabe, T. Watanabe, Y. Onoda, E. Murayama, *ibid.* **1988**, *53*, 1894–1899; C. R. Johnson, J. F. Kadow, *ibid.* **1987**, *52*, 1493–1500.
- [17] a) S. Hanessian, G. McNaughton-Smith, *Bioorg. Med. Chem. Lett.* **1996**, *6*, 1657–1662; see also b) S. Saijo, M. Wada, J.-I. Himizu, A. Ishida, *Chem. Pharm. Bull.* **1988**, *28*, 1449; c) T. Katoh, Y. Nagata, Y. Kobayashi, K. Arai, J. Minami, S. Terashima, *Tetrahedron Lett.* **1993**, *34*, 5473–5476; d) K.-H. Altmann, *ibid.* **1993**, *34*, 7721–7724. e) J. Ackermann, M. Matthes, C. Tamm, *Helv. Chim. Acta* **1990**, *73*, 122–132.
- [18] S. G. Davies, N. M. Garrido, O. Ichihara, I. A. S. Walters, *J. Chem. Soc. Chem. Commun.* **1993**, 1153–1159.
- [19] All new compounds afforded satisfactory spectroscopic and analytical data (^1H , ^{13}C NMR, IR, LRMS, HRMS). Experimental procedures are available upon request. Crystallographic data (excluding structure factors) for the structure reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-100227. Copies of the data can be obtained free of charge on application to The Director, CCDC, 12 Union Road, Cambridge CB21EZ, UK (fax: int. code + (1223) 336-033; e-mail: deposit@chemcrs.cam.ac.uk).
- [20] E. Benedetti, M. R. Ciajolo, A. Maisto, *Acta Crystallogr. Sect. B* **1974**, *30*, 1783–1788.
- [21] a) V. Teetz, R. Geiger, R. Henning, H. Urbach, *Arzneim.-Forsch./Drug Res.* **1984**, *10b*, 1399; b) R. Henning, U. Lerch, H. Urbach, *Synthesis* **1989**, 265–268 and references therein.
- [22] Hydrostannylation of alkenes: M. Lautens, S. Kumanovic, C. Meyer, *Angew. Chem.* **1996**, *108*, 1428–1429; *Angew. Chem. Int. Ed. Engl.* **1996**, *108*, 1428–1431, and references therein.
- [23] a) S.-B. Huang, J. S. Nelson D. D. Weller, *Synth. Comm.* **1989**, *19*, 3485–3496; b) S. A. Hermitage, M. G. Moloney, *Tetrahedron: Asymmetry* **1994**, *5*, 1463–1464.
- [24] J. J. Sierkierka, S. K. Y. Hung, M. Roe, C. S. Lin, N. H. Sigal, *Nature* **1989**, *341*, 755–757.
- [25] a) M. W. Harding A. Galat, D. E. Uehling, S. L. Schreiber, *Nature* **1989**, *341*, 758–760; b) H. Fretz, M. W. Albers, A. Galat, R. F. Standaert, W. S. Lane, S. J. Burakoff, B. E. Bierer, S. L. Schreiber, *J. Am. Chem. Soc.* **1991**, *113*, 1409–1410.
- [26] J. Liu, I. D. Farmer, W. S. Lane, J. Friedman, L. Weissman, S. L. Schreiber, *Cell* **1991**, *66*, 807–815.
- [27] T. M. Zabriskie, *J. Med. Chem.* **1996**, *39*, 3046–3048, and references therein.
- [28] P. J. Murray, I. D. Starkey, *Tetrahedron Lett.* **1996**, *37*, 1875–1878; A. Claesson, B.-M. Swahn, K. M. Edvinsson, H. Molin, M. Sandberg, *Bioorg. Med. Chem. Lett.* **1992**, *2*, 1247–1250.

1,8-Bis(dimethylamino)-4,5-dihydroxynaphthalene, a Neutral, Intramolecularly Protonated “Proton Sponge” with Zwitterionic Structure**

Heinz A. Staab,* Claus Krieger, Gisela Hieber, and Klaus Oberdorf

The interaction of basic groups in close proximity to each other may lead, as in the case of 1,8-bis(dimethylamino)naphthalene (**1**), to unusually high basicities (“proton sponges”).^[1] The influences of gradually changed distances and orientations of the basic centers as well as of inductive, mesomeric, and steric effects on the basicity of such compounds have been thoroughly studied.^[2] In comparison to the basicity of **1** [$pK_a \approx 12.1$ (H_2O); 7.5 (DMSO)],^[3] that of 2,7-dimethoxy-1,8-bis(dimethylamino)naphthalene (**2**) is found to be increased by four powers of ten [$pK_a \approx 16.1$ (H_2O); 11.5 (DMSO)].^[3] To separate the mesomeric effect of the two methoxy groups from their steric effect on the dimethylamino groups, we were interested in **3**, an isomer of **2** in which the two methoxy groups are not in the 2,7-positions but in the opposite *peri*-positions. In fact, 1,8-bis(dimethylamino)-4,5-dimethoxynaphthalene (**3**) is considerably less basic [$pK_a \approx 13.9$ (H_2O); 9.3 (DMSO)] than the isomer **2**, indicating that the main reason for the high basicity of **2** is the steric effect of the methoxy groups in *ortho*-positions to the dimethylamino groups. Irrespective of this primarily intended basicity comparison of **2** and **3**, the synthesis of **3** should allow the easy preparation of the corresponding 4,5-dihydroxy compound **5**, which by intramolecular proton displacement may lead to a new type of neutral, yet zwitterionic “proton sponge” (formula **6**).



For the synthesis of **3**, 1,8-dihydroxynaphthalene^[4] was methylated to give 1,8-dimethoxynaphthalene, which was nitrated (conc. nitric acid, glacial acetic acid/dichloromethane, 9:5) to yield 1,8-dimethoxy-4,5-dinitronaphthalene (39%; m.p. 278 °C); the isomeric 2,5-dinitro product (m.p. 151–153 °C) was separated by chromatography on silica gel with dichloromethane as eluent. Catalytic hydrogenation (10% Pd/C, tetrahydrofuran (THF), 20 °C) resulted in the formation of 1,8-diamino-4,5-dimethoxynaphthalene (97%; m.p. 83–95 °C, decomp), which was N-methylated according to the method of Quast et al.^[5] to give **3** (71%; m.p. 75 °C, from *n*-hexane/ethyl

[*] Prof. Dr. H. A. Staab, C. Krieger, Dr. G. Hieber, Dr. K. Oberdorf
Abteilung Organische Chemie
Max-Planck-Institut für medizinische Forschung
Jahnstrasse 29, D-69120 Heidelberg (Germany)
Fax: Int. code + (6221) 486219
e-mail: staab@mixi.mpihf-heidelberg.mpg.de

[**] New “Proton Sponges”, Part 12. Part 11: H. A. Staab, M. Diehm, C. Krieger, *Tetrahedron Lett.* **1996**, *36*, 2967–2970.