Flexible molecules with defined shape. X. Synthesis and conformational study of 1,5-diaza-*cis*-decalin†,‡

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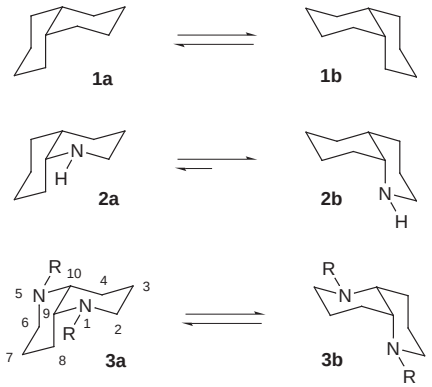
1,5-Diaza-*cis*-decalin populates two conformations in which the two nitrogen atoms are either proximal or distal to one another. The position of the conformer equilibrium depends on the substituents at the nitrogen atom, as well as the solvent and additives.

cis-Decalin (**1**) is, like cyclohexane, a typical bi-conformational molecule, which populates two isoenergetic chair conformations. Bi-conformational molecules are of interest because they are potential starting points for the development of conformational switches, that is molecules that can be flipped from one state (conformational) to another by changing a suitable external parameter such as the solvent or pH.

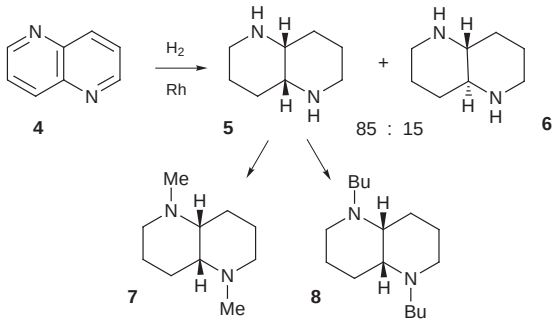


The energetic degeneracy of the two conformers of **1** can be lifted by substitution[2] or by replacing certain CH_2 groups by heteroatoms.[3,4] For instance, replacement of a CH_2 group in **1** by an NH group leads to 1-azadecalin (decahydroquinoline **2**), in which the conformer equilibrium is shifted towards the side of **2b**.[5–7] The simplest explanation refers to the fact that an NH group is slimmer than a CH_2 group; compare the *A* values of 1.8 kcal mol^{-1} for CH_3 *vs. ca.* 1 kcal mol^{-1} for NH_2.[8] Another explanation recognizes that **2b** has five C—H bonds antiperiplanar to the C—N bond, whereas **2a** has only three such arrangements, which are considered to be stabilizing by a $\sigma_{C-H} \rightarrow \sigma^*_{C-N}$ delocalization.[9] Following our study on 1,5-dioxa-*cis*-decalin[4] we report here the conformation analysis of 1,5-diaza-*cis*-decalin (**3**) and *N*-substituted derivatives.

† For Part IX see ref. 1.
‡ *Non-SI units employed:* 1 cal = 4.184 J; 1 bar = 10^5 Pa; 1 Torr ≈ 133 Pa.

Synthesis of 1,5-diaza-*cis*-decalins (*cis*-decahydronaphthyridines)

Naphthyridine (**4**) can be obtained from 3-aminopyridine by the procedure of Hamada and Takeuchi[10] in 50% yield. Reduction of **4** with sodium in ethanol leads exclusively to 1,5-diaza-*trans*-decalin (**6**).[11] Hydrogenation of **4** over rhodium/alumina led to mixtures of the *cis*-(**5**) and *trans*-(**6**) diazadecalins. The highest proportion (85 : 15) of **5** was attained on hydrogenation in acetic acid containing 0.25 equiv. of hydrochloric acid. The *cis* isomer **5** could be further enriched by selective crystallization of the *trans* isomer **6** from ethyl acetate.



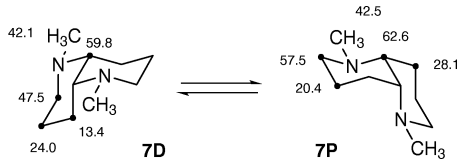
The *cis*-diamine **5** was converted in 90% yield to this bis-*N*-methyl derivative **7** by Eschweiler–Clarke methylation. Alkylation of **5** with *n*-butyl iodide furnished an 88% yield of the *N*,*N*-dibutyl derivative **8**.

Results and Discussion

Conformation analysis

The *N*,*N*-dimethyldiazadecalin **7** showed temperature dependent ^1H and ^{13}C NMR spectra, indicative of an equilibrium between two conformers, **7D** and **7P** (**D** for heteroatoms *anti* = distal, **P** for heteroatoms *gauche* = proximal). Judging from the signal intensities (those in the ^{13}C NMR spectrum corresponded well to those in the ^1H NMR one) in the low temperature region (<253 K) the two conformers are present

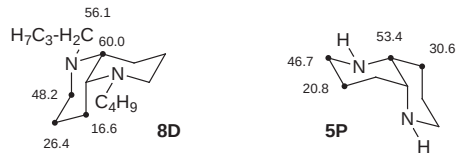
in a *ca.* 1 : 1 ratio in toluene-d_8. The conformer ratio is solvent dependent. From the low temperature ^{13}C NMR spectra in other solvents the following ratios of conformers could be estimated: D_2O, 9 : 1; CH_3OH, 9 : 1; $(CH_3)_2CO$, 3 : 2; CH_3CN, 1 : 1; $CDCl_3$, 2 : 3.



Assignment of the signals to the individual conformers was based on various types of correlation (^{1}H-COSY, HMQC and TOCSY-1D) experiments. The high-field position of the C-4 ^{13}C NMR signal in **7D** (13.4 ppm) relative to 28.1 ppm in **7P** constitutes the most diagnostic difference.[12,13] Moreover, the NCH_3 signals at 42 ppm indicate[14] that the *N*-methyl group is equatorially arranged in both conformers.

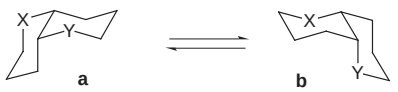
The activation barrier for ring inversion of the diazadecalin **7** can be estimated from the coalescence temperature of pairs of ^{13}C and ^{1}H NMR signals of the NCH_3 group (see Table 1). A mean value of 12.7 $\pm$ 0.2 kcal mol^{-1} for $\Delta G^{\neq}$ is fully in line with the inversion barrier of *ca.* 12.3 kcal mol^{-1} recorded previously for various *cis*-decalin derivatives.[2]

The *N*,*N*-dibutyl derivative **8** showed a broadened ^{13}C NMR spectrum at room temperature. Below 260 K a single set of sharp signals could be recorded in $CDCl_3$. The chemical shifts listed below indicate that the predominant conformer at this temperature is the distal one **8D**.



In contrast, the NH compound **5** showed a sharp ^{13}C NMR spectrum at room temperature. The chemical shifts recorded indicate that the predominant conformer present is the proximal conformer **5P**.

Including the data for the monoazadecalin **2**,[5,7] the results on the conformer equilibria of the diazadecalins in $CDCl_3$ can be summarized as follows:



heteroatoms anti = **distal** (or outside) heteroatoms gauche = **proximal** (or inside)

	X =	Y =		
2	CH_2	NH	10	: 90
9	CH_2	NCH_3	70	: 30
5	NH	NH	<10	: >90
7	NCH_3	NCH_3	40	: 60
8	NBu	NBu	>90	: <10

The NH compound **2** has a clear tendency to populate the conformer **b**, in which the heteroatom is *gauche* to three C—C bonds. This preference for the **b**-type conformer is reinforced with the diazadecalin **5**, having two NH groups. This arrangement corresponds to the one calculated to be the most stable one for ethylenediamine.[15] Hydrogen bonding may be a contributor to this preference. *N*-Alkylation of **2** to **9** causes a shift of the conformer equilibrium in the direction of the **a**-type conformer. The same trend is noted in going from **5** to the *N*-methyl (**7**) and the *N*-butyl (**8**) derivatives.

Table 1 Free energy of activation for the conformer interconversion of **7**[a]

	δ_D, δ_P	$\Delta\nu$/Hz	T_c/K	$\Delta G^{\neq}$/kcal mol^{-1}
NCH_3	1.98, 2.17	99	273	12.9
C-2	48.04, 58.26	1285	288	12.6
C-10	60.25, 63.03	354	283	12.7

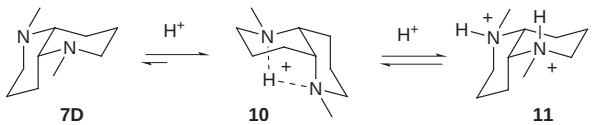
[a] Data were recorded in toluene-d_8 at 500 MHz (^{1}H NMR, 223–293 K) and 125 MHz (^{13}C NMR, 253–353 K).

Some explanations have been advanced[12] as to why *N*-alkylation should shift the conformer equilibrium towards the **a** (distal) conformer. To gain further insights we carried out force field calculations with MM3 on the energies of the proximal and distal conformers of **7** and **8**, as well as of **5** (see Table 2). These calculations show the trend that *N*-alkylation, in going from NH to NCH_3 to NBu, should increase the population of the distal conformer. These calculations substantiate the high preference of the NH compound **5** to populate the proximal conformer. The calculations do not, however, reproduce the experimentally found conformer ratios for **7** and **8**, probably because on transfer from the gas phase (calculated values) to solution both conformers are apparently not stabilized equally by solvation.[16] The data in Table 2 suggest a larger stabilization for the distal conformer by solvation than for the proximal one.

Complexation studies

Since **7** is a conformationally flexible derivative of tetramethylethylenediamine, protonation could lead to a hydrogen-bridged monocation **10**. This should by necessity have the proximal conformation. We therefore tested whether the conformer equilibrium of **7** could be shifted towards the proximal side by protonation. The results of a ^{13}C NMR titration of the dimethyl compound **7** at 260 K with trifluoromethanesulfonic acid are summarized in Fig. 1 for acetonitrile and methanol as solvents.

One sees that starting from 50% (CH_3CN) or 10% (CH_3OH) proximal protonation shifts the equilibrium far over to the proximal conformer, owing to the formation of the monoprotonated species **10**. When more than one equivalent of acid was added to **7** in methanol, precipitation of a salt from the solution started. It is uncertain whether a further ^{13}C NMR signal around 15 ppm should be associated with a diprotonated species such as **11**. It would be expected that a diprotonated species should prefer the distal conformation in order to minimize charge repulsion.



Such conformation changes upon protonation of conformationally flexible diamines has precedent in the protonation of sparteine[17] and 3,7-diaza-bicyclo[3.3.1]nonane-9-one derivatives.[18] The latter diamines have also been switched to the

Table 2 Conformer energies calculated with MM3

Compound	E_{rel}/kcal mol^{-1}		Distal : Proximal ratio	
	Distal	Proximal	Calcd	Exptal
5	22.23	20.40	<5 : >95	<5 : >95
7	32.48	31.52	<10 : >90	≈50 : 50
8	42.42	42.81	≈60 : 40	>95 : <5

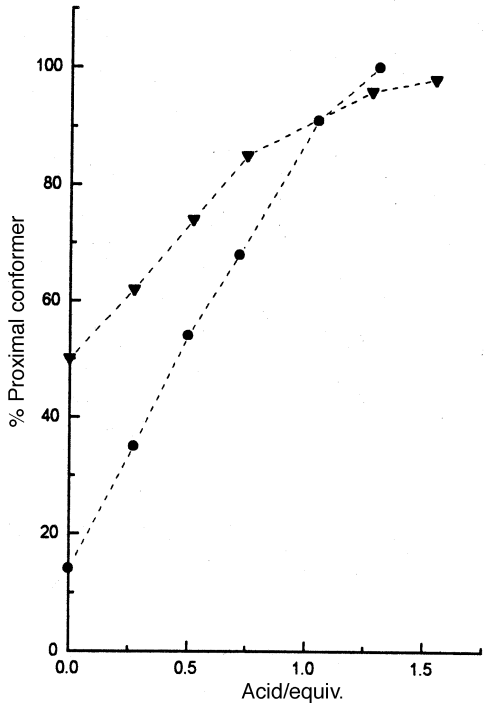
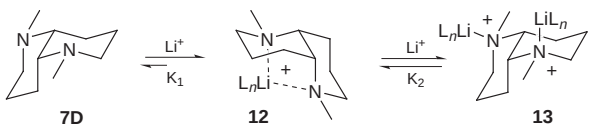


Fig. 1 Acid-induced changes in the conformer population of *N*,*N*-dimethyl-1,5-diaza-*cis*-decalin (**7**) in (●) methanol or (▼) acetonitrile

N,*N*-proximal conformation by complexation with Cu^{2+} and other divalent metal cations.[19] A study on the interaction of the *N*,*N*-dimethyl compound **7** with $Cu(OAc)_2$, $Cu(NO_3)_2$ or $Cu(OTos)_2$ remained inconclusive, since excessive line broadening in the ^{13}C NMR spectra prevented even qualitative interpretations.

On the other hand, titration of **7** in acetonitrile with $LiClO_4$ showed complexation related changes in the conformer population (see Fig. 2). Upon addition of increasing amounts of $LiClO_4$ the proximal : distal conformer ratio levelled off at a value of 4 : 1. This could be best explained by assuming the formation of a 1 : 1 complex (**12**), followed by the formation of a 1 : 2 diamine–lithium complex (**13**). The latter should prefer the distal conformation in order to minimize charge repulsion.



We attempted to fit a curve§ to the data shown in Fig. 2. The curve drawn used the equilibrium constants $K_1 = 2.5$ L mol^{-1} and $K_2 = 0.055$ L^2 mol^{-2}.

Likewise, titration of the *N*,*N*-dibutyl compound **8** with either trifluoromethanesulfonic acid or lithium perchlorate led to increasing population of the proximal conformer (up to 45%), at which point salts precipitated from the solution.

N,*N*-Di-Boc-1,5-diaza-*cis*-decalin

Other types of N substituents that could affect the conformer equilibrium are acyl groups. We therefore converted **5** into its

§ Equations for forming the complexes **12** and **13** from **7** and $LiClO_4$ were transformed into equations containing $[LiClO_4]_{total} = LiClO_4 + \mathbf{12} + 2\ \mathbf{13}$. These led to a cubic polynomial: $x^3 + ax^2 + bx + c$. The complexation constants are contained in *a*, *b* and *c*. The curve was then fitted to the experimental conformer ratios by iteration of these parameters using the Levenberg–Marquardt algorithm.

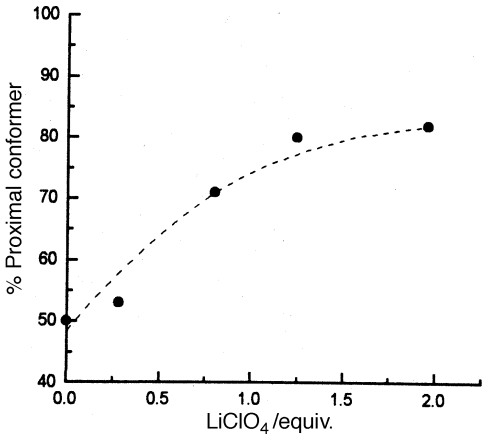
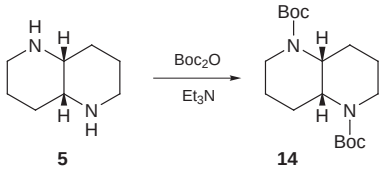


Fig. 2 Lithium-ion-induced changes in the conformer population of *N*,*N*-dimethyl-1,5-diaza-*cis*-decalin (**7**) in acetonitrile. (----) Fitted line using $K_1 = 2.550$ L mol^{-1} and $K_2 = 0.055$ L^2 mol^{-2}

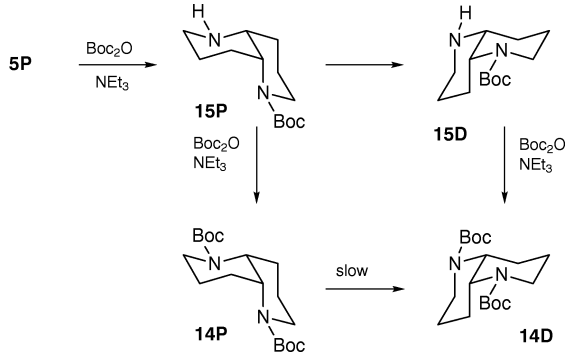
diBoc derivative **14** (Boc = *tert*-butoxycarbonyl). This reaction and the product **14** revealed unexpected conformational peculiarities.



Treatment of **5** with Boc_2O at 0 °C gave rise to the formation of two isomeric diBoc derivatives **14a** and **14b** in 95% yield in a 1 : 1 ratio. Lowering the reaction temperature gave the isomers in a 1 : 4 ratio. In turn, when the reaction was carried out in refluxing chloroform, only **14a** was obtained. The isomers could be separated by column chromatography. **14b** is an oil, whereas **14a** is a solid with a melting point of 136 °C.

It could be shown, with the aid of such mixtures, that isomer **14b** is converted into isomer **14a** at 90 °C with a half-life of *ca.* 30 min. A study of the temperature dependence of the first-order conversion of **14b** into **14a** at temperatures between 333 and 363 K led to $\Delta H^{\neq} = 28$ kcal mol^{-1} and $\Delta S^{\neq} = 13$ kcal mol^{-1}, corresponding to $\Delta G^{\neq} = 23.5$ kcal mol^{-1} at 75 °C.

The NMR spectrum of **14a** was complicated at room temperature due to the presence of amide bond rotamers. At higher temperatures (140 °C) amide rotation was rapid (barrier of *ca.* 16 kcal mol^{-1})[20] and clean spectra could be recorded, but of course, only of the **14a** isomer. The high temperature spectrum could be interpreted to the point that **14a** is the distal conformer **14D**. This follows from the coupling constants of the isochronous 9-H and 10-H protons of 12.7, 3.1, 4.5 and −0.8 Hz, values that allowed a simulation of the complex coupling pattern using the program CALM.[21]



It is clear that of the two decalin conformers of the diBoc derivative **14**, the distal one, **14D**, should be more stable than the proximal one, **14P**, because in **14D** each piperidine ring carries the α-substituent in an axial arrangement. This arrangement is the one in which 1,3-allylic strain is minimized.[22]

On the other hand, the reaction that leads to **14** starts from **5**, which is present essentially in the proximal conformation, **5P**. It is therefore not unexpected that the monoBoc product **15** should be formed initially in the proximal conformation **15P**. If the introduced Boc group raises the activation energy for decalin ring inversion owing to steric hindrance, attachment of the second Boc group could be competitive with the exothermic conformation change of **15P** into **15D**, a situation in which the Curtin–Hammett principle does not apply.

Since the observations made on the *tert*-butoxycarbonylation of the diazadecalin **5** are in full accord with such a mechanistic scenario, we propose that the compounds **14a** and **14b** are the conformational isomers **14D** and **14P**. This would mean that the two Boc groups present in **14P** have raised the barrier for conformational change to 23 kcal mol^{-1}. For the decalin ring inversion of the monoBoc compound **15b**, the barrier should be between that expected for **5** (12 kcal mol^{-1}) and that postulated for **14P** (23 kcal mol^{-1}). If it is on the order of 20 kcal mol^{-1}, the temperature dependence of the **14A** : **14B** isomer ratio is easily accounted for as a consequence of a competition between conformational change of **15P** to **15D** and conversion of **15P** into **14P**.

This study on 1,5-diaza-*cis*-decalin has thus led to novel findings regarding the conformational preferences: proximal for the NH compound **5** and changing progressively to distal on going to the *N*-methyl compound **7**, the *N*-butyl compound **8** and the *N*-Boc derivative **14**. Moreover, the barrier for decalin ring inversion is increased by attachment of a Boc group to the nitrogen to the point that conformational isomers of the diBoc derivative **14** may be isolated and separately studied.

Experimental

All temperatures quoted are uncorrected. ^1H and ^{13}C NMR spectra were taken on Bruker AC-300, ARX-400, AMX-500 and Varian Unity-500 spectrometers. Mass spectra were taken on Vacuum Generators ZAB-E and Autospec instruments with FAB using cesium ion bombardment at 25 kV from a 3-nitrobenzyl alcohol matrix. Boiling range of the petroleum spirit used was 40–60 °C. Column chromatography was performed on silica gel 60 A, Silitech, 32–36 μm and thin layer chromatography on Merck 60F542 plates.

Syntheses

1,5-Diaza-*cis*-decalin (5). A solution of HCl in acetic acid (1 M, 1.0 ml) was added to a solution of naphthyridine (**4**)[10] (0.50 g, 3.8 mmol) in acetic acid (8.5 ml) followed by rhodium (5% on alumina, 22.5 mg). The mixture was stirred for 8 days at 50 °C under hydrogen (6 bar). The mixture was filtered and the solvent was evaporated. The residue was dissolved in water (15 ml), 50% aqueous NaOH solution was added to give a pH > 14 and the solution was extracted with chloroform (3 × 10 ml). The combined extracts were dried over K_2CO_3 and the solvent was removed *in vacuo* to leave a 85 : 15 mixture of the *cis* (**5**) and *trans* (**6**) isomers. Crystallization from ethyl acetate (*ca.* 5 ml) afforded a *ca.* 1 : 1 mixture of **5** and **6** (0.18 g, 33%). Concentration of the mother liquor furnished **5** (0.35 g, 65%) containing less than 5% of **6**. **5**: ^1H NMR (500 MHz, $CDCl_3$, position numbering as shown for **3a**): δ 3.08 (dq, J = 12.5 and 4.0 Hz, 2H, 2-H_{eq}, 6-H_{eq}), 2.70 (t, J = 2.1 Hz, 2H, 9-H, 10-H), 2.64 (td, J = 12.0 and 3.2 Hz, 2H, 2-H_{ax}, 6-H_{ax}), 1.63–1.73 (m, 6H, 3-H_{ax}, 7-H_{ax}, 4-H_{ax}, 8-H_{ax}, 4-H_{eq}, 8-H_{eq}), 1.58 (br s, 2H, 2 × NH), 1.35 (m, 2H 3-H_{eq}, 7-H_{eq}). ^{13}C NMR (100 MHz, $CDCl_3$): δ 53.4 (C-9, C-10), 46.7 (C-2, C-6), 30.6 (C-4, C-8), 20.8 (C-3, C-7). MS (FAB): $C_8H_{16}N_2$ requires 140.13135, found 140.13140.

6: ^1H NMR (300 MHz, $CDCl_3$): δ 2.96 (dqui, J = 12.1, 3.1 and 1.5 Hz, 2H, 2-H_{eq}, 6-H_{eq}), 2.58 (dt, J = 12.1 and 3.1 Hz, 2H, 2-H_{ax}, 6-H_{ax}), 2.10 (m, J = 12.2, 4.3, 3.2 and −0.8 Hz, 2H, 9-H, 10-H), 1.43–1.75 (m, 8H, 2 × 3-H, 2 × 7-H, 4-H_{eq}, 8-H_{eq}, 2 × NH), 1.20 (m, 2H, 4-H_{ax}, 8-H_{ax}). ^{13}C NMR (75 MHz, $CDCl_3$): δ 61.6 (C-9, C-10), 46.7 (C-2, C-6), 32.1 (C-4, C-8), 26.3 (C-3, C-7).

***N*,*N*-Dimethyl-1,5-diaza-*cis*-decalin (7).** Compound **5** (0.20 g, 1.4 mmol) was added to a mixture of formic acid (0.16 ml, 0.19 g) and 37% aqueous formaldehyde solution (0.27 ml). After warming for 1 day to 70 °C, water was added (5 ml), followed by 50% aqueous NaOH to obtain a pH > 14. The mixture was extracted with dichloromethane (3 × 5 ml). The combined extracts were dried with K_2CO_3, the solvents were evaporated and the residue was Kugelrohr distilled at 100 °C and 0.5 Torr, resulting in a colorless liquid (0.22 g, 90%).

7P: ^1H NMR (500 MHz, $CDCl_3$, 223 K): δ 2.93 (dqui, J = 11.0 and 2.0 Hz, 2H, 2-H_{eq}, 6-H_{eq}), 2.16 (s, 6H, 2 × NCH_3), 2.08 (brd, J = 14.0 Hz, 2H, 4-H_{eq}, 8-H_{eq}), 2.02 (ddd, J = 12.6, 11.0 and 2.9 Hz, 2H, 2-H_{ax}, 6-H_{ax}), 1.90 (d, J = 3.0 Hz, 2H, 9-H, 10-H), 1.88 (qt, J = 13.1 and 3.8 Hz, 2H, 3-H_{ax}, 7-H_{ax}), 1.34 (dqui, J = 13.4 and 2.8 Hz, 2H, 3-H_{eq}, 7-H_{eq}), 1.24 (tt, J = 14.0 and 3.5 Hz, 2H, 4-H_{ax}, 8-H_{ax}). ^{13}C NMR (100 MHz, $CDCl_3$, 260 K): δ 62.6 (C-9, C-10), 57.5 (C-2, C-6), 42.5 (CH_3), 28.1 (C-4, C-8), 20.4 (C-3, C-7).

7D: ^1H NMR (500 MHz, $CDCl_3$, 223 K): δ 2.97 (dq, J = 9.2 and 3.0 Hz, 2H, 9-H, 10-H), 2.49 (dd, J = 12.5 and 2.1 Hz, 2H, 2-H_{eq}, 6-H_{eq}), 2.40 (s, 6H, 2 × NCH_3), 2.38 (td, J = 11.8 and 2.3 Hz, 2H, 2-H_{ax}, 6-H_{ax}), 1.75 (dq, J = 9.5 and 2.2 Hz, 2H, 3-H_{eq}, 7-H_{eq}), 1.62 (dm, J = 9.5 Hz, 2H, 4-H_{eq}, 8-H_{eq}), 1.51 (m, 4H, 3-H_{ax}, 4-H_{ax}, 7-H_{ax}, 8-H_{ax}). ^{13}C NMR (100 Hz, $CDCl_3$, 260 K): δ 59.8 (C-9, C-10), 47.5 (C-2, C-6), 42.1 (CH_3), 24.0 (C-3, C-7), 13.4 (C-4, C-8). MS (FAB): $C_{10}H_{21}N_2^+$ requires 169.17047, found 169.16666.

***N*,*N*-Di-*n*-butyl-1,5-diaza-*cis*-decalin (8).** Aqueous NaOH (50%, 1.6 ml) was added to a solution of **5** (0.318 g, 2.27 mmol) in THF (3.0 ml), followed by 1-iodobutane (0.62 ml, 1.00 g, 2.7 mmol). After stirring for 1 day water was added (10 ml) and the mixture was extracted with dichloromethane (3 × 10 ml). The combined extracts were dried with K_2CO_3, the solvents were evaporated and the residue was Kugelrohr distilled at 150 °C, 0.1 Torr to give a colorless liquid (0.50 g, 88%). ^1H NMR (400 MHz, $CDCl_3$, 260 K): δ 2.87 (m, J = 12.0, 5.1, 3.3 and −0.5 Hz, 2H, 9-H, 10-H), 2.46–2.27 (m, 8H, 2-H, 6-H, 2 × $NCH_2CH_2CH_2CH_3$), 1.64–1.34 (m, 12H, 3-H, 7-H, 4-H, 8-H, 2 × $NCH_2CH_2CH_2CH_3$), 1.28 (hex, J = 7.3 Hz, 4H, $NCH_2CH_2CH_2CH_3$), 0.88 (t, J = 7.3 Hz, 6H, 2 × $NCH_2CH_2CH_2CH_3$). ^{13}C NMR (100 MHz, $CDCl_3$, 260 K): δ 60.0 (C-9, C-10), 56.0 [$NCH_2(CH_2)_2CH_3$], 48.2 (C-2, C-6), 31.8 ($NCH_2CH_2CH_2CH_3$), 26.4 (C-3, C-7), 22.7 ($NCH_2CH_2CH_2CH_3$), 16.6 (C-4, C-8), 15.9 ($NCH_2CH_2CH_2CH_3$). MS (FAB): $C_{16}H_{32}N_2^+$ requires 252.25655, found 252.25660.

***N*,*N*-Di-*tert*-butoxycarbonyl-1,5-diaza-*cis*-decalin (14).** Di-*tert*-butyldicarbonate (0.91 ml, 0.93 g, 4.2 mmol) were added to a solution of compound **5** (0.212 g, 1.51 mmol), triethylamine (0.59 ml, 0.43 g, 4.2 mmol) and 4-dimethylaminopyridine (*ca.* 2 mg) in dichloromethane (3.0 ml). The solution was stirred for 4 h at 25 °C. Water (10 ml) was added and the mixture was extracted with dichloromethane (3 × 5 ml). The combined extracts were dried with $MgSO_4$ and the solvents were evaporated. The residue was purified by column chromatography with ether : petroleum spirit (6 : 4), first yielding in the order of elution a colorless oil (0.16 g, 31%) identified as **14P** [TLC: R_f = 0.6 with diethyl

ether : hexane (3 : 7)] which showed complex ^1H and ^{13}C NMR spectra due to the presence of various amide rotamers. ^1H NMR (400 MHz, $CDCl_3$): δ 4.2 (br, 2H, 9-H, 10-H), 3.8 (br, 2H, 2-H_{eq}, 6-H_{eq}), 2.36 (br, 2H, 2-H_{ax}, 6-H_{ax}), 1.37–1.24 (br, 26H).

The second compound eluted was a white crystalline solid of mp 136 °C (0.33 g, 64%) identified as **14D** [TLC: $R_f = 0.4$, diethyl ether : hexane (3 : 7)]. ^1H NMR (500 MHz, $CDCl_2CDCl_2$, 403 K): δ 4.10 (m, J = 12.7, 3.1, 4.5 and −0.8 Hz, 2H, 9-H, 10-H), 3.86 (dt, J = 13.2 and 3.0 Hz, 2H, 2-H_{eq}, 6-H_{eq}), 2.66 (dt, J = 13.2 and 3.0 Hz, 2H, 2-H_{ax}, 6-H_{ax}), 1.74 (m, J = 12.6 and 4.2 Hz, 2H, 3-H_{eq}, 7-H_{eq}), 1.65 (m, J = 10.6 and 3.4 Hz, 2H, 4-H_{eq}, 8-H_{eq}), 1.35–1.45 [m, 22H, 3-H_{ax}, 7-H_{ax}, 4-H_{ax}, 8-H_{ax}, 2 × $(CH_3)_3C$]. ^{13}C NMR (125 MHz, $CDCl_2CDCl_2$, 403 K): δ 154.9 (2 × C=O), 79.6 [2 × $C(CH_3)_3$], 51.4 (C-9, C-10), 39.0 (C-2, C-6), 28.7 [2 × $(CH_3)_3C$], 25.0 (C-3, C-7), 22.5 (C-4, C-8). Anal. $C_8H_{32}N_2O_4$ (340.47) requires C 63.50, H 9.47, N 8.23; found C 63.32, H 9.70, N 8.05%.

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