

Synthesis and crystal structure of the bromide salt of the inside protonated form of the cage amine [(2.3)³]adamanzane, 1,4,8,12-tetraazatricyclo[6.6.3.2^{4,12}]nonadecane and synthesis of the bowl amine [(2.3)².2¹]adamanzane, 1,5,9,12-tetraazabicyclo[7.5.2]-hexadecane

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The reaction of 1,4,7-triazacyclononane with tris(3-chloropropyl)amine affords the inside monoprotonated form of the tricyclic amine 1,4,8,12-tetraazatricyclo[6.6.3.2^{4,12}]nonadecane (**3**), which was isolated as the bromide salt, [H[(2.3)³]adz]Br (yield 38%). The crystal structure of [H[(2.3)³]adz]Br·4H₂O has been solved by X-ray diffraction at *T* = 120 K. In the i⁺,i,i,i-H[(2.3)³]adz⁺ cation (**3a**) the acidic hydrogen atom and the lone pairs of the nitrogen atoms are oriented towards the inside of the cavity. The acidic hydrogen atom is attached to the apical nitrogen atom and both are positioned on a three-fold axis. The distances between the nitrogen atoms are in the range of 2.73(2)–2.99(1) Å. The inside coordinated proton in H[(2.3)³]adz⁺ (**3a**) is unusually inert to reaction with base (*k*_{diss} < 4 × 10⁻⁹ s⁻¹ at 25 °C in 0.01 M NaOD). From ¹H and ¹³C NMR it is concluded that in slightly acidic (pH > 2) and in basic aqueous solutions the dominant form of the cage has all four lone pairs pointing into the cavity. In concentrated strong acid protonation occurs and is believed to involve inversion at one or several of the bridgehead nitrogen atoms. In concentrated boiling hydrochloric acid the cage undergoes a slow cleavage of one trimethylene bridge to give the bowl amine [(2.3)².2¹]adz (**7**), 1,5,9,12-tetraazabicyclo[7.5.2]hexadecane, which was isolated as the triprotonated bromide dichloride salt, [H₃[(2.3)².2¹]adz]BrCl₂·H₂O (yield 40%).

Introduction

Macrocyclic and macrobicyclic polyamines are of current interest and exhibit unusual basicity and coordination chemistry.¹⁻⁹ The class of tricyclic tetraamines, so-called adamanzanes (see Experimental), whose smallest member is the classical compound urotropin or “hexamethylenetetraamine”, has until recently scarcely been studied,^{8,9} and only a few examples of larger tricyclic amines have been reported. Schmidtchen¹⁰ has synthesized and studied the large urotropin analogues having

hexamethylene or octamethylene bridges, [6⁶]adamanzane and [8⁶]adamanzane. Related large tricyclic compounds have been reported by Takemura *et al.*¹¹ and Lehn and co-workers.¹²

Previously we have presented¹³⁻¹⁵ facile methods for the syntheses and crystal structures of the inside protonated forms of the small tricyclic tetraamines [2⁴.3²]adamanzane (**2a**) and [3⁶]adamanzane (**4a**), which both have all lone pairs pointing inwards in the cage (Fig. 1). These are the first examples of adamanzanes containing only small chains (*n* = 2 or 3). Quite recently Miyhara *et al.* reported the synthesis of the

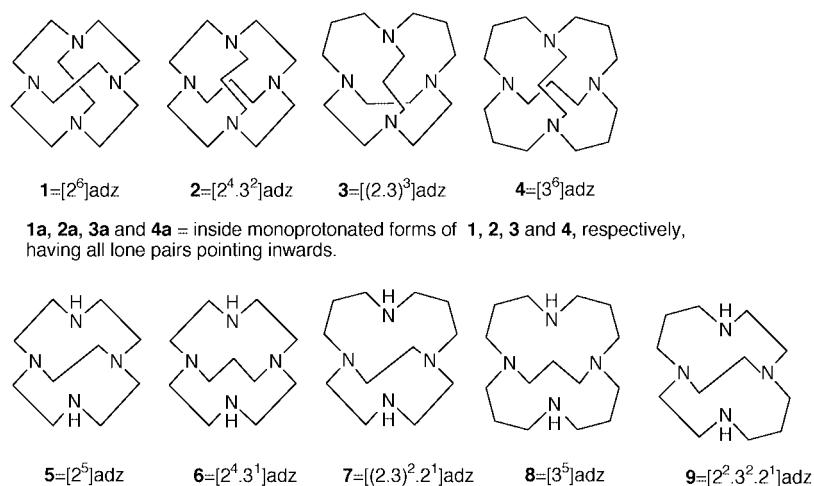


Fig. 1 Small bowls and cages previously reported by Miyahara *et al.* (**1** and **5**), Weisman and co-workers (**9**) and Springborg *et al.* (**2**, **4**, **6** and **8**) along with those reported in this study (**3** and **7**). Very large bowls and cages have been reported by Schmidtchen *et al.* and a series of small bowls by Micheloni and co-workers and by Weisman and co-workers, who also reported the first small bowl adamanzane (*N*-methyl derivative of **9**).

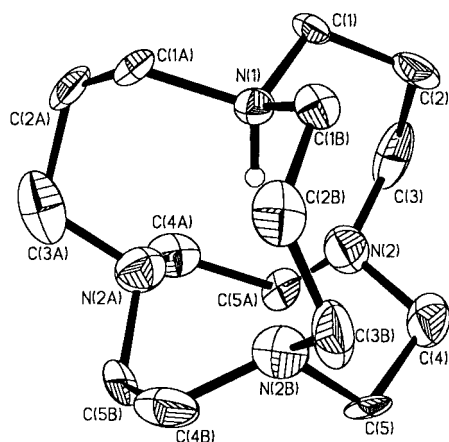


Fig. 2 View of the $i^+,i,i,i\text{-H}[(2.3)^3]\text{adz}^+$ cation **I**. Thermal ellipsoids are drawn at the 50% probability level. With exception of H(1) bound to N(1) the hydrogen atoms have been omitted for clarity. The labelling of cation **II** is similar to that of **I** [N(3), N(4), C(6)–C(10)].

highly symmetrical [2⁶]adamanzane (**1a**), built up by ethylene bridges.¹⁶ These small adamanzanes all act as strong proton sponges and have recently been the subject of *ab initio* calculations of properties such as basicity and strain energy.^{17,18}

The corresponding bicyclic tetraamines (**5**, **6** and **8** in Fig. 1) have also been reported^{16,19,20} and metal ion complexes with these so-called bowl-adamanzanes have been characterized.^{21–23} Other bowl-adamanzanes have also been described^{24–26} and metal ion coordination compounds with some of these amines have been described, as for instance two novel zinc complexes of **9** reported by Weissmann and co-workers.²⁷

In the present paper we report the synthesis and crystal structure of the new cage [(2.3)³]adamanzane (**3**) isolated as the bromide salt of its inside protonated form. Also reported is the cleavage of the cage giving its analogous bowl, [(2.3)².2¹]adamanzane (**7**), which was isolated as a mixed bromide chloride salt. Falling between those previously reported (Fig. 1) in ring size these compounds provide a possibility to study further how size and inherent strain control the properties of these tetraamines and their coordination compounds.

Results and discussion

Crystal structure of [H[(2.3)³]adz]Br·4H₂O

The compound consists of $i^+,i,i,i\text{-H}[(2.3)^3]\text{adz}^+$ (**3a**) and Br[−] ions and water molecules. There are two crystallographic independent cations, **I** and **II**, of $i^+,i,i,i\text{-H}[(2.3)^3]\text{adz}^+$. The two cations are alike. The structure is a racemic twin, where half of the crystal blocks in the crystal contain one enantiomer and the other half contain the other one. The labelling of the atoms in the $i^+,i,i,i\text{-H}[(2.3)^3]\text{adz}^+$ cation **I** is shown in Fig. 2. Bond lengths and bond angles are as found in similar compounds.^{13,15} One of the nitrogen atoms of each of the two independent cations [N(1)(**I**) and N(3)(**II**)] together with their acidic hydrogen atoms [H(1)(**I**) and H(3)(**II**)] are positioned on a three-fold axis and so are the Br[−] ions and the oxygen atoms of two of the water molecules. The acidic hydrogen atom and the lone pairs of the nitrogen atoms are oriented towards the inside of the cavity. The distances between the bridgehead nitrogen atoms in cation **I** are 2.93(2) Å for N(1)⋯N(2) and 2.73(2) Å for N(2)⋯N(2) (−*y*, *x* − *y*, *z*). The corresponding distances in **II** are 2.99(1) Å and 2.91(1) Å, respectively. The N⋯N distances in H[2⁶]adz⁺ (**1a**) are 2.598 and 2.860 Å and in $i^+,i,i,i\text{-H}[3^6]\text{adz}^+$ (**4a**) they are in the range 3.02–3.23 Å.^{15,16} In $i^+,i,i,i\text{-H}[2^4.3^2]\text{adz}^+$ (**2a**) the N⋯N distances are 2.636(7) and 3.081(7) Å, and in $i^+,i,o^+,o^+\text{-H}_3[3^6]\text{adz}^{3+}$ they are in the range 3.15–4.62 Å, making the last two cages somewhat elongated.^{13,15} In cation **I** the acidic hydrogen atom is attached to the apical nitrogen atom N(1), and the H⋯N(2) (all three symmetry related N(2) atom)

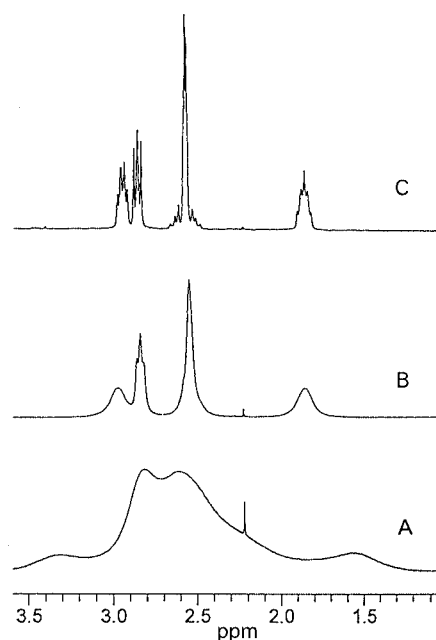
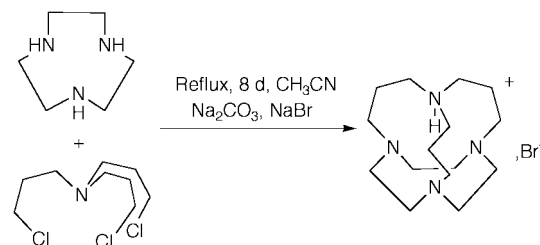


Fig. 3 ¹H NMR spectra of solutions of [H[(2.3)³]adz]Br in D₂O measured at 25 °C (A), 50 °C (B) and 90 °C (C).

distances inside the cavity are 2.20(1) Å. The corresponding distances in **II** are 2.28(1) Å. The four nitrogen atoms of both $i^+,i,i,i\text{-H}[(2.3)^3]\text{adz}^+$ ions (**3a**) form a trigonal pyramid (or a rather distorted tetrahedron) about the centre (M) of the cavities with an average M–N distance of 1.8 Å, to be compared with those of 2.4 Å and 1.9 Å, respectively, found in $i^+,i,i,i\text{-H}[3^6]\text{adz}^+$ (**4a**) and $i^+,i,o^+,o^+\text{-H}_3[3^6]\text{adz}^{3+}$. In the crystal packing the water molecules are hydrogen-bonded to other water molecules and to the Br[−] ions.

Synthesis and solution properties of the cage

The macrotricyclic cage H[(2.3)³]adz⁺ (**3a**) has been made by the reaction of 1,4,7-triazacyclononane with tris(3-chloropropyl)amine as shown in Scheme 1. The monoprotonated



Scheme 1

amine was isolated as a bromide salt, [H[(2.3)³]adz]Br (yield 38%). The ¹³C NMR spectrum in D₂O exhibits four sharp signals (CH₂) with the relative intensities 2 : 1 : 1 : 1 and chemical shift values in the expected^{18–20} regions (see Experimental). The ¹H NMR spectrum of an aqueous, neutral solution at 25 °C shows very broad resonance bands. At higher temperatures the spectrum changes to increasingly more sharp lines as shown in Fig. 3. At the highest temperature of 90 °C the spectrum corresponds to molecular C_{3v} symmetry: a quintet centered around 1.85 ppm (6 protons, C–CH₂–C), an AA'BB' multiplet centered around 2.55 ppm (12 protons, CH₂–N in the triaza-cyclononane entity in agreement with a fast enantiomerization on the ¹H NMR time-scale), two multiplets centered around 2.85 ppm and 2.95 ppm, respectively (6 and 6 protons belonging to the two different CH₂–N of the trimethylene bridges) and finally a singlet at 11.73 ppm (1 inside coordinated proton). The fact that the symmetry is C_{3v} only at high temperature could be

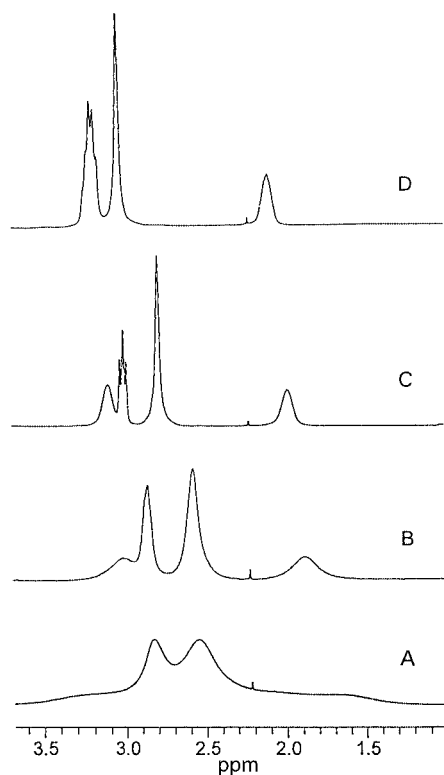


Fig. 4 ^1H NMR spectra of D_2O solutions of $[\text{H}[(2.3)^3]\text{adz}]\text{Br}$ in 0.1 M DCl (A), 1 M DCl (B), 3 M DCl (C) and 6 M DCl (D) measured at 25°C .

due to a slow (on the ^1H NMR time-scale) equilibration reaction at room temperature between different conformations of the trimethylene- and ethylene-bridges, *i.e.* a slow enantiomerization of the racemic isomers present in the solid state as shown by the X-ray crystal data. Another possibility is that the inside coordinated proton shuttles slowly between the four nitrogen atoms, although this is in contrast to crystallographic data, which clearly show that the proton is coordinated to the nitrogen positioned at the molecular C_3 symmetry axis. Finally, slow inversion reactions of the lone pairs of the bridgehead nitrogen atom should be considered, but as discussed below it is most probable that all four lone pairs are oriented inwards in neutral aqueous solutions as was also found in the crystal structure.

The cage **3a** does not react with protons in the region $\text{pH} = 2\text{--}14$ as shown by the ^1H NMR spectra of solutions in 0.01 M DCl, D_2O and 1 M NaOD measured at 50°C . Furthermore, potentiometric titration with hydrochloric acid confirmed that the cage does not react with hydrogen ions to any significant extent at $[\text{H}^+] \leq 0.02$ M ($I = 1.0$ M (NaCl) at 25°C). This points strongly to the suggestion that the $[\text{H}[(2.3)^3]\text{adz}]^+$ ion (**3a**) in solution ($\text{pH} = 2\text{--}14$) has the lone pairs of all four nitrogen atoms pointing inwards as was also found in the crystal structure.

In more acidic solutions, however, the cage does react with hydrogen ions as seen by the change of the ^1H NMR spectrum (25°C) when the acid concentration is increased from 10^{-2} M to 6 M as shown in Fig. 4. As the acid concentration increases, the δ value for the inside coordinated proton decreases from 11.76 ppm (D_2O) to 11.41 ppm (6 M DCl). These changes are interpreted as an inversion of the inwards oriented lone pair of the bridgehead nitrogen atom followed by protonation as illustrated in Scheme 2 for the first outside oriented protonation. From the present data it is not possible to determine how many protons the cage reacts with, but the fact that the spectra continue to change over the entire range 0.01 M to 6 M suggests that the $[\text{H}[(2.3)^3]\text{adz}]^+$ (**3a**) ion reacts with more than one proton.

This result is similar to the results reported for the larger cage

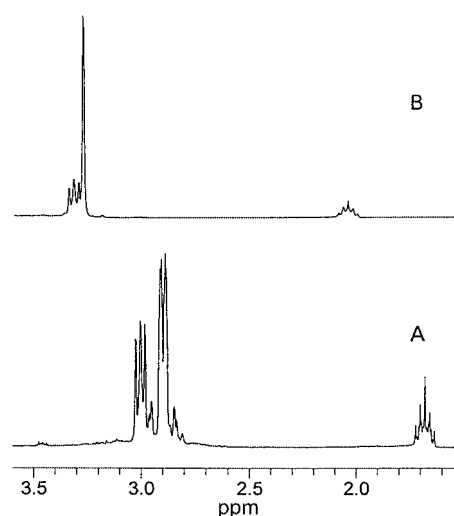
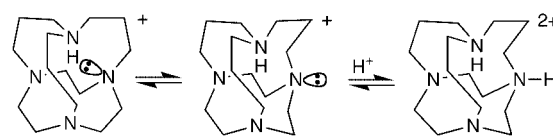


Fig. 5 ^1H NMR spectra of D_2O solutions of $[\text{H}[(2.4.3)^2]\text{adz}]\text{ClO}_4$ in 0.1 M DCl (A) and 3 M DCl (B) measured at 25°C .



Scheme 2 In the solid and in aqueous solutions ($\text{pH} = 2\text{--}14$) of $[\text{H}[(2.3)^3]\text{adz}]\text{Br}$ the cation (**3a**) has all four lone pairs of the N atoms pointing inwards and one proton inside coordinated to the N atom placed at the molecular C_3 -symmetry axis, $i^+,i,i,i\text{-H}[(2.3)^3]\text{adz}^+$. In concentrated strong acid the cage reacts with one or several protons (see also Fig. 4). As outlined above this process involves inversion of the lone pair at one of the unprotonated N atoms followed by reaction with a proton to give the diprotonated form $i^+,i,i,o^+\text{-H}_2[(2.3)^3]\text{adz}^{2+}$.

$[\text{H}[3^6]\text{adz}]^+$ (**4a**), which forms di- and triprotonated species $i^+,i,i,o^+\text{-H}_2[3^6]\text{adz}^{2+}$ and $i^+,i,o^+,o^+\text{-H}_3[3^6]\text{adz}^{3+}$. The diprotonated cation, $i^+,i,i,o^+\text{-H}_2[3^6]\text{adz}^{2+}$, is the dominant species in the region 0.1–3.0 M DCl. The triprotonated species, $i^+,i,o^+,o^+\text{-H}_3[3^6]\text{adz}^{3+}$ is a very strong acid and even in 6 M DCl it is only present in minor amounts. However, the triprotonated cation can be isolated as a mixed tetrabromozincate and bromide salt, which has been characterized by its crystal structure.³

The inside protonated small amine $i^+,i,i,i\text{-H}[2^4.3^2]\text{adz}^+$ (**2a**) is aprotic in the entire pH range 1–14 as reported previously.¹ However, in the present study we found that this cation also undergoes outside protonation at high acid concentrations. The ^1H NMR spectra of solutions of $[\text{H}[2^4.3^2]\text{adz}]\text{Br}$ in D_2O and 0.1 M DCl, respectively, are identical, but different from the spectrum of a solution in 3 M DCl as shown in Fig. 5. Likewise the δ value for the inside coordinated proton changes from 15.20 ppm (D_2O) to 17.34 ppm (3 M DCl). At higher acid concentration (up to 6 M) no further change in the spectrum was observed. The spectrum of the solution in 3 M DCl therefore represents that of either a diprotonated species, $i^+,i,i,o^+\text{-H}_2[2^4.3^2]\text{adz}^{2+}$, or a triprotonated species, $i^+,i,o^+,o^+\text{-H}_3[2^4.3^2]\text{adz}^{3+}$.

The inside coordinated proton of $[\text{H}[(2.3)^3]\text{adz}]^+$ (**3a**) is very inert with respect to dissociation. A solution of $[\text{H}[(2.3)^3]\text{adz}]\text{Br}$ in 0.01 M NaOD shows a ^1H NMR signal at 11.73 ppm for the inside coordinated proton and the intensity decreased less than 5% over a period of 5 months at 25°C . It is therefore concluded that the rate constant, k_{diss} , for dissociation of the proton from $[\text{H}[(2.3)^3]\text{adz}]^+$ (**3a**) must be less than $4 \times 10^{-9} \text{ s}^{-1}$. This is similar to the properties of $[\text{H}[2^4.3^2]\text{adz}]^+$ (**2a**) and $[\text{H}[3^6]\text{adz}]^+$ (**4a**), which both have $k_{\text{diss}} < 4 \times 10^{-8} \text{ s}^{-1}$ (25°C , 1 M NaOD). This unusual inertness has been discussed previously.^{18,19}

The fact that the product in the synthesis is $[\text{H}[(2.3)^3]\text{adz}]^+$ (**3a**) and not the unprotonated free amine (**3**) is similar to the results for the syntheses of the two other cages, $[\text{H}[2^4.3^2]\text{adz}]^+$ (**2a**) and

Table 1 Acid dissociation constants of bowl adamanzanes (25 °C, $I = 1.0$ M)

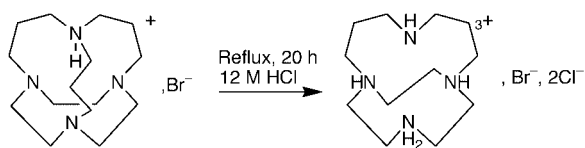
Compound	pK_{a1}	pK_{a2}	pK_{a3}	pK_{a4}
$H_4[3^5]adz^{4+}$ ^a	1–2	1–2	9.65(2)	12.09(4)
$H_4[(2.3)^2.2]adz^{4+}$ ^b	<1	<1	8.5(1)	>11
$H_4[2^4.3^1]adz^{4+}$ ^c	<-1	3.202(7)	7.242(8)	>15

^a From ref. 20, 1 M NaBr. ^b This work, 1 M NaCl. ^c From ref. 19, 1 M NaBr.

$H[3^6]adz^+$ (**4a**), and has been rationalized previously.¹⁹ Also the synthesis of the small cage yields the inside monoprotonated form **1a** and not **1**.¹⁶

Cleavage of $[H[(2.3)^3]adz]Br$ in strong acid to the corresponding bowl adamanzane

The present cage reacts in boiling concentrated hydrochloric acid, and the main process is cleavage of one trimethylene bridge as shown in Scheme 3 to give the new bowl amine



$[(2.3)^2.2^1]adamanzane$ (**7**) (1,5,9,12-tetraazabicyclo[7.5.2]hexadecane). The amine was isolated as the bromide dichloride salt $[H_3[(2.3)^2.2^1]adz]BrCl_2 \cdot H_2O$. The proposed structure was established unambiguously by the ¹³C NMR spectrum which exhibits the expected number of 6 resonance lines including only one resonance line for the two equivalent C–CH₂–C methylene groups. Cleavage at one of the three ethylene bridges would result in $[(2.3)^2.3^1]adz$, which is expected to have 8 resonance lines including two signals for the two different C–CH₂–C methylene groups (ratio 2:1). The ¹³C NMR spectrum of the crude reaction mixture did not give any evidence for the presence of this product. We therefore conclude that $[(2.3)^2.3^1]adz$ only constitutes a minor fraction of the products. In Scheme 3 the product(s) arising from the cleavage of the trimethylene bridge is not shown; possible candidates are propene or propan-1-ol.

It is noted that the present cage behaves very differently from its larger analogue $H[3^6]adz^+$ (**4a**), but is similar to the smaller $H[2^4.3^1]adz^+$ cation (**2a**). The former can be boiled in 12 M HCl for days without any detectable cleavage reaction, while the smaller cage undergoes a slow cleavage of one of the two trimethylene bridges to give quantitatively (as measured by ¹³C NMR) the parent bowl adamanzane $[2^4.3^1]adz$ (**6**) without further cleavage of other N–C bonds.²⁰

Potentiometric determination of the the four acid dissociation constants of $H_4[(2.3)^2.2^1]adz^{4+}$ are given in Table 1 together with those reported for the two other bowls.

Concluding remarks

The present cage has several properties in common with the analogous cages $[2^4.3^1]adz$ (**2**) and $[3^6]adz$ (**4**). Only the two small cages **2** and **3**, *i.e.* those with ethylene bridges and therefore most strain, undergo acid catalysed bridge cleavage and in both cases it is the trimethylene bridge, which is cleaved. This does not occur with the large cage, in which however one trimethylene bridge can be cleaved by an oxidative process involving chlorine or bromine. Inversion of lone pairs of the bridgehead nitrogen atoms followed by outside protonation occurs in acidic solution for all three cages. While the large cage

reacts with one proton at a pH of around 3, the smaller cages require a pH of below 0 for the the first outside protonation. Thus strain and small bridges seem to promote the cleavage and to prohibit the inversion/protonation reaction, which seems to be a reasonable result.

Experimental

Abbreviations and nomenclature

The simplified nomenclature suggested for adamanzanes (bowls and cages) has been discussed recently^{14,15,21} and is illustrated in Fig. 1 and below (adz =adamanzane).

Cages. **1** = $[2^6]adz$ = 1,4,7,10-tetraazatricyclo[5.5.2.2^{4,10}]hexadecane. **2** = $[2^4.3^1]adz$ = 1,4,8,11-tetraazatricyclo[6.6.2.2^{4,11}]octadecane. **3** = $[(2^1.3^1.2^1.3^1.2^1.3^1)]adz$ = $[(2.3)^3]adz$ = 1,4,8,12-tetraazatricyclo[6.6.3.2^{4,12}]nonadecane. **4** = $[3^6]adz$ = 1,5,9,13-tetraazatricyclo[7.7.3.3^{5,13}]docosane.

Bowls. **5** = $[2^5]adz$ = 1,4,7,10-tetraazabicyclo[5.5.2]tetradecane. **6** = $[2^4.3^1]adz$ = 1,4,7,10-tetraazabicyclo[5.5.3]pentadecane. **7** = $[2^1.3^1.2^1.3^1.2^1]adz$ = $[(2.3)^2.2^1]adz$ = 1,5,9,12-tetraazabicyclo[7.5.2]hexadecane. **8** = $[3^5]adz$ = 1,5,9,13-tetraazabicyclo[7.7.3]-nonadecane. **9** = $[2^2.3^2.2^1]adz$ = 1,4,8,11-tetraazabicyclo[6.6.2]-hexadecane.

Protonated forms may be written as for example $H[2^4.3^1]adz^+$ or $H_2[3^6]adz^{2+}$. As suggested previously³ the orientation of the lone pairs at each nitrogen group are given (if necessary) by the suffixes *i* and *o*, respectively, to indicate lone pairs pointing inwards or outwards with respect to the cavity. In protonated forms i^+ and o^+ , respectively, are used to designate inwards and outwards coordinated protons. In the following the prefix *i,i,i* is neglected for simplicity in cases where it follows from the context that all four lone pairs are pointing inwards.

Materials

1,4,7-Triazacyclononane²⁸ and tris(3-chloropropyl)amine²⁹ were prepared by published methods. All other chemicals were of analytical grade.

Analyses

Bromide and chloride analyses were made by potentiometric titrations with silver nitrate.

Mass spectra

Positive ion FABMS were obtained on a JEOL AX505W mass spectrometer using NBA as a matrix.

NMR spectra

¹H and ¹³C NMR spectra were measured at 5.87 T on a Bruker AC 250 NMR spectrometer equipped with a 5 mm probe. ¹H chemical shift values (δ) are reported in ppm and are referenced to internal dioxane ($\delta(\text{dioxane}) = 3.75$ ppm) for D₂O solutions. ¹³C chemical shift values (δ) are referenced to internal dioxane ($\delta(\text{dioxane}) = 67.40$ ppm) for D₂O solutions. For CDCl₃ solutions chemical shift values (δ) are referenced to internal TMS ($\delta(\text{TMS}) = 0$ ppm). ¹³C DEPT NMR spectra were used to assign CH₂ carbon atoms.

Potentiometric titrations

The concentration of hydrogen ions was measured using Metrohm equipment and a Radiometer glass electrode combined with a calomel reference electrode (GK2401 B) as described previously.²⁰

Synthesis

$[H[(2.3)^3]adz]Br$. A mixture of 1,4,7-triazacyclononane

Table 2 Crystal data

Formula	C ₁₅ H ₃₉ BrN ₄ O ₄
Formula weight	419.41
Temperature, T/K	120(2)
Crystal system	Trigonal
a/Å	8.5328(12)
b/Å	8.5328(12)
c/Å	33.241(7)
α/°	90
β/°	90
γ/°	120
Unit-cell volume V/Å ³	2096.0(6)
Space group	P3c1
Formula units per unit cell, Z	4
Calculated density D _x /g cm ⁻³	1.329
Linear absorption coefficient/mm ⁻¹	1.986
Crystal size/mm	0.30 × 0.21 × 0.05
θ-range/°	1.23–34.02
Data total	30274
Data unique	5234
Data observed, I > 2σ(I)	3406
R(int)	0.0491
Transmission factors	1.0000–0.6907
No. of refined parameters	164
Final R-values	R1 = 0.0695 (obs. data), wR2 = 0.1622 (all data)
Goodness-of-fit	1.126
Max, min Δρ/e Å ⁻³	1.04, -0.98 (less than 1 Å from Br1)

(11.22 g, 86.7 mmol), tris(3-chloropropyl)amine (21.4 g, 86.7 mmol), Na₂CO₃ (55 g, 0.52 mol) and molecular sieves (20 g, 0.3 nm, Merck) in acetonitrile (1600 ml) was refluxed for eight days. Evaporation of the filtered reaction mixture to dryness gave 21.6 g of a white solid. This was dissolved in water (350 ml) at 70 °C, and the solution was filtered while hot. A saturated, aqueous solution of sodium bromide (140 ml) was added and the mixture was cooled in ice. Colourless crystals separated out, and after one hour the precipitate was filtered off, washed three times with acetone (10 ml) and dried in the air. This gave 11.3 g of pure [H[(2.3)³]adz]Br (yield 38%). FABMS (*m/z*): 268. Analytical data: Calculated for C₁₅H₃₁N₄Br: Br, 23.0. Found: Br, 22.9. ¹³C NMR data in D₂O δ/ppm: 56.89, 56.37 and 50.05 (CH₂-N) and 21.45 (C-CH₂-C). ¹H NMR data are given in Fig. 3 and 4. Crystals for the X-ray diffraction study were made at room temperature from a saturated, aqueous solution of the bromide salt by slow evaporation of part of the solvent in which case a tetrahydrate was obtained.

[H₃[(2.3)².2¹]adz]BrCl₂·H₂O. A solution of [H[(2.3)³]adz]Br (10.0 g, 28.8 mmol) in 12 M hydrochloric acid (80 ml) was refluxed for 20 h and then evaporated to dryness. Methanol (75 ml) was added to the brownish solid. The mixture was refluxed for 10 min and then filtered after cooling to room temperature. The solid was extracted once more with methanol (75 ml) using the same procedure. The volume of the combined extracts (150 ml) was reduced to 50 ml by evaporation on a rotary evaporator (water bath temperature 40 °C) and a small amount of a brown precipitate was filtered off. Acetone (300 ml) was added to the filtrate, and a greyish precipitate formed. The precipitate was filtered off, washed twice with acetone (10 ml) and dried in the air at 50 °C for 2 h. This gave 4.6 g (yield 40%). Analytical data: Calculated for C₁₂H₃₁N₄BrCl₂O: Br, 20.1; Cl, 17.8. Found: Br, 19.0, Cl, 17.6%; Molar mass based upon potentiometric titration with sodium hydroxide: Calculated: 398.2 g mol⁻¹. Found: 408 g mol⁻¹. ¹³C NMR data in D₂O δ/ppm: 58.62, 51.57, 50.55, 49.38 and 45.01 (CH₂-N) and 23.45 (C-CH₂-C). The ¹³C NMR spectrum of the crude sample sometimes contains a few additional low intensity signals showing that in these cases the product is not 100% pure as is also suggested from the analytical data. However, generally the synthesis gives a pure product (as judged from the ¹³C NMR data), but we never suc-

ceeded in finding an explanation for these variations. The impure products may be purified from ethanol by precipitation with acetone, but the yield is low (<25%).

Crystal structure determination

Crystal data for the compound [H[(2.3)³]adz]Br are listed in Table 2.† The crystal of the compound was cooled to 120 K using a Cryostream nitrogen gas cooler system. The data were collected on a Siemens SMART Platform diffractometer with a CCD area sensitive detector. The structure was solved by direct methods and refined by full-matrix least-squares against *F*² of all data. The structure is best described in space group *P3c1* and refined as a racemic twin. The Flack *x* parameter is 0.50(4).^{30,31} The non-hydrogen atoms were refined anisotropically. The hydrogen atoms could be located from electron-density difference maps, but all the hydrogen atoms of the cations are at calculated positions using a riding model with fixed thermal parameters [*U*(H) = 1.2 × *U* for attached atom]. The hydrogen atoms of the two water molecules situated on the 3-fold axis are disordered. Of the other two water molecules, the hydrogen atoms are refined isotropically with fixed O-H bond lengths. Programs used for data collection, data reduction and absorption were SMART, SAINT and SADABS.^{32,33} The program SHELXTL 95³⁴ was used to solve the structure and for molecular graphics. PLATON³⁵ was used for overlooked symmetry.

† CCDC reference number 188/190. See <http://www.rsc.org/suppdata/p2/1999/2701> for crystallographic files in .cif format.

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