Aust. J. Chem., 1983, **36**, 927–35

Cation-Exchange Chromatography and Selective Complexation in the Isolation of Branched Acyclic Polyamines: Syntheses of Ethylidynetris(methanamine) [tame], 2,2-Bis(aminomethyl)propan-1-ol [hmmp], 4,4′,4″-Ethylidynetris(3-azabutan-1-amine) [sen] and 5,5′,5″-Ethylidynetris(4-azapentan-1-amine) [stn]

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Abstract

Large-scale syntheses of ethylidynetris(methanamine)* (tame), 2,2-bis(aminomethyl)propan-1-ol* (hmmp), 4,4′,4″-ethylidynetris(3-azabutan-1-amine)* (sen) and 5,5′,5″-ethylidynetris(4-azapentan-1-amine)* (stn) are described. The pure hydrochloride salts of tame, hmmp, sen and stn are isolated directly from the crude amine mixtures by acidification and cation-exchange chromatography. Alternatively, selective complexation as [Co(hexamine)] Cl_3 followed by Zn/HCl reduction and cation-exchange chromatography is used to isolate the hexamines sen and stn as their hexahydrochloride salts. These isolation procedures are exceptionally efficient compared with the conventional solvent extraction and (often pyrolytic) high-vacuum distillation methods.

Introduction

The branched acyclic polyamines ethylidynetris(methanamine)[1–13] (tame), (1), 4,4′,4″-ethylidynetris(3-azabutan-1-amine)[14,15] (sen), (3), and 5,5′,5″-ethylidynetris(4-azapentan-1-amine)[15,16] (stn), (4), have been of interest recently in studies of their metal complexes and as intermediates in syntheses of other ligands. Their cobalt(III)

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* The abbreviations are derived from non-systematic names commonly used in the literature: tame, 1,1,1-tris(aminomethyl)ethane; hmmp, 2-hydroxymethyl-2-methylpropane-1,3-diamine; sen, 1,1,1-tris(2′-aminoethylaminomethyl)ethane; stn, 1,1,1-tris(3′-aminopropylaminomethyl)ethane.

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[2] Durham, D. A., Hart, F. A., and Shaw, D., *J. Inorg. Nucl. Chem.*, 1967, **29**, 509.
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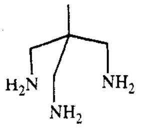
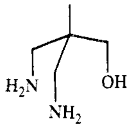
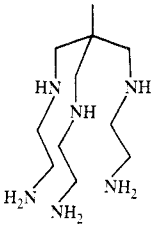
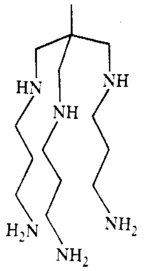
0004-9425/83/050927$02.00

complexes [Co(tame)$_2$]$^{3+}$,[17,18] [Co(sen)]$^{3+}$ [19,20] and [Co(stn)]$^{3+}$ [21] have also been used as substrates in the synthesis of a variety of bicyclic, tricyclic and tetracyclic polyazacryptate complexes. The cobalt(III) complex [Co(hmmp)$_3$]$^{3+}$ of 2,2-bis(aminomethyl)propan-1-ol (hmmp), (2), also has potential application in this area of metal ion encapsulation chemistry,[21] as well as in stereochemical studies of complexes of prochiral sinambic ligands.[22,23]


tame (1)


hmmp (2)


sen (3)


stn (4)

Large-scale syntheses of these amines are tedious and it is difficult to obtain pure products in reasonable yields by reported procedures, especially with the high-boiling amines sen and stn. We here report modified condensation procedures for tame, sen and stn to give improved yields, and more efficient methods for their purification and isolation as hydrochloride salts. A convenient synthesis of hmmp is also described.

Difficulties with conventional methods for isolating polyamines (solvent extraction, distillation under reduced pressure, recrystallization of hydrochloride mixtures) are obviated by the following approaches: (i) cation-exchange chromatography to separate polyamines having different numbers of amine functions, as described in the syntheses of tame, hmmp and stn, or (ii) selective complexation and precipitation of inert cobalt(III) complexes of hexadentate amines by oxidative formation in methanol, followed by reduction and cation-exchange chromatography as described for sen and stn. These isolation procedures should have general applicability to polyamine syntheses.

Results and Discussion

Ethylidynetris(methanamine) (tame) (1)

Recent methods for preparing tame have involved reduction of ethylidynetris(methanazide).[6,7] However, due to potential hazards with the azide these methods are only suitable for preparations on restricted scales.

The synthesis described here (Scheme 1) is essentially a refinement of the method of Stetter and Böckmann.[1] In the Stetter procedure ethylidynetris(methyl) tris(*p*-

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[17] Gainsford, G. J., Geue, R. J., and Sargeson, A. M., *Chem. Commun.*, 1982, 233.

[18] Geue, R. J., McCarthy, M. G., and Sargeson, A. M., unpublished data.

[19] Sargeson, A. M., *Chem. Br.*, 1979, **15**, 23.

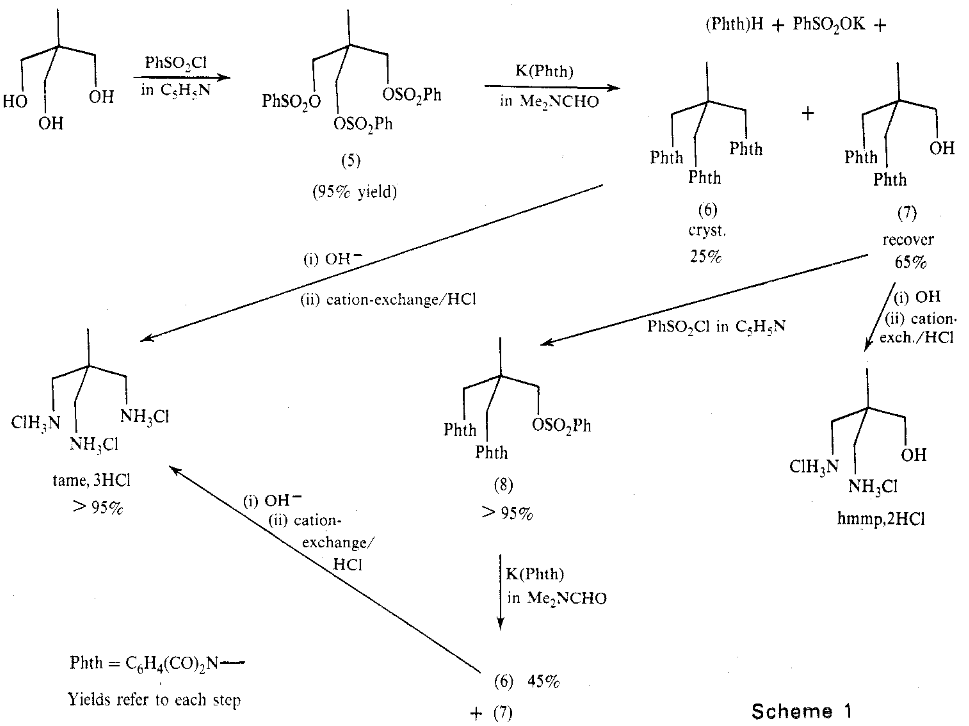
[20] Creaser, I. I., Geue, R. J., Harrowfield, J. MacB., Herlt, A. J., Sargeson, A. M., Snow, M. R., and Springborg, J., *J. Am. Chem. Soc.*, 1982, **104**, 6016.

[21] Geue, R. J., unpublished data.

[22] Tapscott, R. E., *Inorg. Chem.*, 1975, **14**, 216.

[23] Mather, J. D., and Tapscott, R. E., *J. Coord. Chem.*, 1981, **11**, 5.

toluenesulfonate) was converted into the tris(phthalimido) derivative (6) by heterogeneous reaction with potassium phthalimide in xylene. Treatment of (6) with aqueous potassium hydroxide (2–3 days at room temp.) followed by distillation (> 200°C) gave impure aqueous tame (1). The reaction with potassium phthalimide necessitated prolonged reaction at elevated temperatures (6 h at > 200°C), and presumably some decomposition of the reactants would occur under these conditions.



Phth = $C_6H_4(CO)_2N$—

Yields refer to each step

Scheme 1

When we hydrolysed (6) on a large scale (> 100 g) by a procedure similar to that of Stetter,[1] we found that only about 30% of the tame could be recovered from the aqueous reaction mixture by distillation, the rest remaining in the distilling flask. Impurities identified in the distilled amine solution were ammonia and the diamino alcohol hmmp (2). The ammonia was evidently formed by hydrolysis of phthalimide, and hmmp was produced by hydrolysis of (7) and/or by direct OH^- substitution at a methylene carbon of (6). (Phthalimide and (7) are impurities in (6), Scheme 1.) Moreover, these ammonia and hmmp impurities appeared to be concentrated in the distilled amine fraction, and overall the method gave a very low yield of impure tame.

Our new procedures eliminate these difficulties and provide for large-scale synthesis of pure tame,3HCl. We have used ethylidynetris(methyl) tris(benzenesulfonate) (5) for the condensation with potassium phthalimide and have found this reaction to proceed rapidly in freshly distilled dry dimethylformamide at 170°C. The *N,N′,N″*-[ethylidynetris(methyl)]tris(phthalimide) (6) then co-crystallizes with water-soluble potassium benzenesulfonate from the reaction mixture on cooling. The *N,N′*-(2-hydroxymethyl-2-methylpropane-1,3-diyl)bis(phthalimide) (7) is the only co-product under the above conditions, although the monophthalimide dialcohol derivative might be formed under conditions which are not entirely anhydrous. The bis(phthalimide) alcohol (7) is readily recovered, for recycling by benzenesulfonation and condensation with potassium phthalimide to give further tris(phthalimide) (6) (Scheme 1).

The hydrolysis of (6) was carried out with aqueous KOH in a high-pressure autoclave (12 h at 200°C) to give a nearly quantitative yield of tame (1). This solution was then diluted and acidified, and sorbed directly onto a column of strong-acid cation-exchange resin (H^+ form). The NH_4^+, $Me_2NH_2^+$ and $hmmpH_2^{2+}$ impurities were first removed by elution at low HCl concentration. Pure $tameH_3^{3+}$ was then rapidly eluted with 3 M HCl, and readily isolated as the trihydrochloride salt on solvent removal. This cation-exchange treatment gave a virtually quantitative and relatively rapid recovery of the tame from the hydrolysis mixture.

The overall yield of pure tame,3HCl from (5) by this procedure, including one recycling of (7), is relatively high (*c.* 50%), and the method allows for multi-batch large-scale synthesis with further recycling of the diphthalimide condensation coproduct (7) formed from (8).

2,2-Bis(aminomethyl)propan-1-ol (hmmp) (2)

The pure diamino alcohol dihydrochloride (2),2HCl was obtained by a nearly quantitative hydrolysis of (7) followed by cation-exchange chromatography in the manner outlined above. In the synthesis of hmmp from (5) it is not necessary to isolate (7), and the amine may be obtained more directly by removal of dimethylformamide from the reaction mixture (containing (6) and (7), Scheme 1), base hydrolysis, acidification, and cation-exchange chromatography. The $hmmpH_2^{2+}$ is eluted with 1·5 M HCl (after removal of 1+-charged impurities), ahead of $tameH_3^{3+}$ which is apparent on the column as a separate band.

The Hexamines sen and stn

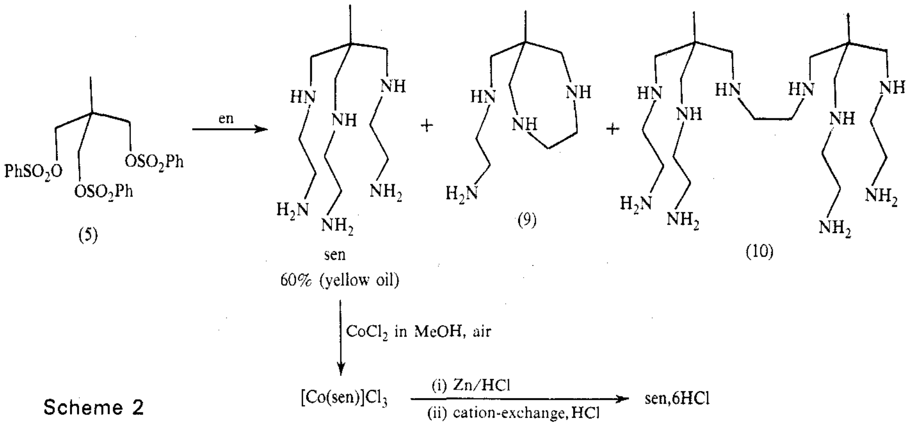
Previous syntheses of these amines have followed a procedure outlined by Green *et al.*[24] in which ethylidynetris(bromomethane)[1] (analogue of (5), see Scheme 2) was made to react with anhydrous ethane-1,2-diamine (en),[14,15] or propane-1,3-diamine (tn).[15,16] After dissolution of the resulting melts in aqueous KOH and extraction with pyridine, the crude amines were obtained in relatively low yields by distillation under high vacuum (e.g. 176°C at 0·05 mm for sen[14]). We have found that this distillation procedure is tedious and that several distillations carried out with care are necessary to obtain the pure amines (>95% pure). Our yields of pure amines obtained in this way were low, <35%.

We have synthesized sen (3) (Scheme 2) and stn (4) by condensation of ethylidynetris(methyl) tris(benzenesulfonate) (5) with en and tn (respectively), used in large excess. The crude yellow oils obtained after extraction from the reaction mixtures are grossly impure. For example, the sen extract (*c.* 35% sen) contains substantial en and benzenesulfonate impurities, and condensation co-products such as (9), (10) and higher oligomers are likely additional contaminants.

It is clearly difficult to effect complete separations of the required sen or stn from such mixtures by distillation. Further, some pyrolysis of the constituents occurs under the high temperatures required (even under vacuum) for the distillations. As well as product loss by pyrolysis, distillation leads to substantial mechanical loss.

[24] Green, R. W., Catchpole, K. W., Phillip, A. T., and Lions, F., *Inorg. Chem.*, 1963, **2**, 597.

To avoid the difficulties with distillation, two procedures have been developed for the isolation of these amines from the crude reaction mixtures. Both methods give high recovery, and the amines are obtained as the pure hexahydrochloride salts sen,6HCl and stn,6HCl,$2H_2O$.



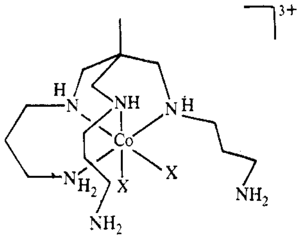
Scheme 2

The first method involves direct application of the reaction mixture (after removal of excess en or tn) to a column of cation-exchange resin followed by chromatographic elution with HCl in the manner outlined for tame. This direct method was highly successful for both amines and is to be preferred. The whole procedure starting from (5) can be carried out on a large scale (1 mol), and overall yields from (5) of the amine hydrochlorides of around 60% or better have been obtained.

An alternative procedure, which may be used in cases of difficult chromatographic separation such as with isomeric amine mixtures, involves selective complexation of a hexadentate amine as the cobalt(III) complex by oxidative formation in methanol, followed by Zn/HCl reduction and cation-exchange chromatography. In applying the method to obtain sen,6HCl, the amine in the crude product was converted into [Co(sen)] Cl_3 by oxidation from Co^{II} in methanol. We have found this preparative method for $CoN_6{}^{3+}$-type complexes to be highly efficient, usually giving yields *c.* 95%. In the present instance complexation appears to be highly selective, there being no evidence (elemental analyses, ^1H and ^{13}C n.m.r., Sephadex chromatography) for the precipitation of other complexes from the methanol. Apparently amine (9) does not compete with sen in methanol. Complexation with nickel(II) appeared to be less selective.

The ligand is recovered by reduction of the cobalt(III) complex with Zn/HCl, and sorbing the products on strong-acid cation-exchange resin. The ions Co^{2+}, Zn^{2+}, Cl^-, $NH_4{}^+$ are removed by their elution from the resin with water, NH_4CNS and HCl in that order, leaving pure $senH_6{}^{6+}$ to be eluted subsequently with 4 M HCl. With these procedures pure sen,6HCl is obtained in *c.* 50% yield from (5).

The analogous preparation of stn involves variations only in the conditions to form [Co(stn)] Cl_3. Anhydrous conditions in methanol[16] are required to obtain a high yield of this complex (>90%) since water is a more effective competitor with stn, and heating is beneficial in enhancing the breakdown of the peroxy intermediate complex during the oxidative process. $[Co(stn)]^{3+}$ is less robust to acid than $[Co(sen)]^{3+}$, and our experiments indicate that on prolonged exposure to strong acid two arms of the ligand dissociate to give (11); reassociation occurs slowly with base in methanol but not with base in water. However, under the normal conditions for isolating, purifying, and chromatographing complexes, losses of $[Co(stn)]^{3+}$ from this effect are small. The overall yield of stn,6HCl,$2H_2O$ from (5) is around 40%.



X = H_2O, Cl^- (11)

Experimental

N.M.R. Spectra

^1H n.m.r. spectra were recorded on a Jeol JNM-PMX60 spectrometer. The 20·1-MHz ^{13}C n.m.r. spectra in D_2O, broad-band proton decoupled, were measured on a Bruker WP-80DS spectrometer locked to deuterium, by using an 8192 data table. These ^{13}C spectra in D_2O were referenced to a t-butyl alcohol capillary (618·9 Hz, δ 30·79 ppm downfield from $SiMe_4$).

N,N′,N″-[*Ethylidynetris*(*methyl*)]*tris*(*phthalimide*) (*6*)

Ethylidynetris(methyl) tris(benzenesulfonate) (5) was prepared by the procedure of Fleischer *et al.*[6] and recrystallized from acetone. It was washed with water until the pH was 7 to remove small amounts of acidic contaminants (py,HCl), and after filtering off it was washed with water, methanol and ether, and thoroughly dried (vacuum 1 mm over P_2O_5). Yield 95%.

The triester (5) (400 g, 0·74 mol) was dissolved in dry (important!) freshly distilled dimethylformamide (700 ml) and stirred under nitrogen. Potassium phthalimide (480 g) was added and the stirred mixture was heated at 170° for 3 h. After cooling to room temperature, the *product* (6) as Me_2NCHO solvate was filtered off, washed with a little methanol/Me_2NCHO 50 : 50, then thoroughly with water (to remove potassium benzensulfonate), methanol and ether, and air-dried. Yield 100 g, 25% (Found: C, 67·0; H, 4·3; N, 8·5. $C_{29}H_{21}N_3O_6,\frac{1}{3}(C_3H_7NO)$ requires C, 67·7; H, 4·4; N, 8·8%). ^1H n.m.r. in $CDCl_3$: δ 0·98 (s, 3H, CH_3), 3·87 (s, 6H, CH_2), 7·9 (m, 12H, aromatic protons); doublet due to Me_2NCHO; signals of (7) were absent. The filtrate containing (7) was reserved for later recycling.

Ethylidynetris(*methanamine*) *Trihydrochloride*, (*tame*,*3HCl*) [(*1*),*3HCl*]

A mixture of (6),$\frac{1}{3}Me_2NCHO$ (96 g, 0·180 mol) and KOH (128 g) in water (200 ml) was heated in a high-pressure stainless steel autoclave (500 ml capacity) at 200° for 12 h. The colourless solution was neutralized with HCl to pH 3, then diluted (water to 8 l.) and applied to a column (5 by 50 cm) of Dowex 50W-X2 cation-exchange resin, 200–400 mesh, H^+ form. The column was washed with water to remove all phthalate ion, then washed thoroughly with 1 M HCl to remove $NH_4{}^+$, $Me_2NH_2{}^+$, and any (2); $tameH_3{}^{3+}$ was then eluted off with 3 M HCl. In this system the separation of bands on the column can be monitored visually. *tame,3HCl* was obtained by evaporation to crystallization, and methanol was added to complete the crystallization. Yield 39 g, 95% (Found: C, 26·7; H, 8·1; Cl, 46·8; N, 18·6. $C_5H_{18}Cl_3N_3$ requires C, 26·5; H, 8·0; Cl, 46·9; N, 18·5%). ^1H n.m.r. in D_2O with sodium trimethylsilylpropanesulfonate reference: δ 1·30, s, 3H, CH_3; 3·25, s, 6H, CH_2. ^{13}C n.m.r. in D_2O: δ 17·2, CH_3; 35·5, quaternary; 43·2, CH_2 (ratio $1 : 1^- : 3$).

N,N′-(*2-Hydroxymethyl-2-methylpropane-1,3-diyl*)*bis*(*phthalimide*) (*7*) *and its Recycling*

The dimethylformamide filtrate containing (7) was reduced to a sludge, and dissolved in hot glacial acetic acid; (7) was crystallized by repeated cooling and reduction of volume. The *product* was washed thoroughly with hot water (to remove phthalimide) and methanol, then recrystallized from hot chloroform by cooling and the addition of methanol. It was dried under vacuum. Yield 182 g, 65% from (5) (Found: C, 66·2; H, 4·9; N, 7·4. $C_{21}H_{18}N_2O_5$ requires C, 66·6; H, 4·8; N, 7·4%). ^1H n.m.r. in $CDCl_3$: δ 0·88, s, 3H, CH_3; 3·35, s, 2H, CH_2O; 3·82, s, 4H, CH_2N; 7·9, m, 8H, aromatic.

To (7) (300 g, 0·793 mol) in dry pyridine (1 l., distilled over KOH), benzenesulfonyl chloride (254 g) was added slowly (2 h), and the mixture was stirred at room temperature for 2 days. It was poured into an ice-cold mixture of water (3 l.), methanol (2 l.) and concentrated HCl (2·5 l.). The granular product *2,2-bis(phthalimidomethyl)propyl benzenesulfonate* (8) was filtered off, washed copiously with water, then with methanol and ether. It was recrystallized from hot acetone and dried thoroughly (vacuo over P_2O_5). Yield 390 g, 95% (Found: C, 62·8; H, 4·3; N, 5·5; S, 6·0. $C_{27}H_{22}N_2O_7S$ requires C, 62·5; H, 4·3; N, 5·4; S, 6·2%). ^1H n.m.r. in $CDCl_3$: δ 1·03, s, 3H, CH_3; 3·75, s, 4H, CH_2N; 4·03, s, 2H, CH_2O; 7·8, m, 13H, aromatic.

The benzenesulfonate (8) (400 g, 0·771 mol) was dissolved in dried freshly distilled dimethylformamide (600 ml) and stirred under nitrogen. Potassium phthalimide (200 g) was added, and the mixture was heated at 160° for 2 h. After cooling in ice, the crystals of (6),$\frac{1}{3}Me_2NCHO$ were filtered off and washed as previously. Yield 188 g, 45%. This (6) was converted into tame,3HCl by the hydrolysis and cation-exchange procedure described above. Alternatively, both lots of (6) shown in Scheme 1 could be combined for conversion into tame,3HCl. By-product (7) (from (8)) could be crystallized from the dimethylformamide filtrate as described, and could be added in to any subsequent recycling.

2,2-Bis(aminomethyl)propan-1-ol Dihydrochloride, (hmmp,2HCl) [*(2),2HCl*]

This was obtained by hydrolysis of (7) followed by cation-exchange. The procedure was similar to that for the conversion of (6) into tame,3HCl, except that (2) was eluted from the Dowex with 1·5 M HCl (Found: C, 31·7; H, 8·5; Cl, 36·3; N, 14·7. $C_5H_{14}N_2O$,2HCl requires C, 31·4; H, 8·4; Cl, 37·1; N, 14·7%). ^1H n.m.r. in D_2O with sodium trimethylsilylpropanesulfonate: δ 1·12, s, 3H, CH_3; 3·13, s, 4H, CH_2N; 3·66, s, 2H, CH_2O. ^{13}C n.m.r. in D_2O: δ 16·7, CH_3; 36·4, quaternary; 44·3, C–NH_2; 65·9, C–OH (ratio 1 : 1^- : 2 : 1).

5,5′,5″-Ethylidynetris(4-azapentan-1-amine) Hexahydrochloride Dihydrate, stn,6HCl,2H_2O, [*(4),6HCl,2H_2O*] *by Direct Cation-Exchange*

Ethylidynetris(methyl) tris(benzenesulfonate) (5) (540 g, 1·00 mol) and anhydrous propane-1,3-diamine (5 l.,* refluxed over KOH, then distilled) were heated under reflux for 48 h. Excess tn was removed on a rotary evaporator and recovered. The remaining yellow oil was diluted (10 l. water) and acidified (pH 3, HCl), and sorbed onto a column (12 by 50 cm) of Dowex 50W-X2 cation-exchange resin, 200–400 mesh, H^+ form. The column was washed thoroughly with water, then with 1 M HCl (5 l.) to remove diamine impurities. The $stnH_6{}^{6+}$ was eluted off with 4 M HCl (10 l.). The $stnH_6{}^{6+}$ shows as a lighter-coloured band on the column, and the effluent from the immediate front of the band was discarded to ensure that any lower-charged species analogous to (9) were not collected. The collected effluent was evaporated to dryness. The residue was redissolved in warm water, and the product crystallized on addition of ethanol and cooling. The white crystals of *stn,6HCl,2H_2O* were filtered off, washed with ethanol and ether and dried under vacuum. Yield 310 g, 57% (Found: C, 30·7; H, 8·4; Cl, 39·4; N, 15·0. $C_{14}H_{42}Cl_6N_6$,2H_2O requires C, 31·0; H, 8·5; Cl, 39·2; N, 15·5%). The ^{13}C n.m.r. spectrum (see below) showed no impurity resonances after 14000 accumulations, so that any possible co-products analogous to (9) and (10) had been effectively removed by the particular conditions of elution and crystallization.

4,4′,4″-Ethylidynetris(3-azabutan-1-amine) Hexahydrochloride, sen,6HCl, [*(3),6HCl*] *by Direct Cation-Exchange*

This was prepared from (5) (540 g, 1·00 mol) and anhydrous ethane-1,2-diamine (4 l.) by an analogous procedure to the above. The *sen,6HCl* was obtained as white crystals. Crude yield 305 g, 65% (Found: C, 29·1; H, 7·7; N, 17·3. $C_{11}H_{36}Cl_6N_6$ requires C, 28·4; H, 7·8; N, 18·1%).

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* The larger excess of tn, 20-fold, used in this synthesis should ensure complete condensation, and the consequent higher dilution should minimize the formation of co-products analogous to (9) and (10).

Co(sen)] Cl_3 *from Crude sen* (3)

Ethylidynetris(methyl) tris(benzenesulfonate) (5) (150 g, 0·227 mol) and anhydrous ethane-1,2-diamine (700 ml, refluxed over KOH, then distilled; 10-fold excess) were heated under reflux for 48 h. Excess en was removed on a rotary evaporator. The remaining yellow oil was diluted with methanol (250 ml) and ether (750 ml), and on slowly adding KOH in methanol (54·4 g in 500 ml) white potassium benzenesulfonate precipitated. After refrigeration, the supernatant liquid was decanted through a sinter, and further amine was extracted with ether. Removal of solvent left a yellow oil (120 g). The weights show that this oil was grossly impure sen, but the yield in this step was *c.* 60%.

The above oil (120 g) was dissolved in methanol (1 l.), and glacial acetic acid (23 g) was added. Anhydrous $CoCl_2$ (63 g, equiv. to moles of sen if oil were pure)* was stirred in, and the solution was aerated for 6 h. The orange *crystals* of [Co(sen)] Cl_3 were filtered off and washed with methanol, then recrystallized from water by the addition of ethanol. Yield 64 g (Found: C, 31·8; H, 7·2; Cl, 25·3; Co, 14·2; N, 20·3. $[Co(C_{11}H_{30}N_6)]$ Cl_3 requires C, 32·1; H, 7·3; Cl, 25·8; Co, 14·3; N, 20·4%). ^{13}C n.m.r. in D_2O: δ 19·7, CH_3; 40·6, quaternary; 42·8, 54·7 and 56·9, CH_2 (ratio $1 : 1^- : 3 : 3 : 3$). The complex was confirmed pure (absence of $[Co(en)_3]^{3+}$) by chromatography on SP-Sephadex C-25 cation-exchange resin with 0·1 M Na_3PO_4 eluent.[25]

In separate experiments, some of the crude yellow oil was distilled carefully to give some pure sen (b.p. 148–50°/0·025 mm). When this was used to prepare the cobalt(III) complex by the above method, yields of [Co(sen)] Cl_3 obtained were greater then 90%. On this basis, the above condensation reaction gives *c.* 42 g of sen, i.e. *c.* 60% yield.

sen,6HCl from [*Co*(*sen*)] Cl_3

[Co(sen)] Cl_3 (5·00 g, 0·0121 mol) was dissolved in water (100 ml) and stirred with excess zinc powder (5 g) and excess concentrated HCl (20 ml), until all the zinc had dissolved and an acidic pink Co^{II} solution was left. The filtered solution was diluted 50 times and applied to a column of Dowex 50W-X2 cation-exchange resin, 200–400 mesh, H^+ form (4 by 11 cm in water);† the sen formed a light-coloured band on top. The column was washed with water, 0·5 M NH_4CNS (500 ml) to remove Co^{II} and Zn^{II}, water, and 0·5 M HCl (500 ml) to remove NH_4^+. The $senH_6^{6+}$ was then eluted off with 4 M HCl and was collected in 50-ml fractions. Evaporation of fractions showed that almost all the sen,6HCl was contained in the first 400 ml. This eluate was evaporated to a small volume, and crystallization commenced on the dropwise addition of ethanol and stirring. Finally excess ethanol was added, and the sen,6HCl was filtered off, washed with ethanol, and dried. Yield 5·33 g, 94% (Found: C, 28·3; H, 7·7; Cl, 46·0; N, 17·8. $C_{11}H_{36}Cl_6N_6$ requires C, 28·4; H, 7·8; Cl, 45·7; N, 18·1%). ^{13}C n.m.r. in D_2O: δ 18·5, CH_3; 35·7, 46·3 and 52·3, CH_2; 36·6, quaternary (ratio $1 : 3 : 3 : 3 : 1^-$).

[*Co*(*stn*)] Cl_3 *from Crude stn* (4)

stn was obtained as a yellow oil from reaction of (5) (75 g, 0·139 mol) with anhydrous propane-1,3-diamine (350 ml) in the same manner as described for sen. This crude oil (40 g) was stirred with methanol (500 ml), and glacial acetic acid (5 g) was added. Anhydrous $CoCl_2$ (18·0 g) in methanol was added to the mixture which was aerated for 6 h at 40°. [Co(stn)] Cl_3 separated as orange-pink crystals. This crude product contained KCl, but otherwise appeared to be pure by ^1H n.m.r. and chromatography on SP-Sephadex. It was purified by applying to a column of Dowex 50W-X2 resin, H^+ form, washing with 1 M HCl to remove KCl, then eluting off the complex with 3 M HCl. After evaporation to crystallization, ethanol was added. The *complex* was filtered off, washed with ethanol, and air-dried (Found: C, 33·4; H, 8·1; Cl, 21·3; N, 16·8. $[Co(C_{14}H_{36}N_6)]Cl_3,3H_2O$ requires

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* The equivalent amount of $CoCl_2,6H_2O$ can be used with sen, but *anhydrous* $CoCl_2$ must be added in the analogous preparation of [Co(stn)] Cl_3. $CoCl_2$ (anhydrous) was from Research Organic/Inorganic Chemical Corp., Sun Valley, California.

† Excess resin (about four times) is necessary as channeling occurs during application of the product and the column requires periodic stirring.

[25] Searle, G. H., *Aust. J. Chem.*, 1977, **30**, 2625.

C, 33·1; H, 8·3; Cl, 21·0; N, 16·6%). ^{13}C n.m.r. in D_2O, $Co(NH_2C_dH_2C_cH_2C_bH_2NHC_aH_2)_3$-$CCH_3{}^{3+}$:[16] δ 21·1, CH_3; 22·4, C_c; 38·0, 48·3 and 54·9, C_a, C_d, C_b; 35·9, quaternary (ratio 1 : 3 : 3 : 3 : 3 : 1⁻). In an independent synthesis with pure stn, [Co(stn)] Cl_3 was obtained in >90% yield. Calculations give the yield from the condensation as >45%.

stn,6HCl,2H₂O from [Co(stn)] Cl₃

The procedure was identical to that for sen,6HCl. From 5·00 g of [Co(stn)] Cl_3,$3H_2O$, yield of stn,6HCl,$2H_2O$ 5·13 g, 96% (Found: C, 31·2; H, 8·5; Cl, 39·5; N, 15·8%). ^{13}C n.m.r. in D_2O, $(NH_2C_dH_2C_cH_2C_bH_2NHC_aH_2)_3CCH_3$:[16] δ 18·4, CH_3; 23·7, C_c; 36·9, 46·9 and 51·9, C_a, C_d, C_b; 36·4, quaternary (ratio 1 : 3 : 3 : 3 : 3 : 1⁻).

Manuscript received 13 December 1982