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Synthesis and Complexation Properties of a New Macrocyclic Polyaza Polyphosphinate Ligand, DOTEP (1,4,7,10-Tetraazacyclododecane-1,4,7,10-tetrakis(methyleneethylphosphinate))†

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A new macrocycle, 1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrakis(methyleneethylphosphinate) (DOTEP), has been synthesized, and its protonation constants and metal ion binding properties have been examined. The first two chelate protonations occur at nitrogens (log K_1 and log K_2: 10.94 and 8.24, respectively) while the pendant phosphinate groups are protonated only below pH 4. DOTEP forms less stable complexes with the alkaline-earth-metal cations, Cu^{2+}, Zn^{2+}, and Cd^{2+}, and the trivalent lanthanides (Ln^{3+}) than does the tetraacetate analogue, DOTA, largely due to the lower basicity of the nitrogen and oxygen donor atoms of DOTEP. Like DOTA, DOTEP forms complexes with the trivalent lanthanide ions rather slowly in the pH range 6-7 but, once formed, the $Ln(DOTEP)^-$ complexes release free Ln^{3+} slowly in strong acid.

Introduction

Tetrasubstituted derivatives of tetraazacyclododecane appear to have near-optimal chelating properties for the formation of stable complexes with divalent calcium and the trivalent lanthanides; consequently, many derivatives of cyclen with varying side-chain chelating groups have been reported.[1-8] The tetraacetate derivative, DOTA, forms unusually stable complexes with Ca^{2+}, Sr^{2+}, Y^{3+}, and the lanthanides, and the kinetic inertness of these species has been the basis of new chelate designs for applications ranging from monoclonal antibody labeling[9] to MRI contrast agents.[4,10] We have been interested in derivatives of cyclen which contain a phosphorus nucleus in the chelating arms which may be used to monitor intracellular cation concentrations by ^{31}P NMR spectroscopy.[11] We report here the synthesis, acid-base, and complexation properties of 1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrakis(methyleneethylphosphinic acid) (H_4DOTEP), a new derivative of cyclen containing four phosphinic acid side chains.

Materials and Methods

The following materials and chemicals of highest grade were purchased and used without further purification: cyclen·4HCl (Parish), dichloroethylphosphine, paraformaldehyde, potassium chloride, potassium nitrate, potassium deuterioxide in deuterium oxide, deuterium oxide, deuterium chloride in deuterium oxide (Aldrich), Dowex 50-X4 cation-exchange resin (100-200 mesh) (Sigma), absolute ethanol (Aaper Alcohol and Chemical Co.), anhydrous ether (J. T. Baker), and hydrochloric acid (Fisher Scientific). The elemental analyses were carried out by Oneida Research Services Inc. (Whitesboro, NY).

In Situ Preparation of Ethylphosphinic Acid Solution. Dichloroethylphosphine (2.00 mL, 19.2 mmol) was added to 4 g of ground ice at 0 °C in an ice bath under vigorous stirring, and the mixture was allowed to warm to room temperature after 1 h. *Warning*! This reaction is very vigorous at room temperature or higher and produces a gas (probably ethylphosphine or a derivative) that ignites spontaneously on contact with air. Dichloroethylphosphine has a strong, unpleasant odor and is highly toxic and corrosive. Handle under nitrogen.

Preparation of H_4DOTEP. Cyclen tetrahydrochloride (390 mg, 1.23 mmol) was added to the previously prepared ethylphosphinic acid solution, and the mixture was heated to reflux. An acidic formaldehyde solution (157 mg of paraformaldehyde dissolved into 1 mL of 6 M hydrochloric acid) was added at a rate of 0.5 mL/h for 12 h using a Harvard Apparatus Model 11 syringe pump followed by an additional 6 h of reflux. After cooling, the mixture was evaporated under reduced pressure to yield a viscous, yellow oil. The oil was redissolved in water, evaporated four times to remove all excess formaldehyde, and finally dissolved in 6 mL of water and loaded onto a Dowex cation-exchange column (50-X4, 100-200 mesh, 7.5-mL bead volume, acid form). The column was washed to neutrality with water and eluted with 100 mL of 0.66 M hydrochloric acid followed by 200 mL of 2 M hydrochloric acid. A 1-mL sample taken from each 10-mL fraction was evaporated under reduced pressure and subjected to ^1H NMR analysis. The first six fractions contained pure H_4DOTEP, while fractions 7-30 contained mixtures of partially N-(ethylphosphino)methylated and N-methylated macrocyclic derivatives. Fractions 1-6 were combined, evaporated, and redissolved in absolute ethanol. Evaporation of this solution yielded a white, hygroscopic solid (360 mg, 44% yield) that was judged pure by ^1H NMR spectroscopy. Elemental CHN analyses indicated that the solid was H_4DOTEP·2HCl. Anal. Calcd for $C_{20}H_{50}N_4O_8P_4Cl_2$ (M_r 669.4): C, 35.88; H, 7.52; N, 8.37. Found: C, 35.86; H, 7.52; N, 8.07. ^1H NMR (D_2O, pD = 7.0, reference TSP): δ 3.40 (s, 16 H, NCH_2), 3.22 (broad s, 8 H, NCH_2P), 1.58 (m, 8 H, PCH_2), 1.07 (overlapping t's, 12 H, CH_3, J_{HP} = 18.4 Hz). ^1H NMR (D_2O + NaOD, pD = 12.0, reference TSP): δ 2.92 (s, 16 H, NCH_2), 2.71 (d, 8 H, NCH_2P, J_{HP} = 8.6 Hz), 1.58 (m, 8 H, PCH_2), 1.05 (overlapping t's, 12 H, CH_3, J_{HP} = 15.9 Hz). The NCH_2P resonance appears as a doublet only between pD = 11.4 and pD = 13.0. ^{13}C NMR (90 mg of H_4DOTEP·2HCl dissolved in 4 mL of 5% CD_3CN-D_2O, reference CD_3CN = 118.2 ppm): δ 50.3 (s, CC), 49.4 (d, NCP, J_{PC} = 88 Hz), 20.9 (d, PC, J_{PC} = 94 Hz), 3.5 (s, CH_3). The ^1H and ^{13}C NMR spectra were entirely consistent with the structure shown. This material was dried under high vacuum over phosphorus pentoxide at 80 °C for several days to constant weight and then used for potentiometric titrations without further purification. Under these conditions the hydrochloric acid was removed and the remaining solid proved to be H_4DOTEP (calculated from the potentiometric titration curve).

Potentiometric Measurements. pH-potentiometric titrations were performed using either a Corning Ion Analyzer 250 pH meter, an Orion 8103 ROSS combination electrode, and a Metrohm 665 Dosimat automatic buret or a Radiometer PHM 84 pH meter, a G2028 glass electrode and a K401 calomel electrode, and an ABU 80 automatic buret. Titrated solutions (5-10 mL) were kept under a CO_2-free nitrogen atmosphere and the cell was thermostated to 25 °C. The ionic strength was held constant with either 0.1 M KCl, KNO_3, or $(CH_3)_4NCl$. The hydrogen ion concentration was obtained from the pH values by using a method described by Irving[12] (pK_W = 13.95). The concentration of the ligand stock solution was determined from potentiometric titrations of the ligand in the presence and absence of excess $CuCl_2$ and by colorimetric com-

† Abbreviations: H_4DOTA, 1,4,7,10-tetraazacyclododecane-1,4,7,10-tetraacetic acid; H_4DOTP, 1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrakis(methylenephosphonic acid).

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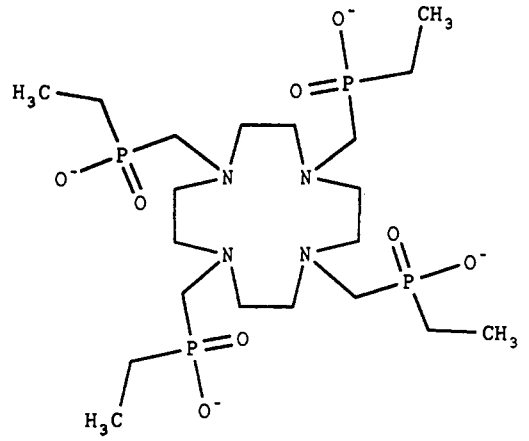

DOTEP

plexometric titrations. A known concentration $CuCl_2$ was added to the ligand solution, and excess copper was titrated with standardized EDTA in the presence of murexide as indicator. The metal solutions used were standardized by EDTA titrations.

Protonation constants and metal ion stability constants were calculated from the potentiometric titration data using either a Simplex/Marquardt algorithm[6] or PSEQUAD.[13] The standard deviations for all reported protonation constants (determined from parallel titration curves) were less than 1×10^{-2}, while the standard deviations for the metal stability constants were less than 5×10^{-2}.

NMR Spectroscopy. All high-resolution spectra were recorded on a General Electric GN-500 spectrometer in 5-mm tubes. The sample temperature was maintained at 20 °C using a GE variable-temperature accessory. Water proton T_1 relaxation times were measured on 50-μL samples of $Gd(DOTEP)^-$ using an inversion-recovery sequence on a spin-lock pulsed NMR instrument operating at 40 MHz.

Results

A potentiometric titration curve of H_4DOTEP with KOH is shown in Figure 1. These data indicate two protons are titrated below pH 4.5–5 and two between pH 7 and 12. A computer fit of these data using standard techniques gave the protonation constants summarized in Table I. Similar pK's were found in 0.1 M KNO_3, KCl, or $(CH_3)_4NCl$ as supporting electrolyte, indicating that, unlike the case for DOTA[14], K^+ binds only weakly with DOTEP at low ionic strengths.

Since the highest protonation constants of the phosphonate analogue, DOTP (DOTP = 1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrakis(methylenephosphonate)), are in dispute,[6,15] we have carefully measured the total number of protons released from H_4DOTEP and from $H_4DOTEP \cdot 2HCl$ upon addition of excess Cu^{2+} and Ca^{2+}. Exactly four protons are released when either of these ions are complexed by H_4DOTEP (see Figure 1) and six are released upon complexation to $H_4DOTEP \cdot 2HCl$ (data not shown). In the latter case, all six protons (two ring nitrogens and four phosphinic acid groups) are titrated in the free ligand by pH $\simeq$11.5 and in $Cu(DOTEP)^{2-}$ by pH $\simeq$5. Therefore, we conclude $DOTEP^{4-}$ is the predominant species in solution above pH $\simeq$12 and the ligand does not undergo further deprotonation above this pH.

The ^1H NMR spectrum of H_4DOTEP was also recorded as a function of added KOH (Figure 2). These data were recorded on a single solution below pH $\simeq$12, where the KOH concentration was varied and the solution pH measured. Above this pH, individual solutions were prepared from a pH 12 $DOTEP^{4-}$ stock solution in D_2O by adding known amounts of KOH. $-\log [H^+]$ was calculated for each solution by making the assumption that the ligand does not contribute to the proton concentration at these high pH values ($[DOTEP^{4-}]$ = 1 mM). The NMR data show

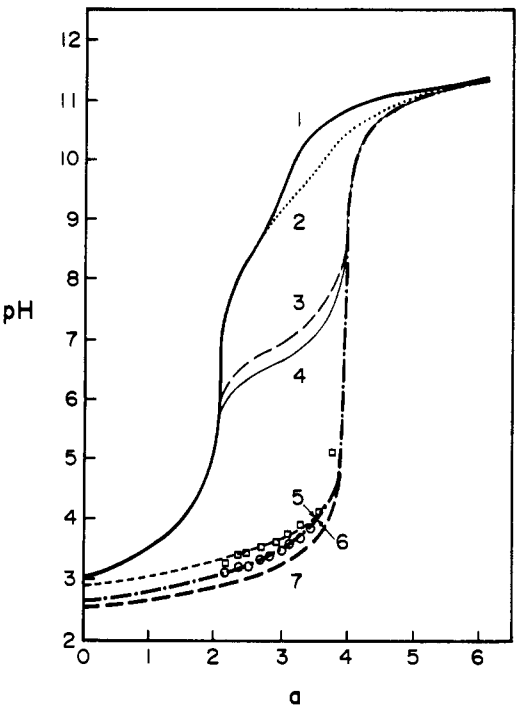

Figure 1. Potentiometric titration curves for H_4DOTEP (1) or the ligand in the presence of Mg^{2+} (2), Sr^{2+} (3), Ca^{2+} (4), Zn^{2+} (5), Cd^{2+} (6), Cu^{2+} (7), Ce^{3+} (□), or Gd^{3+} (○) at 1:1 metal:ligand ratios. a is the equivalents of KOH per ligand equivalent.

Table I. Comparison of Protonation Constants and Metal Ion Stability Constants for Cyclen and the Tetrakis(methyleneethylphosphinate) (DOTEP), -tetraacetate (DOTA), and -tetrakis(methylenephosphonate) (DOTP) Derivatives of Cyclen

	cyclen[a]	DOTEP[b,c]	DOTA[a,d-f]	DOTP[g,h]
log K_1	10.7	10.94, 10.87	11.08, 11.36, 12.09, 11.22	13.7, 12.6
log K_2	9.7	8.24, 8.21	9.23, 9.73, 9.68, 9.75	12.2, 9.3
log K_3	1.73	3.71	4.24, 4.54, 4.55, 4.37	9.28, 8.0
log K_4	0.94		4.18, 4.41, 4.13, 4.36	8.09, 6.0
log K_5			1.88	6.12, 5.2
log K_6			1.71	5.22

	log K_{ML}					
	cyclen[i]	DOTEP[b]	DOTA[d,e]		DOTP[g,j]	
Mg^{2+}		4.41	11.03	11.92	9.38	7.3
Sr^{2+}		8.86	12.80	15.22	10.95	9.8
Ca^{2+}	3.1	9.39	15.85	17.23	11.12	10.3
Zn^{2+}	16.2	15.80	18.90	21.05		
Ce^{3+}		15.80	23.4[k]			
Gd^{3+}		16.50	24.6[k]			
Cd^{2+}	14.3	16.65	19.08			
Cu^{2+}	24.8	19.57	19.06	22.21		

[a] From ref 14 (1 M NaCl, 25 °C). [b] Present work; determined by potentiometry (0.1 M KNO_3, 25 °C). The errors in log K_i and log K_{ML} were ±0.03 and ±0.05, respectively, on the basis of three or more replicate titrations. [c] Present work; determined by ^1H NMR spectroscopy (1 M KCl, 25 °C). [d] From ref 1 (0.1 M KCl, 25 °C). [e] From ref 18 (0.1 M Me_4NNO_3, 25 °C). [f] From ref 18 (0.1 M KNO_3, 25 °C). [g] From ref 15 (0.1 M Me_4NNO_3, 25 °C). [h] From ref 6 (0.1 M Me_4NCl_6, 25 °C). [i] From ref 24 (I = 0.2 M, 25 °C). [j] From ref 21 (1 M KNO_3). [k] From ref 19; determined by colorimetry (0.1 M NaCl, 25 °C).

that the two highest pK's (see Table I) correspond to protonations at ring nitrogens, identical with the protonation sequence observed for H_4DOTA.[14] No protonations are evident from the ^1H NMR data between pH 7 and 4, while the shifts are consistent with protonation of the remaining nitrogens and the phosphinic acid side chains below pH 4. A computer fit of these data between pH 7 and 12 gives virtually identical log K_1 and log K_2 values as obtained by potentiometry. At KOH concentrations above 0.1 M, the macrocyclic ring protons shift to low frequency (suggesting

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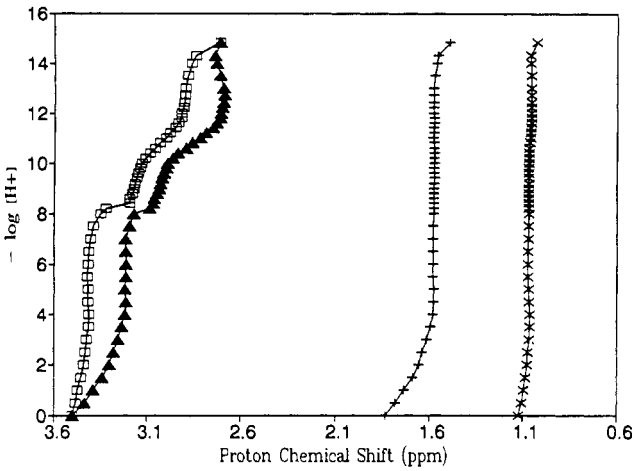

Figure 2. ^{1}H chemical shifts of the nonexchangeable protons in H_4DOTEP recorded as a function of solution pH. The KOH concentration was varied and the solution pH measured on a single sample up to pH $\simeq$12. Above this pH, individual solutions were prepared in D_2O containing known amounts of KOH and -log [H^+] was calculated. The curves correspond to the macrocyclic ethylene protons (□), the NCH_2P methylene protons (▲), and the methylene (+) and methyl (×) protons of the phosphinic acid ethyl group, respectively.

yet another deprotonation is occurring) while the NCH_2P methylene resonance first shifts toward higher frequencies and then at very high KOH concentrations (38%) appears to shift once again toward lower frequencies. Interestingly, the ethyl protons of the phosphinic acid side chains, which are quite insensitive to deprotonation of the macrocyclic nitrogens between pH 7 and 12, also appear to shift toward lower frequencies at very high KOH concentrations. This observation tends to confirm our conclusion that these ^{1}H NMR shifts do not reflect deprotonation of a more basic nitrogen, as has been recently suggested.[16]

The stability constants of the Mg^{2+}, Ca^{2+}, Sr^{2+}, Zn^{2+}, Cd^{2+}, and Cu^{2+} DOTEP complexes were determined by direct potentiometric titration (the titration curves are shown in Figure 1). Each of these ions form 1:1 complexes quite rapidly, and in the process all protons are released from the ligand. The trivalent lanthanides form complexes with DOTEP too slowly for normal potentiometric studies so the Gd(DOTEP)$^-$ and Ce(DOTEP)$^-$ stability constants were determined on nine separately prepared solutions which had been equilibrated for 72 h prior to pH measurement. No evidence was found for formation of MHL species for any of the metal ion complexes.

Water proton T_1 relaxation rates were measured at pH 7 and 25 °C on aqueous solutions containing various concentrations of Gd(DOTEP)$^-$. This complex has a somewhat higher water proton relaxivity than Gd(DOTA)$^-$ (5.1 versus 4.6 mM^{-1} s^{-1} at 40 MHz) and decomposes to free Gd^{3+} plus ligand in 0.1 M HCl only slightly faster ($t_{1/2} \simeq$ 30 h) than does Gd(DOTA)$^-$ ($\simeq$150 h).

Discussion

The new macrocycle, 1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrakis(methyleneethylphosphinic acid) (H_4DOTEP), has less basic nitrogens than the corresponding tetraacetic acid (H_4DOTA) or tetrakis(methylenephosphonic acid) (H_4DOTP) derivatives of H_4cyclen. This indicates that the RPO_2^- functionality is more electron withdrawing than either CO_2^- or PO_3^{2-}. A similar trend in nitrogen protonation constants is observed in the disubstituted ethylenediamine series, where the amine basicity order is H_4EDDPI (methylenephosphinic acid) < H_4EDDA (acetic acid) < H_4EDDPO (methylenephosphonic acid).[22]

The oxygen donor basicities of these same three substituents also fall in the order $RPO_2^- < CO_2^- < PO_3^{2-}$. This order holds for the simple acids, i.e., dimethylphosphinic acid versus acetic acid versus methylphosphonic acid,[23] and is also reflected in the log K_3 values for the three chelates (Table I). Thus, all donor atoms in DOTEP are less basic than the corresponding atoms in DOTA or DOTP and this results in weaker metal ion–DOTEP complexes than the respective DOTA or DOTP complexes. Molecular modeling indicates that the four RPO_2^- side chains can coordinate without significant steric interactions occurring between these bulky donor groups, at least with the large cations such as Ca^{2+} and the trivalent lanthanide cations. The observation that the Gd(DOTEP)$^-$ stability constant reported in Table I agrees with that predicted from the linear relationship between log K_{ML} and the sum of ligand pK_a's reported[19] for a series of Gd^{3+} chelates also indicates that steric factors do not significantly contribute to the measured stability constants.

A comparison of the cyclen versus DOTEP stability constants (Table I) indicates that the phosphinate side chains contribute substantially to the stability of the Ca^{2+} complex, contribute only slightly to the stability of the Cd^{2+} complex, slightly destabilize the Zn^{2+} complex, and strongly destabilize the Cu^{2+} complex. This same behavior is exhibited by the Cu(DOTA)$^{2-}$ complex.[20] Thus, those ions which prefer oxygen donors (Mg^{2+}, Sr^{2+}, Ca^{2+}, Ce^{3+}, Gd^{3+}) are likely stabilized by the presence of the phosphinate side chains even though the macrocyclic nitrogens, on average, are less basic. Similarly, Cu(DOTEP)$^{2-}$ is likely destabilized relative to Cu(cyclen)$^{2+}$ because of this ion's greater affinity for nitrogen donors, while the two effects virtually cancel in the Zn^{2+} and Cd^{2+} complexes.

DOTEP forms complexes with the trivalent lanthanide ions that are considerably less stable than the analogous DOTA complexes (Δ log K_{ML} = 8), although this difference in stability drops to Δ log K_{ML} = 7 at pH 7.4 due to decreased competition between protons and the Ln^{3+} cation for binding to DOTEP at this pH. The Ln(DOTEP)$^-$ complexes are slow to form at pH values less than 7 but, once formed, they dissociate quite slowly in strong acid, thereby giving these complexes similar kinetic advantages as the Ln(DOTA)$^-$ complexes for in vivo use. If further more detailed kinetic studies substantiate this, one advantage of H_4DOTEP over H_4DOTA might be that multiple phosphinic acid derivatives with differing solubility characteristics and perhaps differing biodistribution may be easily prepared.

The synthesis, pK_a's, and the Mg^{2+} and Ca^{2+} stability constants of the methylphosphinic acid analogue of DOTEP was recently reported in a short communication.[16] These authors reported two potentiometrically determined protonation constants (8.12 and 3.66) similar to the values we report here for DOTEP but concluded from ^{31}P NMR titration data (similar to the ^{1}H data we report here) that their ligand has two very basic nitrogens with pK_a's greater than 14. These conclusions were later withdrawn, citing ionic strength effects as the origin of the ^{31}P NMR shifts.[17] Our potentiometric titrations show quite conclusively that the NMR observations at high pH cannot be due to titration of other dissociable protons. We must conclude the observed NMR shifts result from either (a) K^+ binding to the macrocycle at these very high KOH concentrations, (b) dissociation of a proton(s) which in normally not titrated, such as one of the bridging methylene protons, or (c) some unusual conformational behavior of the macrocycle which is ionic strength dependent. We do not detect changes in ^{1}H resonance areas at high pH (the samples contained a mixture of KOH and D_2O), so option b may be discounted. Since the ^{31}P data[16] on the methyl analogue of DOTEP were measured in the presence of $(CH_3)_4NOH$, we must conclude that

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either K^+ and $(CH_3)_4N^+$ are both capable of binding to these macrocycles at very high cation concentrations or simply their presence leads to some unusual conformational effects. We conclude these NMR chemical shifts most likely arise from the very dramatic changes in ionic strength which occur in these solutions.

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Registry No. H_4DOTEP·2HCl, 136705-17-4; H_4DOTEP, 136705-18-5; cyclen tetrahydrochloride, 10045-25-7.

Contribution from the Department of Chemistry and Molecular Structure Center, Indiana University, Bloomington, Indiana 47405

A Triangular Heterometallic Siloxide Containing Barium

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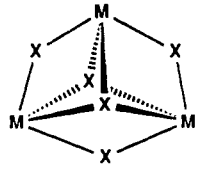
Reaction of $KOSiPh_3$ with $Ba_3(OSiPh_3)_6(THF)$ in THF displaces barium from the triangular reagent to yield a colorless solid. Recrystallization in the presence of $MeOC_2H_4OMe(DME)$ yields $KBa_2(OSiPh_3)_5(DME)_2$, characterized by ^1H and ^{29}Si NMR spectroscopy and X-ray diffraction. The molecule contains a triangular $KBa_2(\mu_3\text{-}OSiPh_3)_2(\mu_2\text{-}OSiPh_3)_3$ core with η^1- and η^2-DME ligation on each barium. The benzene-soluble molecule is fluxional in solution at both the $OSiPh_3$ and the DME groups. At −70 °C in CH_2Cl_2/C_6D_6, both η^1-DME/η^2-DME site exchange and intramolecular siloxide migration have been slowed, and the spectra are in agreement with retention of the solid-state structure in solution. Crystallographic data for $KBa_2(OSiPh_3)_5(DME)_2$ (−159 °C): a = 15.474 (3) Å, b = 26.466 (6) Å, c = 23.783 (5) Å, β = 99.80 (1)° with Z = 4 in space group $P2_1/n$.

Introduction

We have reported recently[1] that barium granules react with Ph_3SiOH in THF solvent only in the presence of NH_3 as a catalyst. After crystallization from toluene, the product has empirical formula $Ba(OSiPh_3)_2(THF)_{0.5}$. This molecule is actually a trimer which is noteworthy for having barium in coordination numbers 4 (once) and 5 (twice). The underlying feature it *shares* with many other trimetal species[2] is the $M_3(\mu_3\text{-}X)_2(\mu_2\text{-}X)_3$ core (A).



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For the purposes of incorporating other metal ions (e.g. copper) into such a species, it would be useful to have an anionic barium siloxide (eq 1).[3] We therefore report here on our attempts to produce such an anionic barium synthon.

$$Ba_n(OR)_m^- + CuCl_2 \rightarrow ClCuBa_n(OR)_m + Cl^- \quad (1)$$

Experimental Section

Materials and Procedures. All manipulations were performed using standard Schlenk techniques either under an atmosphere of nitrogen or in a nitrogen-filled drybox. Toluene, pentane, hexanes, dimethoxyethane, and tetrahydrofuran were dried over potassium benzophenone ketyl, distilled under nitrogen, and subjected to freeze–pump–thaw cycles prior to use. The compound $Ba_3(OSiPh_3)_6(THF)\cdot x$THF was synthesized by a literature method.[1] $KOSiPh_3$ was synthesized[4] by addition of Ph_3SiOH to excess KH in toluene. The excess KH was filtered away and the solvent removed under vacuum to yield $KOSiPh_3$ as a colorless solid. Barium granules (Alfa) and triphenylsilanol (Aldrich) were used as received. Potassium hydride (Aldrich) was washed repeatedly with hexanes and dried under vacuum.

Physical Measurements. Hydrogen-1 NMR spectra were recorded on a Nicolet NT-360 spectrometer (360 MHz) and on a Bruker AM-500 spectrometer (500 MHz) and referenced to residual protons in the solvent. Silicon-29 NMR spectra were recorded on a Bruker AM-500 spectrometer (99.4 MHz) using an inverse-gated decoupling routine. Spectra were externally referenced to $SiMe_4$.

Table I. Crystallographic Data for $KBa_2(OSiPh_3)_5(DME)_2$·hexane

chem formula	$C_{98}H_{95}Ba_2KO_9Si_5$·solvent	fw	1871.03
a, Å	15.474 (3)	space group	$P2_1/n$
b, Å	26.466 (6)	T, °C	−159
c, Å	23.783 (5)	λ, Å	0.710 69
β, deg	99.80 (1)	ρ_{calcd}, g cm^{-3}	1.295
V, Å^3	9597.97	μ(Mo K$_\alpha$), cm^{-1}	9.7
Z	4	R	0.0705
		R_w	0.0681

Synthesis of $KBa_2(OSiPh_3)_5(DME)_2$. $KOSiPh_3$ (0.315 g, 1.0 mmol) was combined with $Ba_3(OSiPh_3)_6(THF)$ (1.42 g, 0.667 mmol) in a Schlenk flask. THF (35 mL) was added to dissolve both solids, and the solution was stirred for 3 h at room temperature. The solution was concentrated under vacuum and layered with hexanes. Over the next several hours, colorless microcrystals formed. The solvent was removed via cannula. The microcrystals immediately lost solvent under vacuum and formed a white powder. Recrystallization from DME/hexanes gave colorless cubes. Yield: 0.990 g, 53%. ^1H NMR (C_6D_6 298 K): δ 7.68 (br, 30 H, ortho), 6.98 (m, 45 H, meta + para), 2.96 (s, DME), 2.79 (s, DME), 1.25 (m, hexanes), 1.18 (m, hexane), 0.88 (m, hexane). Note: The integrated intensity ratio of phenyl region to DME region varied from sample to sample. ^{29}Si NMR (C_6D_6, 298 K): δ −27.8 (br). Anal. Calcd for $C_{104}H_{109}Ba_2KO_9Si_5$: C, 63.82; H, 5.12. Found: C, 63.75; H, 5.59.

X-ray Structure Determination of $KBa_2(OSiPh_3)_5(DME)_2$·hexane. A crystal of suitable size was mounted in a nitrogen atmosphere glovebag using silicone grease, and it was then transferred to a goniostat where it was cooled to −159 °C for characterization and data collection[5] (Table I). A search of a limited hemisphere of reciprocal space revealed intensities with Laue symmetry and systematic absences consistent with space group $P2_1/n$; this choice was later confirmed by the successful solution of the structure. Following complete data collection ($6° < 2\theta < 45°$), data processing gave a residual of 0.056 for the averaging of 1043 unique intensities which had been observed more than once. Four standards measured every 400 data showed no significant trends. No correction was made for absorption. The structure was solved using a combination of direct methods (MULTAN78) and Fourier techniques. The Ba positions were determined from an E map. The remaining non-hydrogen atoms were obtained from subsequent iterations of least-squares refinement and difference Fourier calculation. These included an elongated group of peaks assigned as a disordered molecule of hexane which

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