Insight into Self-Assembly: Reaction Intermediates and Kinetic Mistakes Observed in a Remarkably Slow Reaction

Virginia M. Cangelosi, Timothy G. Carter, Lev N. Zakharov, and Darren W. Johnson*

Department of Chemistry and Materials Science Institute, University of Oregon, Eugene, OR 97403-1253, and the Oregon Nanoscience and Microtechnologies Institute (ONAMI).

dwj@uoregon.edu

Supporting Information

Experimental:

General Procedures. Commercially available reagents were used as received. All ligands were prepared following literature procedures.1 Caution: Arsenic compounds are hazardous and should be handled with care!

NMR Experiments. 1H NMR spectra were measured using a Varian INOVA-300 spectrometer. Spectra were referenced using the residual CHCl3 solvent resonance as an internal standard.

As2L2Cl2 (4a). 1,4-bis(mercaptomethyl)benzene (H2L2, 16.1 mg, 94.9 μmol) was dissolved in 2.0 mL CDCl3 in a scintillation vial. In a separate vial, AsCl3 (94.8 μmol, 8.09 μL) was dissolved in 2.0 mL CDCl3. The AsCl3 solution was added to the solution containing ligand and mixed well (T=0). An aliquot was transferred to an NMR tube and monitored by 1H NMR.

As2L2Cl2 (4b). 1,4-bis(mercaptomethyl)durene (H2L2, 14.0 mg, 61.8 μmol) was dissolved in 4.0 mL CDCl3 in a scintillation vial. AsCl3 (61.8 μmol, 5.28 μL) was added and the solution was mixed well (T=0). An aliquot was transferred to an NMR tube and monitored by 1H NMR (Figure S1). Colorless X-ray quality crystals were grown by the slow diffusion of pentane into a CHCl3 solution of As2L2Cl2. Crystallographic Data: C24H32As2Cl2S4, M = 669.48, 0.16 x 0.14 x 0.10 mm, T = 293 K, Triclinic, space group P-1, a = 8.4667(7) Å, b = 10.6932(9) Å, c = 17.0485(15) Å, α = 87.852(2)°, β = 77.066(2)°, γ = 68.0790(10)°, V = 1393.8(2) Å3, Z = 2, Dc = 1.595 Mg/m3, μ = 2.901 mm⁻¹, F(000) = 680, 2θmax = 27.00°, 15620 reflections (-10 ≤ h ≤ 10, -13 ≤ k ≤ 13, -21 ≤ l ≤ 21), 6027 independent reflections [Rint = 0.0306], R1 = 0.0624, wR2 = 0.1638 and GOF = 1.033 for 6027 reflections (298 parameters) with I>2σ(I), R1 = 0.0945, wR2 = 0.1892 and GOF = 1.033 for all reflections, max/min residual electron density +1.741/-0.704 eÅ3, CCDC: 741267.

S1
As₂L₄Cl₄ (3'). AsCl₃ (3.44 μL, 0.0404 mmol) was added slowly to a solution of 2,5-bis(mercaptomethyl)-1,4-dimethoxybenzene (H₂L₄) (9.30 mg, 0.0404 mmol) in CHCl₃ (4 mL) and mixed well. An aliquot of the solution was transferred into a vial and layered with pentane. Slow diffusion of pentane into this solution yielded colorless crystals after one week. Crystallographic Data: C₁₀H₁₂As₂Cl₄O₂S, M = 519.96, 0.27 x 0.22 x 0.14 mm, T = 173(2) K, monoclinic, space group P₂₁/c, a = 8.1642(8) Å, b = 11.7354(12) Å, c = 9.2996(9) Å, β = 106.451(2)°, V = 854.52(15) Å³, Z = 2, Dᵣ = 2.021 Mg/m³, μ = 4.775 mm⁻¹, F(000) = 508, 2θmax = 28.19°, 9618 reflections (-10 ≤ h ≤ 10, -13 ≤ k ≤ 13, -21 ≤ l ≤ 21), 2030 independent reflections (Rint = 0.0194), R1 = 0.0202, wR2 = 0.0547 and GOF = 1.039 for 2030 reflections (115 parameters) with I>2σ(I), R1 = 0.0212, wR2 = 0.0554 and GOF = 1.039 for all reflections, max/min residual electron density +0.490/-0.222 eÅ³, CCDC: 741266.

Mass Spectroscopy Experiments. Laser Desorption Ionization experiments on H₂Lb with AsCl₃ where performed on a Waters Micromass Q-TOF MALDI mass spectrometer (Milford, MA USA) using V-Optics and positive ionization mode. Samples were prepared by spotting NMR solutions (CDCl₃) containing the analyte directly onto the sample plate, without the use of a matrix, at various time intervals ranging from T=0 to T=2hrs after the addition of AsCl₃. Initial spectra where nearly devoid of macrocycle 4b and contained mostly M₄L₄ species. After sampling at T=30 minutes, macrocycle 4b was the prominent species detected. Sodium adducts of the species of interest most likely resulted as the direct laser desorption technique. Additionally, multiply protonated thiols (M+2H+Na)⁺ where observed for species containing single thiols while (M+4H+Na)⁺ where observed for those containing two thiols.² Ligands capped with arsenic (no free thiols) flew as (M+Na)⁺ and did not contain additional protons.

X-ray Crystallography. Diffraction intensities for As₂L₄Cl₄ were collected at 173 K on a Bruker Apex diffractometer using MoKα radiation λ = 0.71073 Å. Crystals of As₂(Lb)₂Cl₂ crack at low temperatures, so X-ray diffraction data for this compound was collected at room temperature, 293 K. Space groups were determined based on systematic absences (As₂L₄Cl₄) and intensity statistics (As₂(Lb)₂Cl₂). Absorption corrections were applied by SADABS. Structures were solved by direct methods and standard Fourier techniques and refined on F² using full matrix least-squares procedures. Non-H atoms were refined with anisotropic thermal parameters. H atoms in As₂L₄Cl₄ were found on the F-map and refined with isotropic thermal parameters. H atoms in As₂(Lb)₂Cl₂ were refined in calculated positions in a rigid group model. All calculations were performed by the Bruker SHELXTL package. Single crystal X-ray diffraction studies were performed on a Bruker SMART APEX diffractometer.

References:

Figure S1. CH$_2$ region of $^1$H NMR spectra of reaction of H$_2$L$^b$ with AsCl$_3$ after a) 0, b) 4, c) 75, d) 147, e) 1559, f) 2666, g) 3995, and h) 8395 minutes and dissolved crystals of As$_2$L$_2$Cl$_2$ (4$^b$).
**Figure S2.** MALDI mass spectroscopy data for $1^b$. Predicted data shown on top and actual data shown on the bottom.

**Figure S3.** MALDI mass spectroscopy data for $2^b$. Predicted data shown on top and actual data shown on the bottom.
Figure S4. MALDI mass spectroscopy data for 3b. Predicted data shown on top and actual data shown on the bottom.

Figure S5. MALDI mass spectroscopy data for 4b. Predicted data shown on top and actual data shown on the bottom.
**Figure S6.** MALDI mass spectroscopy data for 5b. Predicted data shown on top and actual data shown on the bottom.

**Figure S7.** MALDI mass spectroscopy data for 6b. Predicted data shown on top and actual data shown on the bottom.
Figure S8. MALDI mass spectroscopy data for $7^b$. Predicted data shown on top and actual data shown on the bottom.

Figure S9. MALDI mass spectroscopy data for $8^b$. Predicted data shown on top and actual data shown on the bottom.
Figure S10. MALDI mass spectroscopy data for 9b. Predicted data shown on top and actual data shown on the bottom.