

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.

As₂L^a₂Cl₂ (4^a). 1,4-bis(mercaptomethyl)benzene (H₂L^a, 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.

As₂L^b₂Cl₂ (4^b). 1,4-bis(mercaptomethyl)durene (H₂L^b, 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 As₂L^b₂Cl₂. 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, *D_c* = 1.595 Mg/m³, *μ* = 2.901 mm⁻¹, *F*(000) = 680, 2 θ _{max} = 27.00°, 15620 reflections (-10 ≤ *h* ≤ 10, -13 ≤ *k* ≤ 13, -21 ≤ *l* ≤ 21), 6027 independent reflections [*R*_{int} = 0.0306], *R*1 = 0.0624, *wR*2 = 0.1638 and *GOF* = 1.033 for 6027 reflections (298 parameters) with *I*>2σ(*I*), *R*1 = 0.0945, *wR*2 = 0.1892 and *GOF* = 1.033 for all reflections, max/min residual electron density +1.741/-0.704 eÅ⁻³, CCDC: 741267.

$As_4L^cCl_4$ (**3^c**). $AsCl_3$ (3.44 μ L, 0.0404 mmol) was added slowly to a solution of 2,5-bis(mercaptomethyl)-1,4-dimethoxybenzene (H_2L^c) (9.30 mg, 0.0404 mmol) in $CHCl_3$ (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: $C_{10}H_{12}As_2Cl_4O_2S$, $M = 519.96$, $0.27 \times 0.22 \times 0.14$ mm, $T = 173(2)$ K, monoclinic, space group $P2_1/c$, $a = 8.1642(8)$ Å, $b = 11.7354(12)$ Å, $c = 9.2996(9)$ Å, $\beta = 106.451(2)^\circ$, $V = 854.52(15)$ Å³, $Z = 2$, $D_c = 2.021$ Mg/m³, $\mu = 4.775$ mm⁻¹, $F(000) = 508$, $2\theta_{max} = 28.19^\circ$, 9618 reflections ($-10 \leq h \leq 10$, $-13 \leq k \leq 13$, $-21 \leq l \leq 21$), 2030 independent reflections [$R_{int} = 0.0194$], $R1 = 0.0202$, $wR2 = 0.0547$ and $GOF = 1.039$ for 2030 reflections (115 parameters) with $I > 2\sigma(I)$, $R1 = 0.0212$, $wR2 = 0.0554$ 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 H_2L^b with $AsCl_3$ 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 ($CDCl_3$) containing the analyte directly onto the sample plate, without the use of a matrix, at various time intervals ranging from $T=0$ to $T=2$ hrs after the addition of $AsCl_3$. Initial spectra were nearly devoid of macrocycle **4^b** and contained mostly M_nL_m species. After sampling at $T=30$ minutes, macrocycle **4^b** 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 $(M+2H+Na)^+$ were observed for species containing single thiols while $(M+4H+Na)^+$ were 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 $As_2L^cCl_4$ were collected at 173 K on a Bruker Apex diffractometer using $MoK\alpha$ radiation $\lambda = 0.71073$ Å. Crystals of $As_2(L^b)_2Cl_2$ 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 ($As_2L^cCl_4$) and intensity statistics ($As_2(L^b)_2Cl_2$). Absorption corrections were applied by SADABS. Structures were solved by direct methods and standard Fourier techniques and refined on F^2 using full matrix least-squares procedures. Non-H atoms were refined with anisotropic thermal parameters. H atoms in $As_2L^cCl_4$ were found on the F-map and refined with isotropic thermal parameters. H atoms in $As_2(L^b)_2Cl_2$ 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:

- 1) H_2L^a : P. Zhang and D. R. Bundle, *Isr. J. Chem.* **2000**, *40*, 189-208.
 H_2L^b : W. D. Rohrbach and V. Boekelheide, *J. Org. Chem.* **1983**, *48*, 3673-3678.
 H_2L^c : V. M. Cangelosi, L. N. Zakharov, S. A. Fontenot, M. A. Pitt and D. W. Johnson, *Dalton Trans.* **2008**, 3447.
- 2) R. Zenobi and R. Knochenmuss, *Mass Spectrom. Rev.* **1998**, *17*, 337.

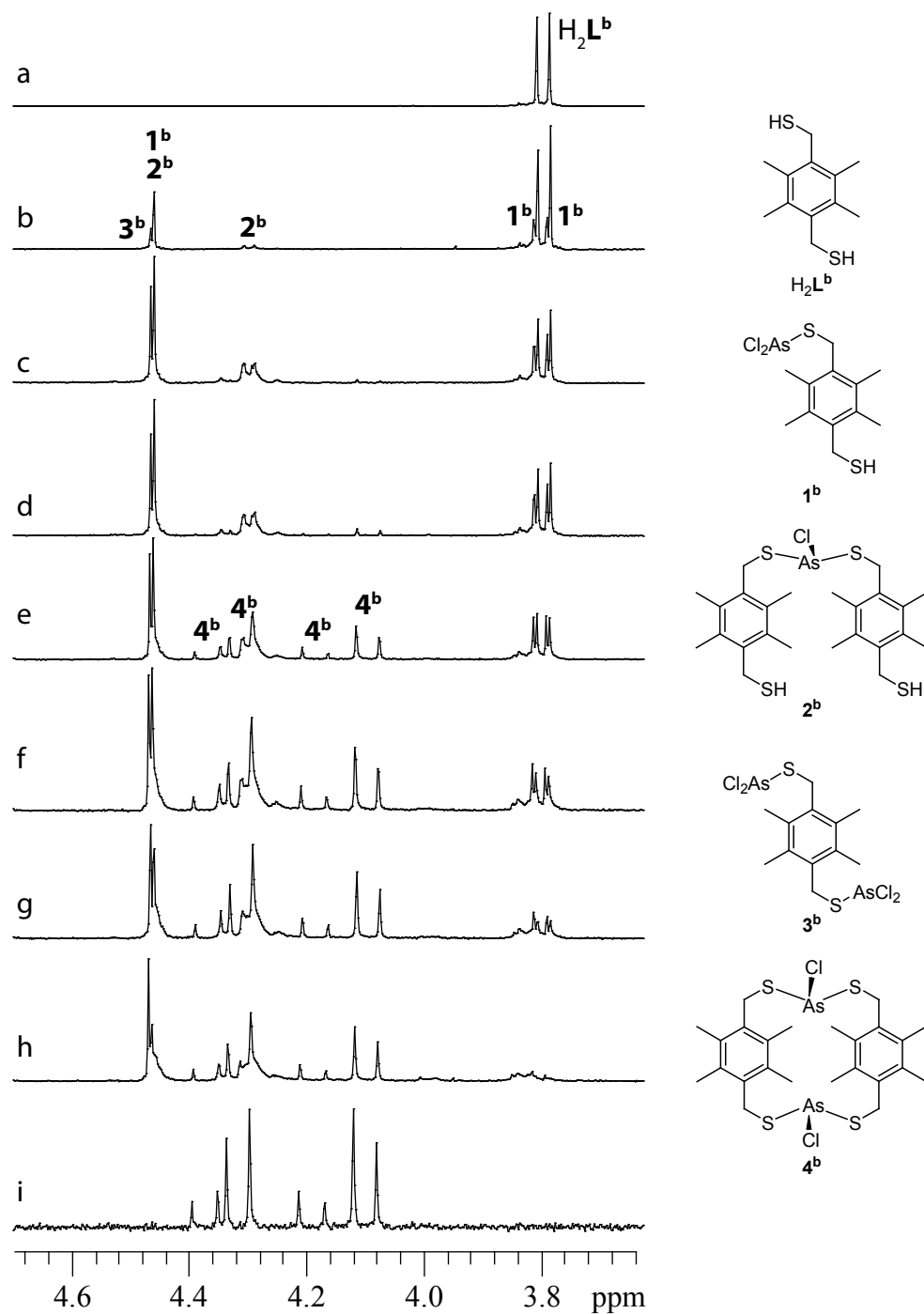


Figure S1. CH₂ region of ¹H NMR spectra of reaction of H₂L^b with AsCl₃ after a) 0, b) 4, c) 75, d) 147, e) 1559, f) 2666, g) 3995, and h) 8395 minutes and dissolved crystals of As₂L₂Cl₂ (4^b).

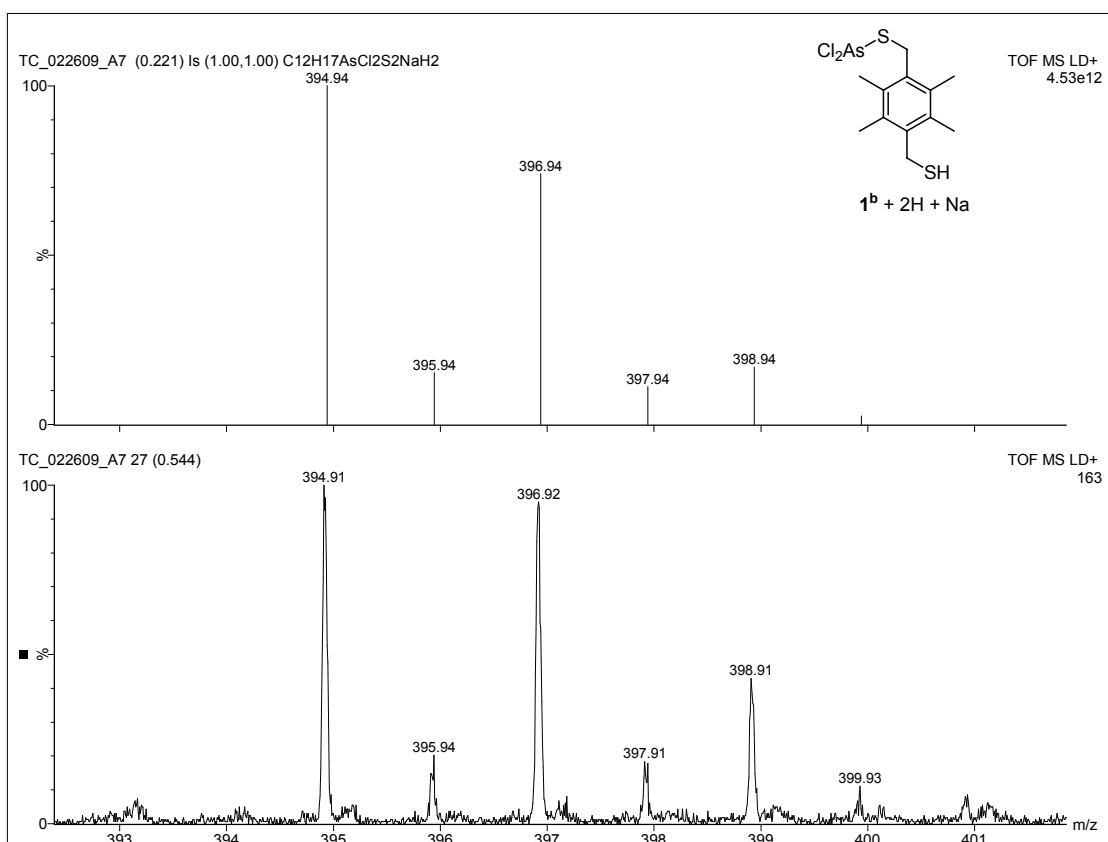


Figure S2. MALDI mass spectrometry data for **1^b**. Predicted data shown on top and actual data shown on the bottom.

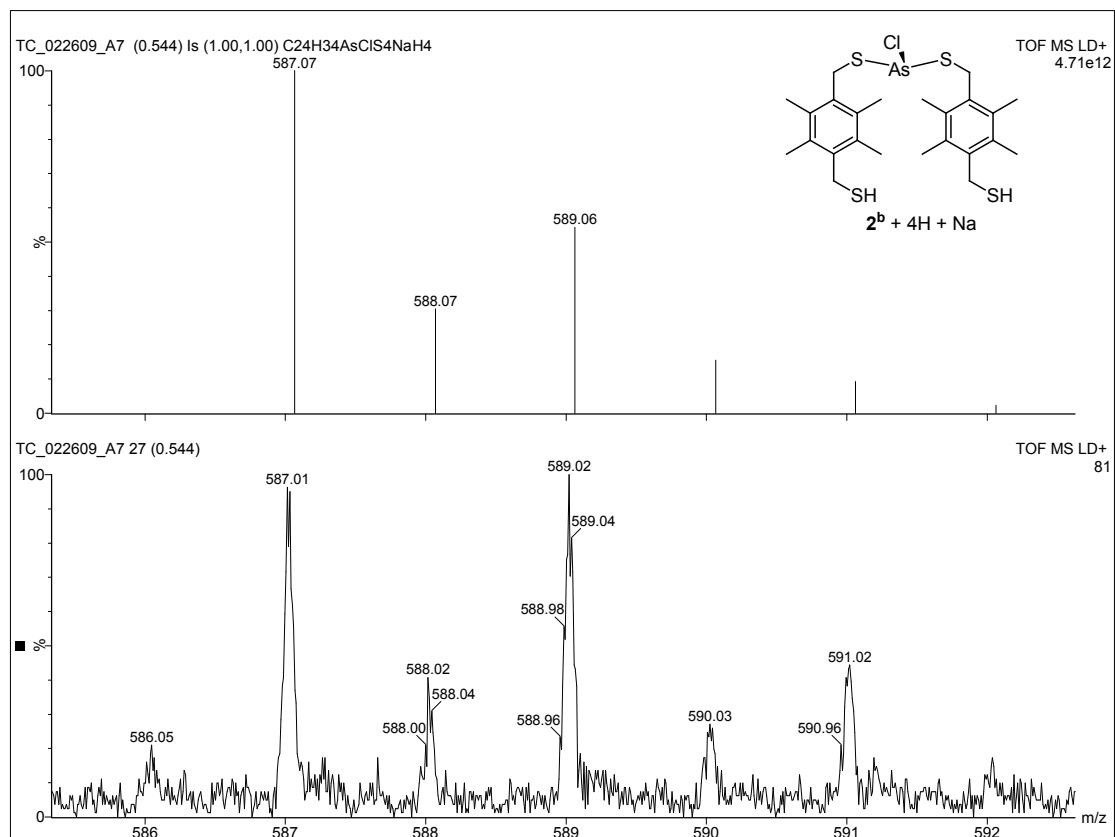
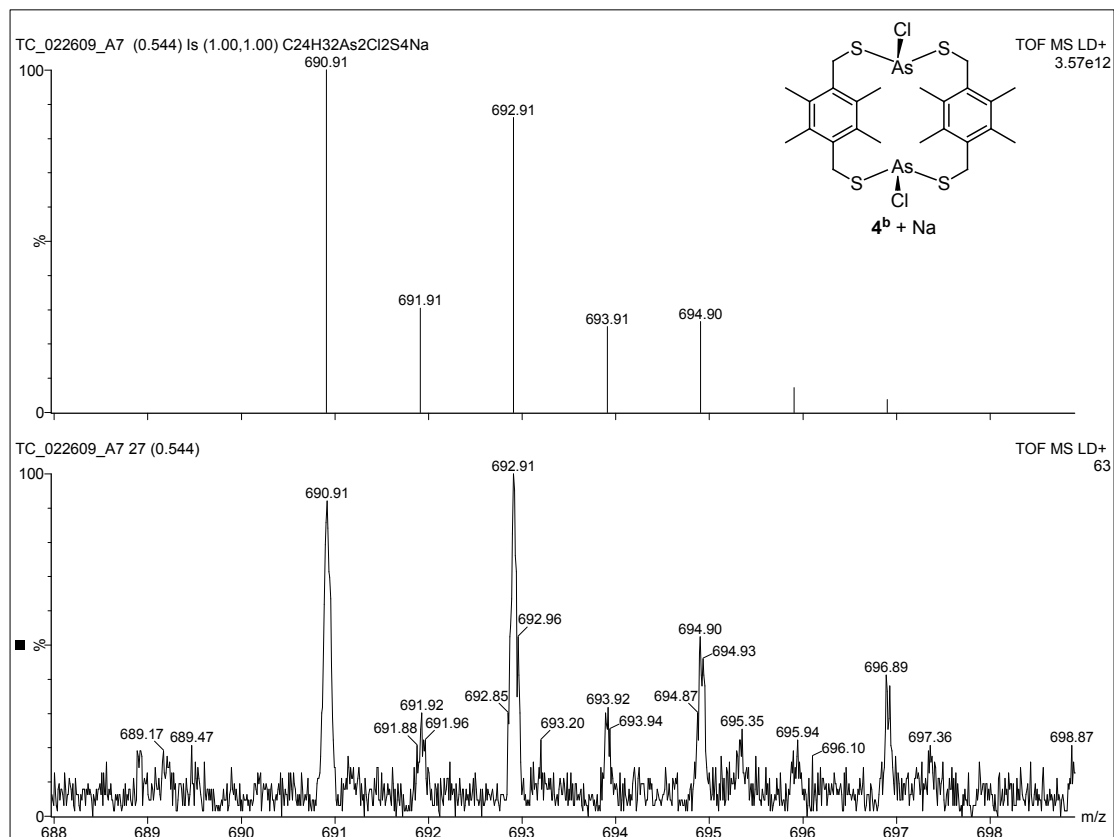
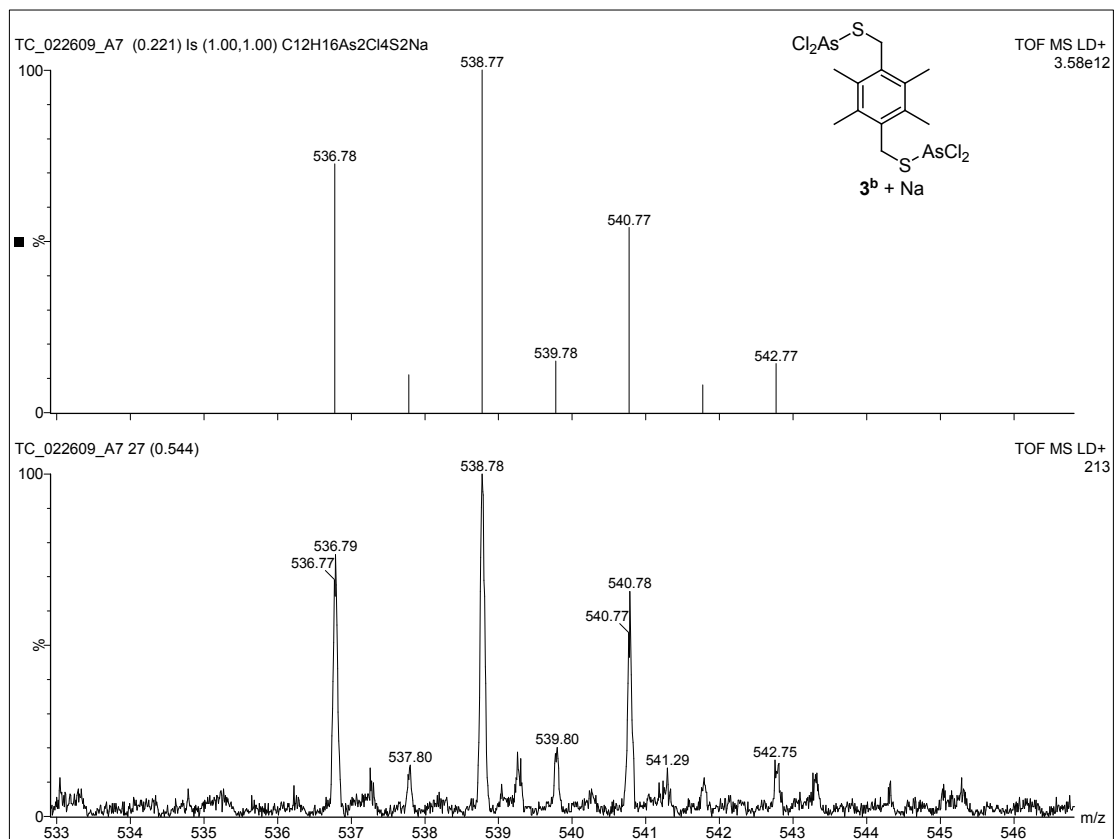
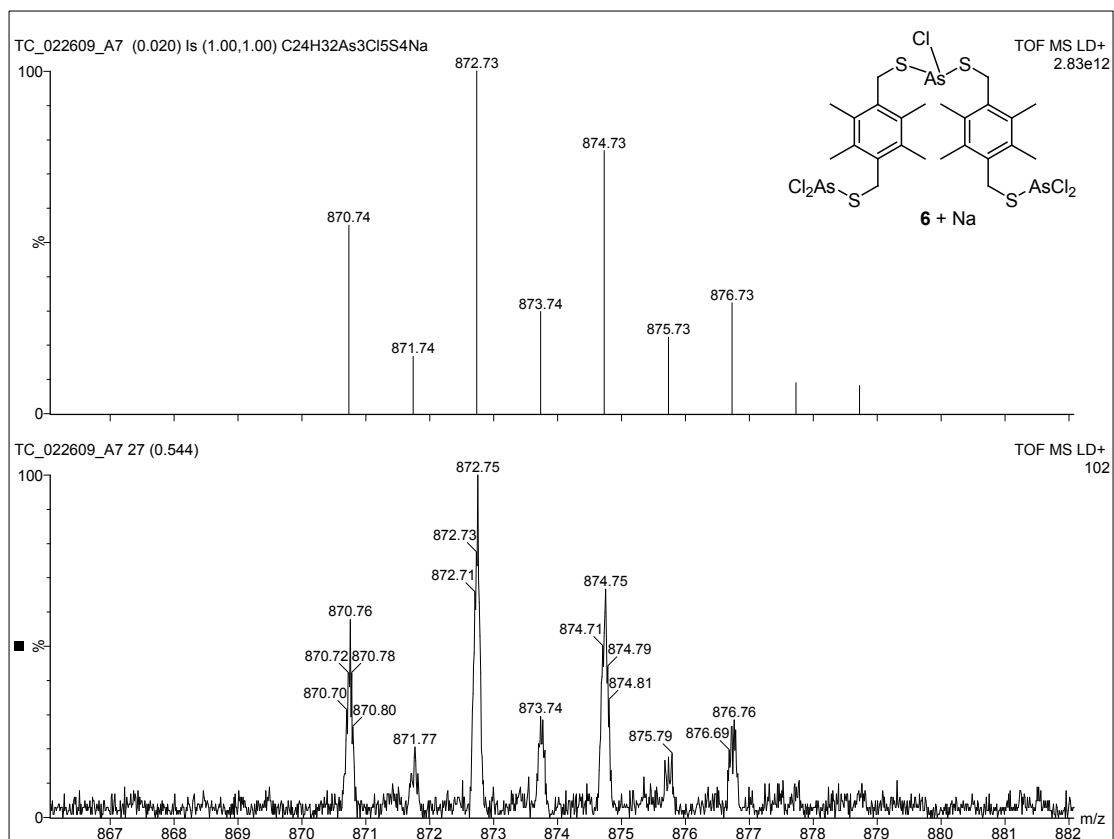
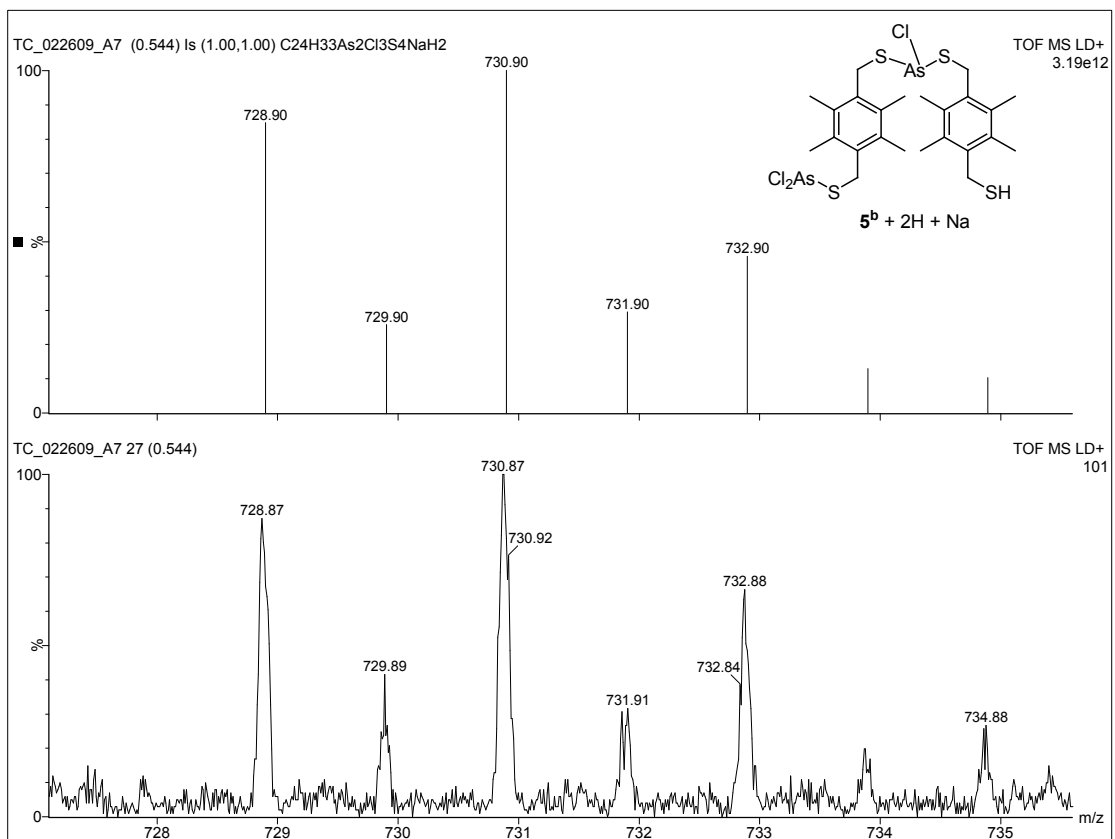


Figure S3. MALDI mass spectrometry data for **2^b**. Predicted data shown on top and actual data shown on the bottom.





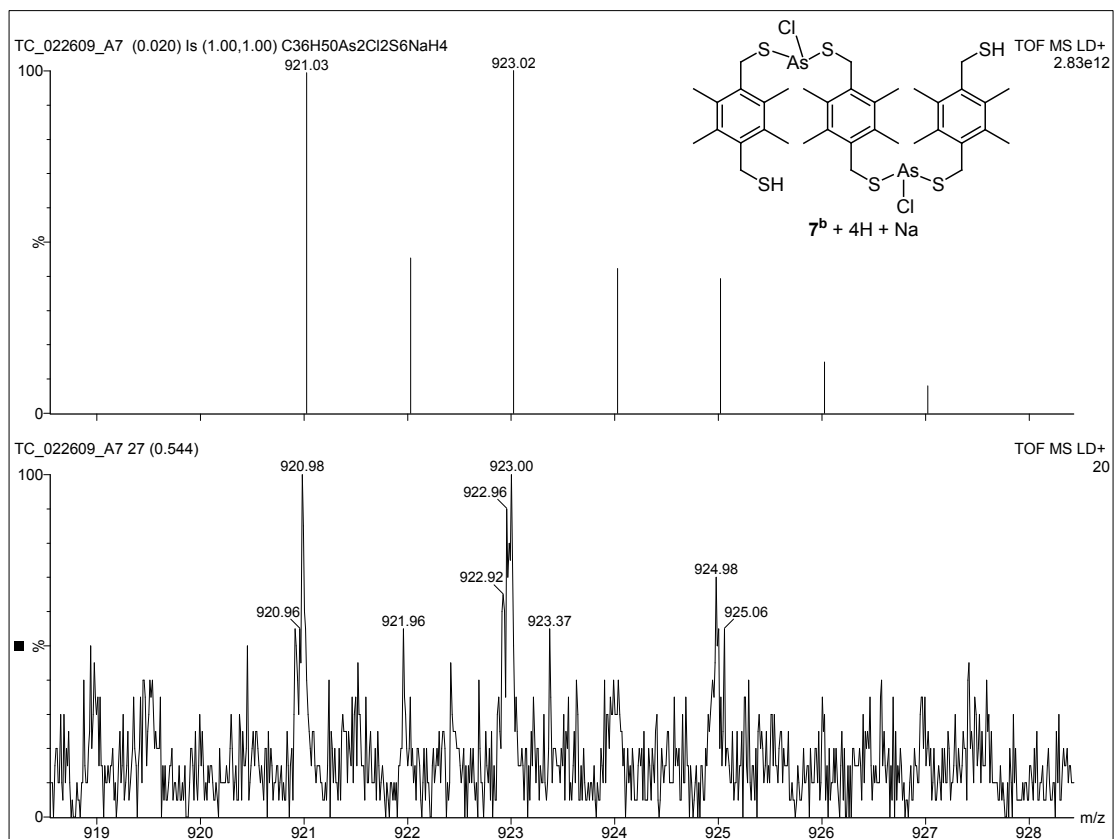


Figure S8. MALDI mass spectroscopy data for **7^b**. Predicted data shown on top and actual data shown on the bottom.

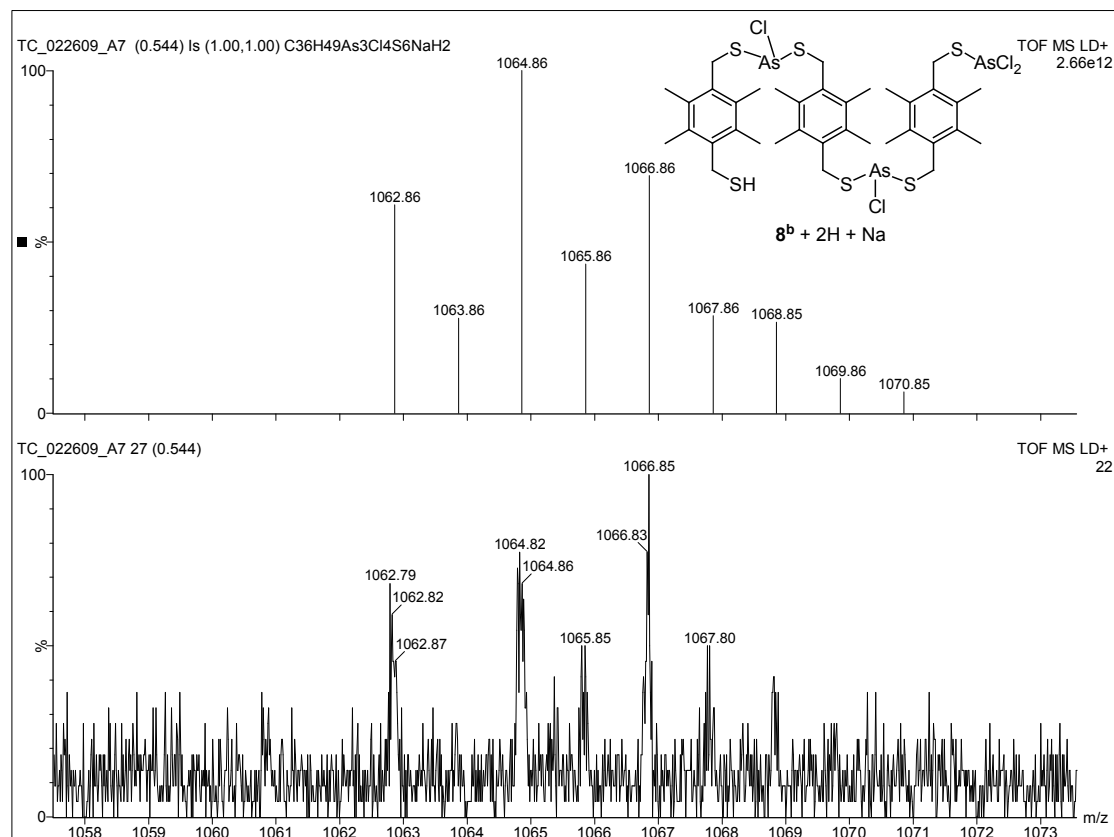


Figure S9. MALDI mass spectroscopy data for **8^b**. Predicted data shown on top and actual data shown on the bottom.

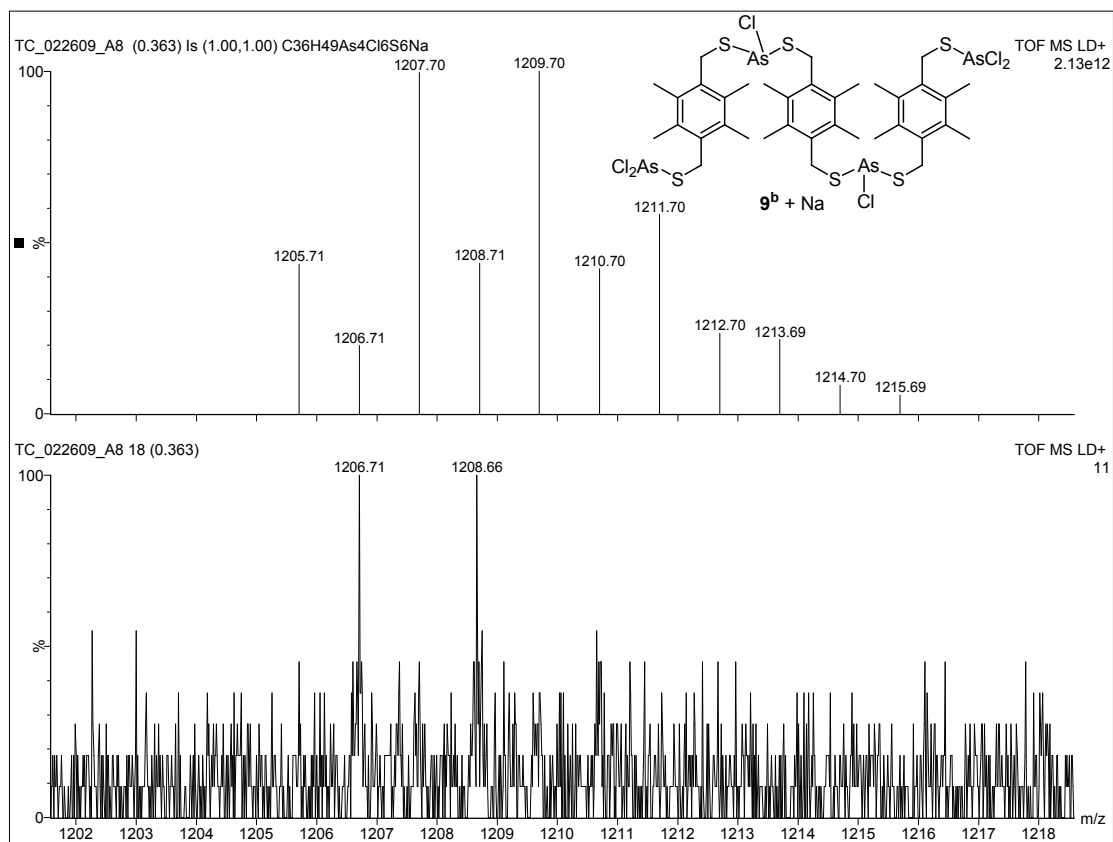


Figure S10. MALDI mass spectroscopy data for **9^b**. Predicted data shown on top and actual data shown on the bottom.