Electronic Supplementary Material (ESI) for RSC Advances.

Electronic Supplementary Information

A Pb^{2+}-Binding Polychelatogen Derived from Thionated Lactide

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Materials and Equipment: All syntheses were performed under a dinitrogen atmosphere unless otherwise noted. All reagents were purchased from Sigma Aldrich or VWR and used as received unless otherwise noted. Toluene and dichloromethane (DCM) were dried and collected from a PureSolv MD solvent purification system (Innovative Technology, Inc.) equipped with two activated alumina columns. Benzene was dried over sodium/benzophenone for 24 hours and distilled prior to use. Dialysis bags (MWCO = 3.5 kDa) were purchased from Fisher Scientific. ^{1}H spectra were recorded on a Bruker 500 MHz spectrometer and calibrated to the residual protonated solvent peak at δ 7.24 for deutrated chloroform ($CDCl_3$) and δ 4.79 for deutrated water (D_2O). Resonances at *ca*. 1.56 ppm are attributed to residual H_2O in $CDCl_3$.[1] ^{13}C NMR spectra were calibrated at δ 77.23 for $CDCl_3$. Molecular weights (M_n and M_w) and dispersity ($Đ_M$) were determined by gel permeation chromatography (GPC) using a Malvern Viscotek TDAmax chromatograph equipped with tetrahydrofuran (THF) as the mobile phase at 30 °C. The chromatograph was equipped with two PLC mixed columns and one PLD mixed column. Output was detected with a Viscotek TDA 305-055 Tetra Detector Array (PDA + RI + Visc + LALS / RALS) using an eluent flow rate of 1 mL/min and a 60 μL injection loop. Molecular weights were determined from a 10-point calibration curve created using polystyrene standards purchased from Polymer Laboratories. Differential scanning calorimetry (DSC) was performed on a TA Instruments Discovery differential scanning calorimeter at a scan rate of 10 °C min^{-1}. All DSC data were recorded from the second heating scans. Thermal gravimetric analyses were performed on a TA Instruments Discovery thermogravimetric analyzer at a scan rate of 20 °C min^{-1} up to 700 °C. Chiral phase chromatography was performed on a PerkinElmer Flexar HPLC equipped with a Chiralpak AD-H (0.46 x 25 cm) column using a mobile phase of *n*-hexane/*i*-PrOH (95/5), 1.0 mL/min. All optical rotations were measured using a Jasco P-1020 polarimeter (589, 20 °C). Solid-state infrared spectra were recorded on a Nicolet 6700 FTIR-ATR Series spectrometer (4 cm^{-1} resolution). Aqueous Pb^{2+} concentrations were measured using a Thermo Scientific atomic absorption spectrometer. All Pb^{2+} solutions for calibration curves and sequestration studies were prepared from a Fisher Scientific Lead reference standard solution (certified 1000 ppm ± 1%).

Single Crystal X-ray Analysis: A suitable crystal of each compound was mounted on a Bruker-AXS SMART APEX II CCD diffractometer at 100(1)K. The cell dimensions and the intensities were all collected with CuK□ radiation (□ = 1.54178 Å). Data processing, Lorentz-polarization, and face-indexed numerical absorption corrections were performed using SAINT, APEX, and SADABS computer programs.[2] The structures were solved by direct methods and refined by full-matrix least-squares methods on F^2, using the SHELXTL V6.14 program package.[3] All non-hydrogen atoms were refined anisotropically. All H atoms were found in electron-density difference maps and allowed to ride on their respective C atoms. The methyl H atoms were placed in ideally staggered positions with C---H distances of 0.98 Å and $U_{iso}(H) = 1.5U_{eq}(C)$. The methylene, methine, and bridgehead H atoms were all placed in geometrically-idealized positions and constrained to ride on their parent C atoms with C---H distances of 0.99, 0.95, and 1.000 Å, respectively, and $U_{iso}(H) = 1.2U_{eq}(C)$. The numbers in parentheses are the errors in the least sig. digit. Compounds **1**, **1b** and **2** were all refined as 2-component inversion twins. X-ray crystallographic files in CIF format have been deposited with the Cambridge Structural Database as files CCDC 1477173, 1477175, and 1477174. These materials can be obtained, free of charge, on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK. (fax: +44 1223 336033 or e-mail: deposit@ccdc.cam.ac.uk).

Experiential:

Compound 1. A pressure vessel (equipped with a sidearm and stir bar) was charged with L-lactide (10.00 g, 69.40 mmol), P_4S_{10} (7.71 g, 17.35 mmol) and hexamethyldisiloxane (18.81 g, 115.87 mmol) in *ca*. 70 mL of anhydrous toluene. After refluxing the contents for 24 h, the reaction was cooled to room temperature and the solvent removed under reduced pressure. The residue was taken up in DCM and passed through a silica column (Sorbtech silica gel; porosity, 60Å; particle size, 40-60 μm; column, 4 cm diameter, 15 cm length, R_f = 1.0) to remove sulfur impurities. The crude product was then passed through a second silica column (diameter, 4 cm; length, 15 cm) using a diethyl ether/hexane solvent mixture (25/75) as the eluent (R_f = 0.45). After solvent removal, the yellow solid was recrystallized thrice from cold diethyl ether (*ca*. -20 °C) and sublimed to afford analytically pure product (2.00 g, Yield: 18%). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 5.04 (q, $^3J_{HH}$ = 13.41, $^3J_{HH}$ = 6.73, 1H), 4.96 (q, $^3J_{HH}$ = 12.77, $^3J_{HH}$ = 6.41, 1H), 1.76 (d, $^3J_{HH}$ = 6.40, 3H), 1.73 (d, $^3J_{HH}$ = 6.68, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ 211.4, 167.5, 78.4, 75.1, 19.3, 15.5. IR: ν = 2996, 1759, 1441, 1370, 1350, 1323, 1303, 1259, 1226, 1147, 1080, 1063, 1035, 1010, 959, 833, 751, 727 cm^{-1}. $[\alpha]_D^{23}$ = -512.9 (*c* 0.59, $CHCl_3$). Melting point: 82-83 °C. Anal. Calc. for $C_6H_8O_3S$: C, 44.99; H, 5.03; N, 0.00. Found: C, 45.13; H, 4.99; N, 0.00.

Note A: A racemic mixture of **1** was prepared under identical conditions with the exception that D,L-LA was used in lieu of L-LA. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 5.04 (q, $^3J_{HH}$ = 13.35, $^3J_{HH}$ = 6.79, 1H), 4.95 (q, $^3J_{HH}$ = 12.79, $^3J_{HH}$ = 6.40, 1H), 1.77 (d, $^3J_{HH}$ = 6.40, 3H), 1.74 (d, $^3J_{HH}$ = 6.67, 3H). ^{13}C NMR (125 MHz, $CDCl_3$): δ 211.3, 167.4, 78.4, 75.1, 19.3, 15.5. IR: ν = 3501, 2997, 2943, 2903, 1753, 1717, 1614, 1448, 1437, 1390, 1369, 1351, 1327, 1302, 1257, 1224, 1197, 1113, 1079, 1066, 1036, 1013, 957, 884, 752, 729 cm^{-1}. $[\alpha]_D^{23}$ = -0.1 (*c* 0.56, $CHCl_3$). Melting point: 48-50 °C. Anal. Calc. for $C_6H_8O_3S$: C, 44.99; H, 5.03; N, 0.00. Found: C, 45.17; H, 5.02; N, 0.00.

Note B: During the purification **1** by column chromatography, a small quantity of dithionated product (Yield, 2%) **1b** can be isolated (eluent diethyl ether/hexane solvent mixture (25/75), R_f = 0.65). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 4.99 (q, $^3J_{HH}$ = 13.19, $^3J_{HH}$ = 6.31, 2H), 1.85 (d, $^3J_{HH}$ = 6.34, 6H). ^{13}C NMR (125 MHz, $CDCl_3$): δ 211.3, 81.2, 19.0. Melting point: 89-93 °C Recrystallization from a diethyl ether/hexane solvent mixture (50:50) at 0°C affords yellow crystals. See cif. file for single-crystal X-ray diffraction structure.

Compound 2. A pressure vessel (equipped with a sidearm and stir bar) was charged with **1** (1.40 g, 8.74 mmol) and freshly distilled cyclopentadiene (2.90 g, 43.72 mmol, 5 equiv) in 10 mL of anhydrous benzene and heated to 130 °C for 5 h. After cooling to room temperature, both solvent and excess cyclopentadiene were removed by reduced pressure and the residue passed through a silica gel column using a diethyl ether/hexane solvent mixture (5/95) as the eluent (R_f = 0.6). Compound **2** was isolated from its mixture of stereoisomers by recrystallization from boiling hexanes (thrice) to afford a white solid (0.50 g, Yield: 25%). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 6.60 (q, $^3J_{HH}$ = 5.71, $^3J_{HH}$ = 2.77, 1H), 5.93 (q, $^3J_{HH}$ = 5.62, $^3J_{HH}$ = 3.21, 1H), 4.71 (q, $^3J_{HH}$ = 13.99, $^3J_{HH}$ = 7.01, 1H), 4.21 (m, 2H), 3.16 (d, $^3J_{HH}$ = 1.72, 1H), 2.23 (d, $^3J_{HH}$ = 9.42, 1H), 1.91

(m, 1H), 1.56 (m, 6H). ^{13}C NMR (125 MHz, $CDCl_3$): δ 169.8, 143.2, 129.5, 102.1, 83.3, 71.9, 54.1, 52.7, 51.6, 19.7, 18.1. IR: ν = 2990, 2935, 1737, 1441, 1375, 1332, 1269, 1228, 1182, 1153, 1124, 1107, 1078, 1046, 1011, 980, 970, 958, 909, 884, 812, 798, 761, 733, 691 cm^{-1}. Melting point: 103-104 °C. Anal. Calc. for $C_{11}H_{14}O_3S$: C, 58.39; H, 6.24; N, 0.00. Found: C, 58.46; H, 6.11; N, 0.00.

Compound 3. Thia-Diels-Alder adduct **2** (20 mg, 0.0884 mmol) was added to 2 mL aq. NaOH solution (4 mg, 0.0972 mmol, 1.1 equiv) and stirred overnight at room temperature where it eventually dissolved. The solution was then filtered through a 0.2 μm syringe filter and the solvent removed to afford a white solid. ^{1}H NMR (500 MHz, D_2O): δ = 6.53 (q, $^3J_{HH}$ = 5.56, $^3J_{HH}$ = 2.65, 1H), 6.11 (q, $^3J_{HH}$ = 5.50, $^3J_{HH}$ = 3.33, 1H), 4.53 (q, $^3J_{HH}$ = 13.89, $^3J_{HH}$ = 6.95, 1H), 4.24 (s, 1H), 3.47 (d, $^3J_{HH}$ = 13.11, $^3J_{HH}$ = 6.56, 1H), 3.20 (s, 1H), 2.10 (d, $^3J_{HH}$ = 9.63, 1H), 1.86 (d, $^3J_{HH}$ = 9.68, 1H), 1.34 (m, 6H). ^{13}C NMR (125 MHz, $CDCl_3$): δ 182.5, 141.2, 132.5, 110.7, 77.0, 75.0, 55.6, 53.3, 50.7, 19.4, 18.2.

Poly-2a. A pressure vessel (equipped with a sidearm and stir bar) was charged with **2** (100 mg, 4.4 mmol) and the appropriate amount of Grubbs 2nd generation catalyst (Ru) in *ca.* 2 mL of anhydrous DCM. The reaction was quenched with butyl vinyl ether (10 equiv. wrt (Ru)) after consumption of the monomer was complete (as determined by ^{1}H NMR spectroscopy). **Poly-2a** was then precipitated upon dropwise addition of the reaction solution into cold (*ca.* 0 °C) methanol. After dissolving and precipitating the polymer in triplicate, the polymer was dried under vacuum for 24 h.

Poly-2a ($[2]_0/[Ru]_0$ = 100). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.36 (br s, 5H), 5.81 – 5.65 (br m, 217H), 4.70 (br s, 105H), 4.53 – 4.11 (br m, 221H), 3.15 – 2.84 (br m, 219H), 1.75 (br s, 107H), 1.55 – 1.42 (br m, 640H).

Poly-2a ($[2]_0/[Ru]_0$ = 200). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.36 (br, s, 5H), 5.81 – 5.65 (br m, 305H), 4.70 (br s, 145H), 4.53 – 4.11 (br m, 308H), 3.14 – 2.84 (br m, 305H), 1.75 (br, s, 149H), 1.55 – 1.41 (br, m, 1089H).

Poly-2a ($[2]_0/[Ru]_0$ = 400). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.36 (br s, 5H), 5.81 – 5.65 (br m, 325H), 4.70 (br s, 150H), 4.53 – 4.11 (br m, 325H), 3.15 – 2.83 (br, m, 323H), 1.75 (br s, 158H), 1.54 – 1.42 (br m, 1128H).

Poly-2a ($[2]_0/[Ru]_0$ = 800). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.36 (br. s, 5H), 5.81 – 5.66 (br m, 333H), 4.70 (br, s, 155H), 4.53 – 4.11 (br m, 338H), 3.15 – 2.84 (br m, 340H), 1.75 (br s, 163H), 1.54 – 1.42 (br m, 1203H)

Poly-2b. A solution of **poly-2a** ($[\mathbf{2}]_0/[Ru]_0$ = 100, 50 mg in 5 mL THF) was added to 5 mL of 1 M NaOH (aq) and stirred for 48 h at room temperature. The solution was concentrated under reduced pressure and dialyzed against a 3500 M_w cutoff in deionized water for 48 h under sink conditions. The solvent was removed by reduced pressure and the white solid dried under vacuum for 24 h (52 mg). ^{1}H NMR (500 MHz, D_2O): δ = 5.77 – 5.66 (br m, 2H), 4.389 (br s, 1H), 4.13 – 4.09 (br m, 1H), 3.85 (br s, 1H), 3.34 (br, s, 1H), 3.02 (br s, 1H), 2.17 (br s, 1H), 1.92 (br s, 1H), 1.44 – 1.28 (br m, 5H).

Pb^{2+}-Binding Experiments. A typical experiment was performed by adding 1 mL of **poly-2b** solution ([**poly-2b**] = *ca*. 0.1 mg/mL) to 2 mL of Pb^{2+} solution of an appropriate concentration. Results for the retention study described in Figure 2 were obtained by varying $[Pb^{2+}]_0$ between 10 and 200 ppm with the pH maintained at *ca*. 6 using a 0.5 M NaOH solution. Prior to centrifugation, reaction mixtures were allowed to stir for 24 h at room temperature until the equilibrium state was achieved. The solution was then centrifuged (3000 rpm for 60 min) through an Amicon Ultra - 4 centrifugal filter with a regenerated cellulose membrane (MWCO = 3 kDa) and the filtrate analyzed for Pb^{2+} using atomic absorption spectroscopy. A calibration curve for Pb^{2+} was obtained by preparing five different known concentrations (1, 5, 10, 15, 20 ppm) in DI water prior to every Pb^{2+}-binding experiment.

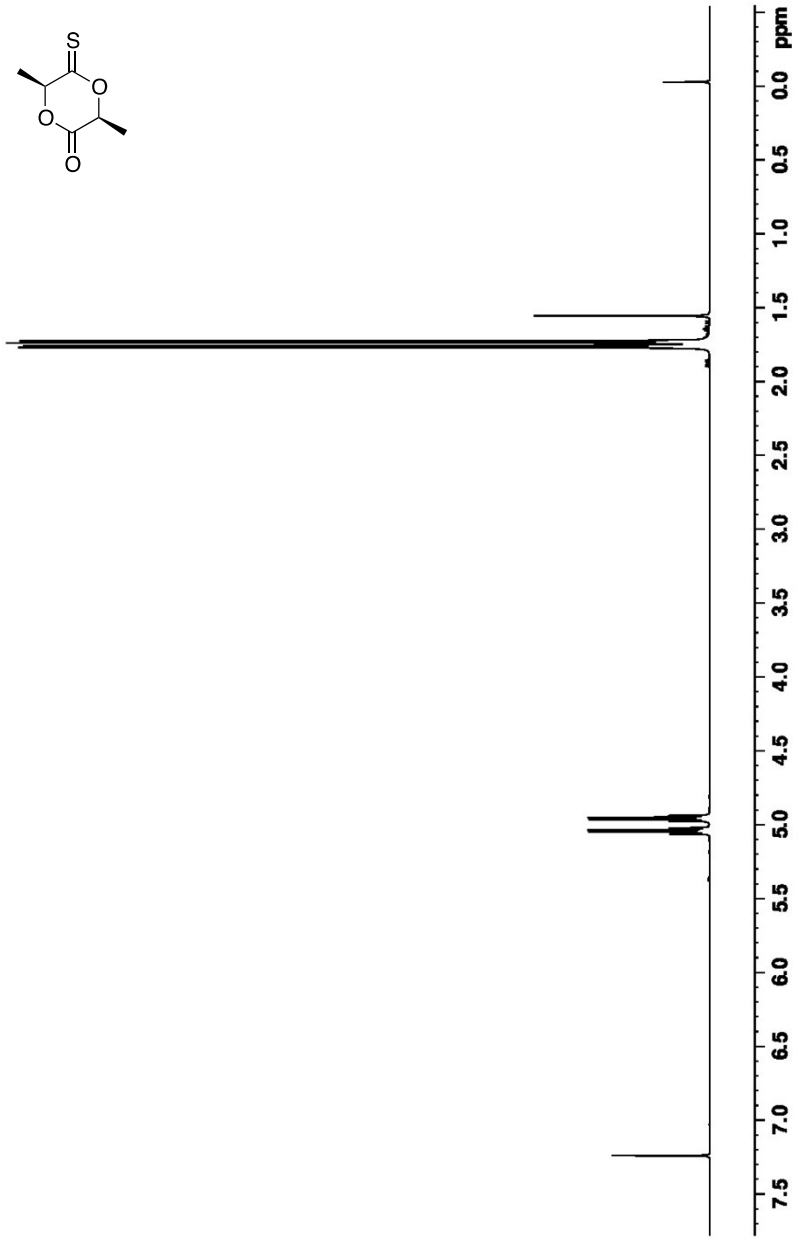

Figure S 1. ^{1}H NMR spectrum of **1** (500 MHz, $CDCl_3$).

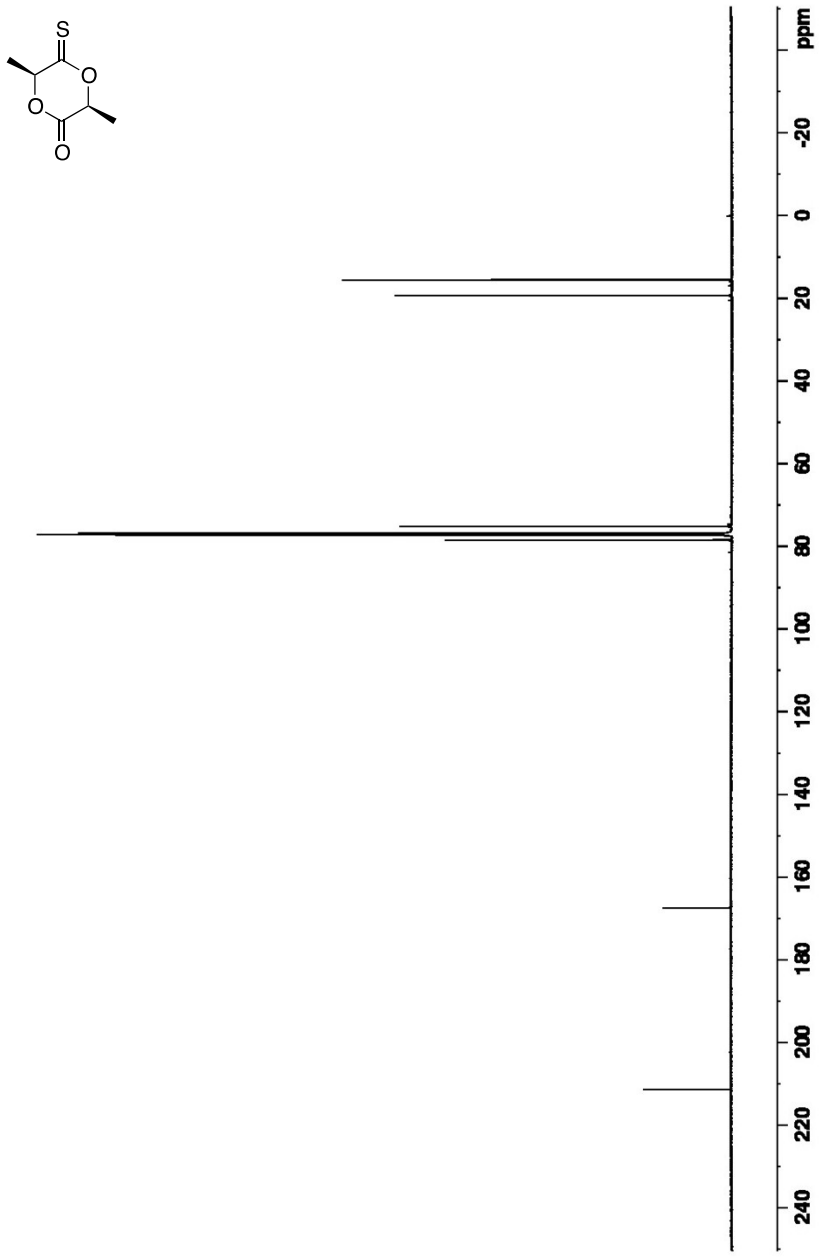

Figure S 2. ^{13}C NMR spectrum of **1** (125 MHz, $CDCl_3$).

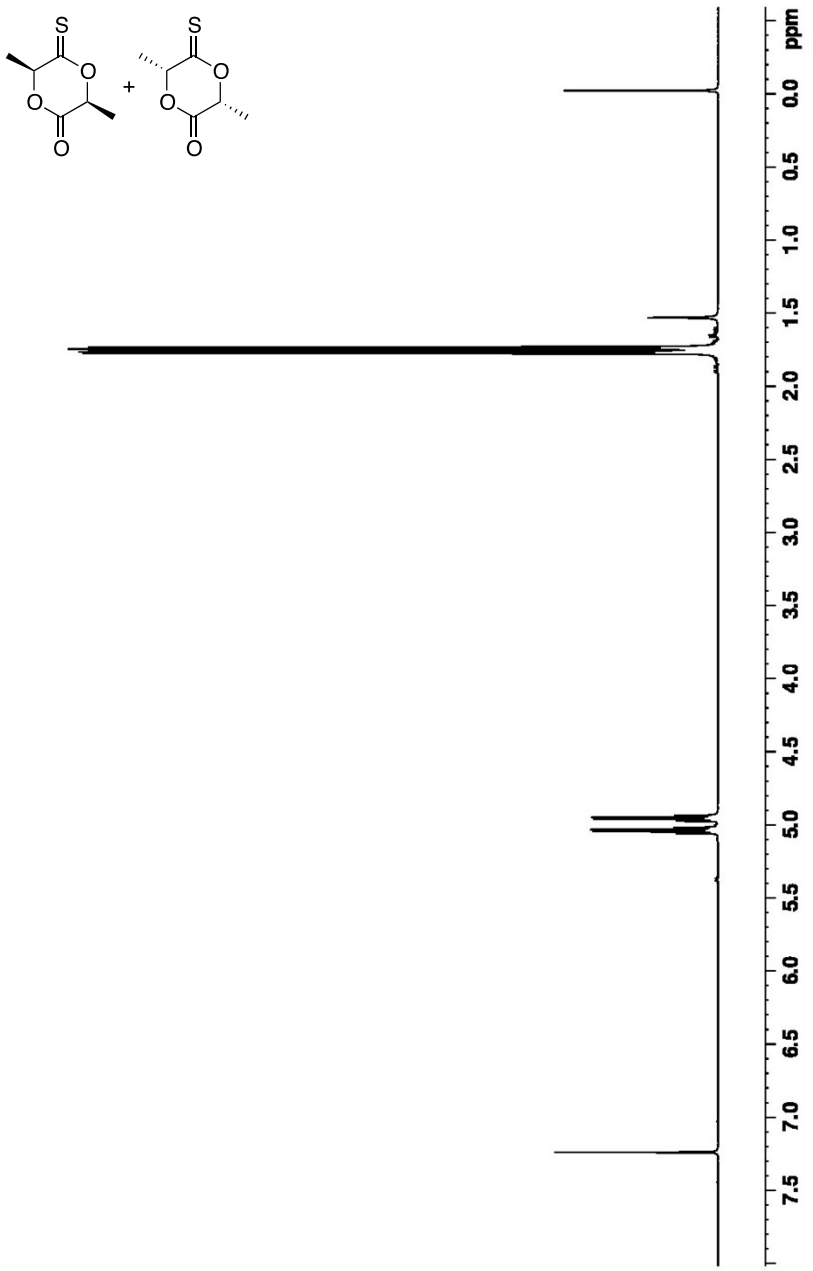

Figure S 3. ^{1}H NMR spectrum of racemic **1** (500 MHz, $CDCl_3$).

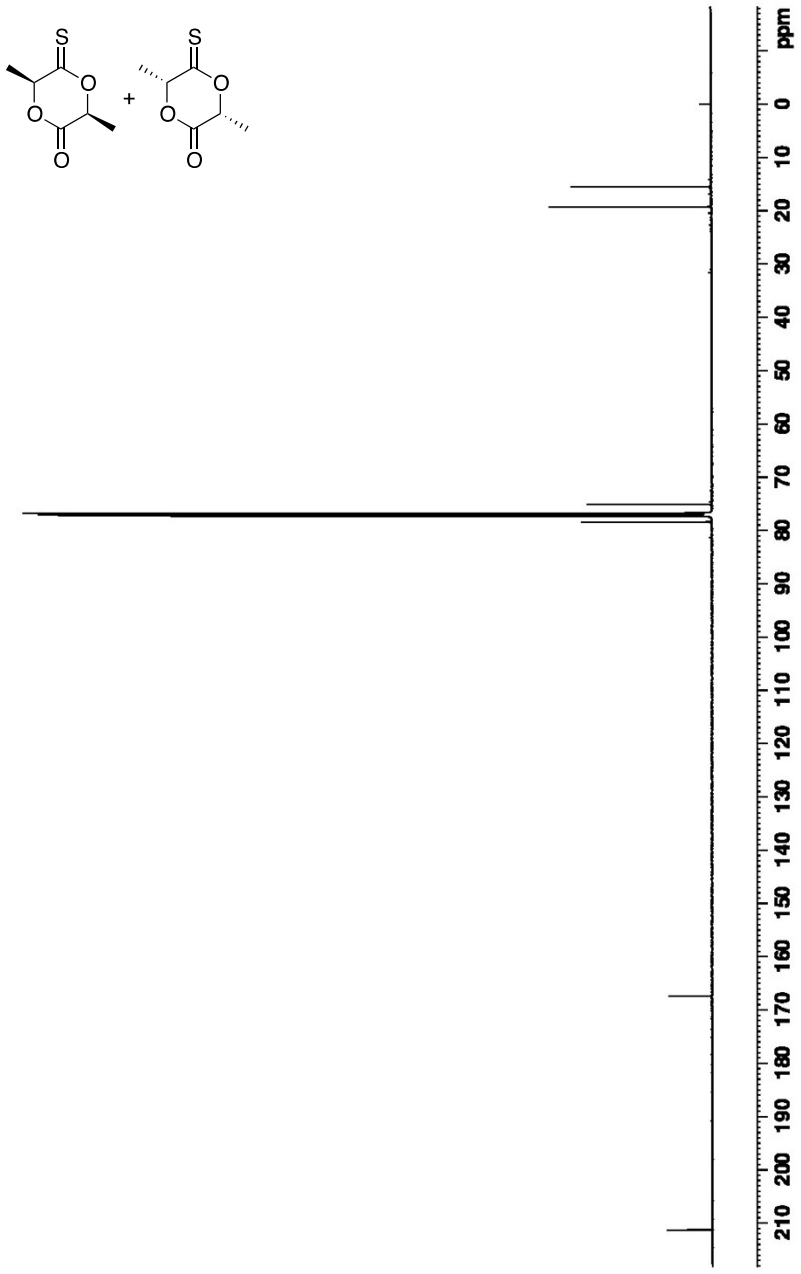

Figure S 4. ^{13}C NMR spectrum of racemic **1** (125 MHz, $CDCl_3$).

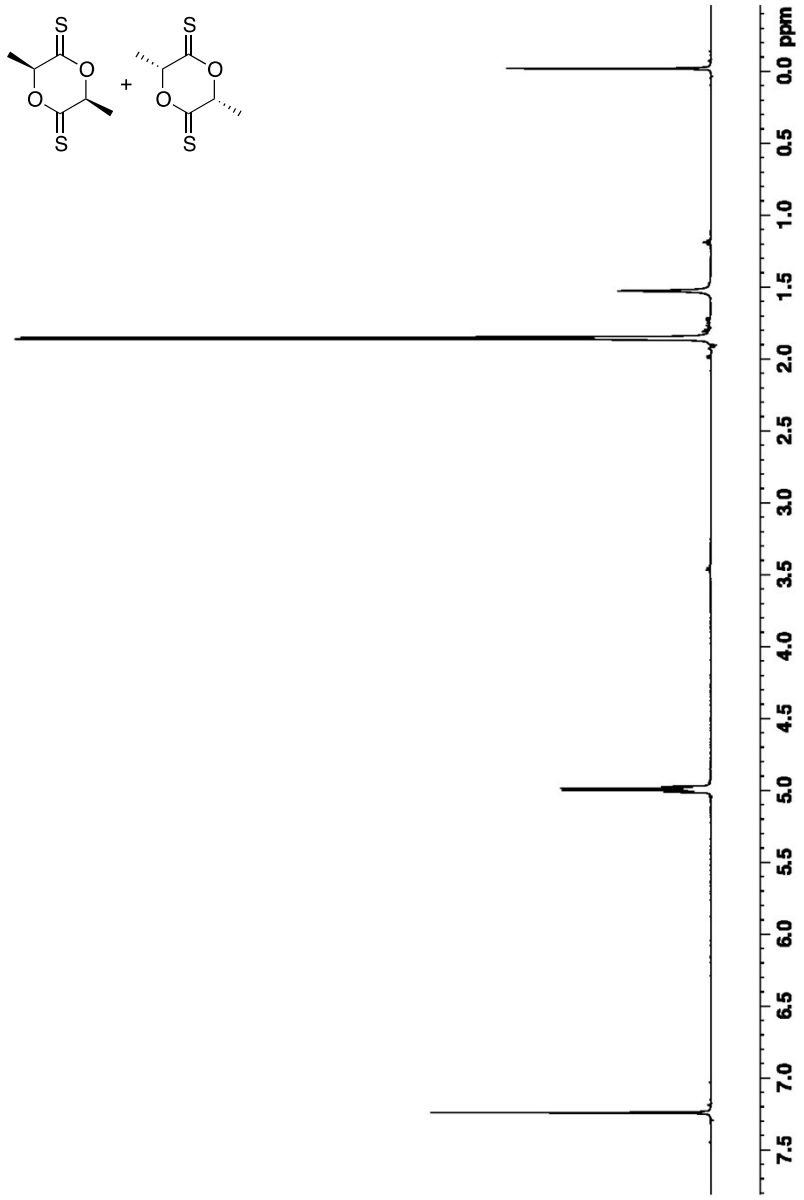

Figure S 5. ^{1}H NMR spectrum of racemic dithionated lactide **1b** (500 MHz, $CDCl_3$).

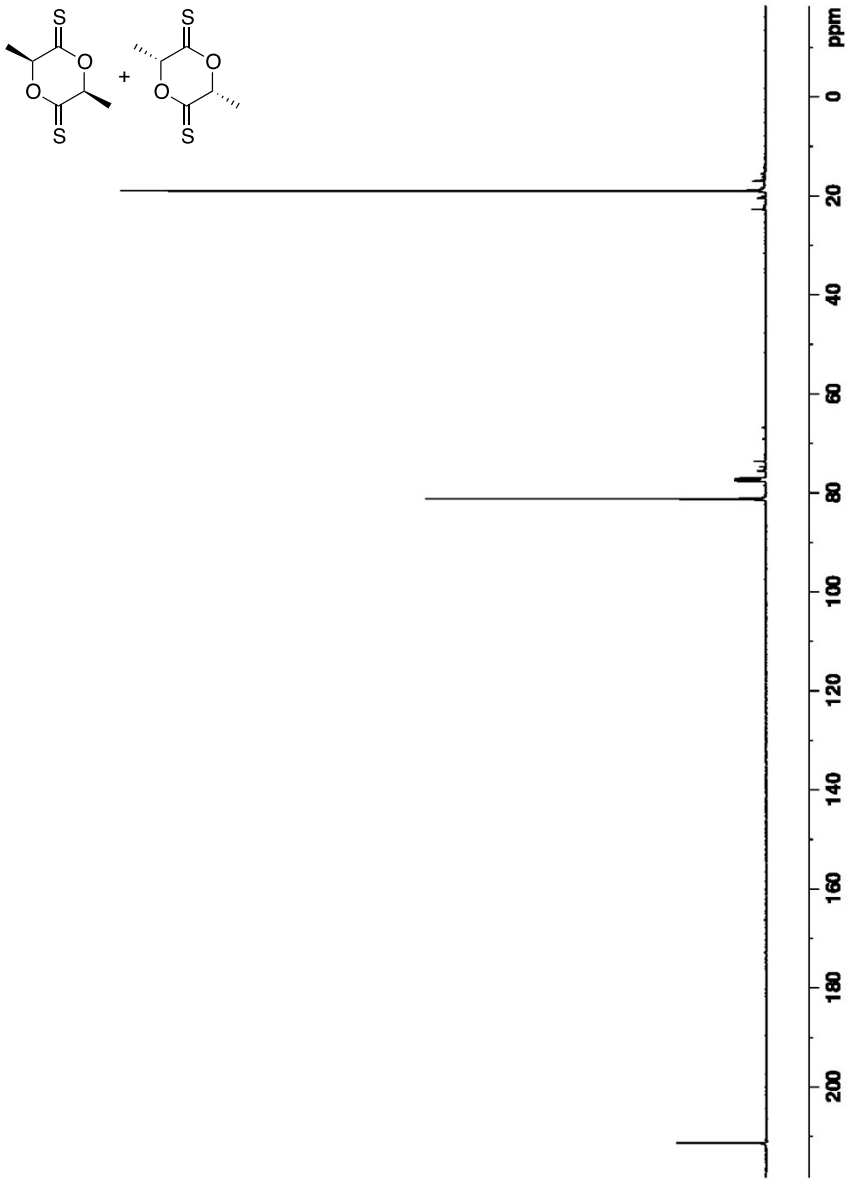

Figure S 6. ^{13}C NMR spectrum of racemic dithionated lactide **1b** (125 MHz, $CDCl_3$).

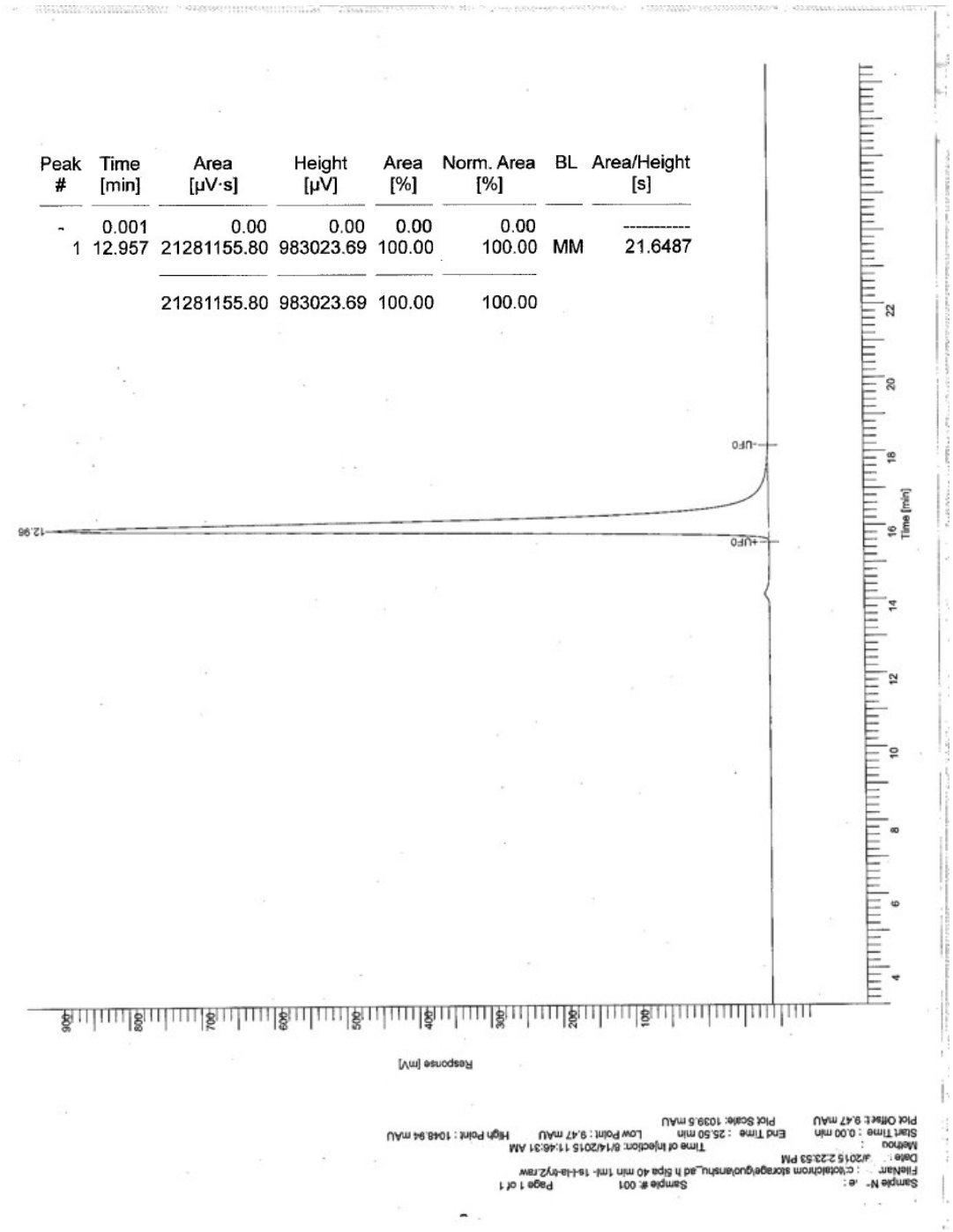

Figure S 7. Chiral phase HPLC chromatogram of **1**.

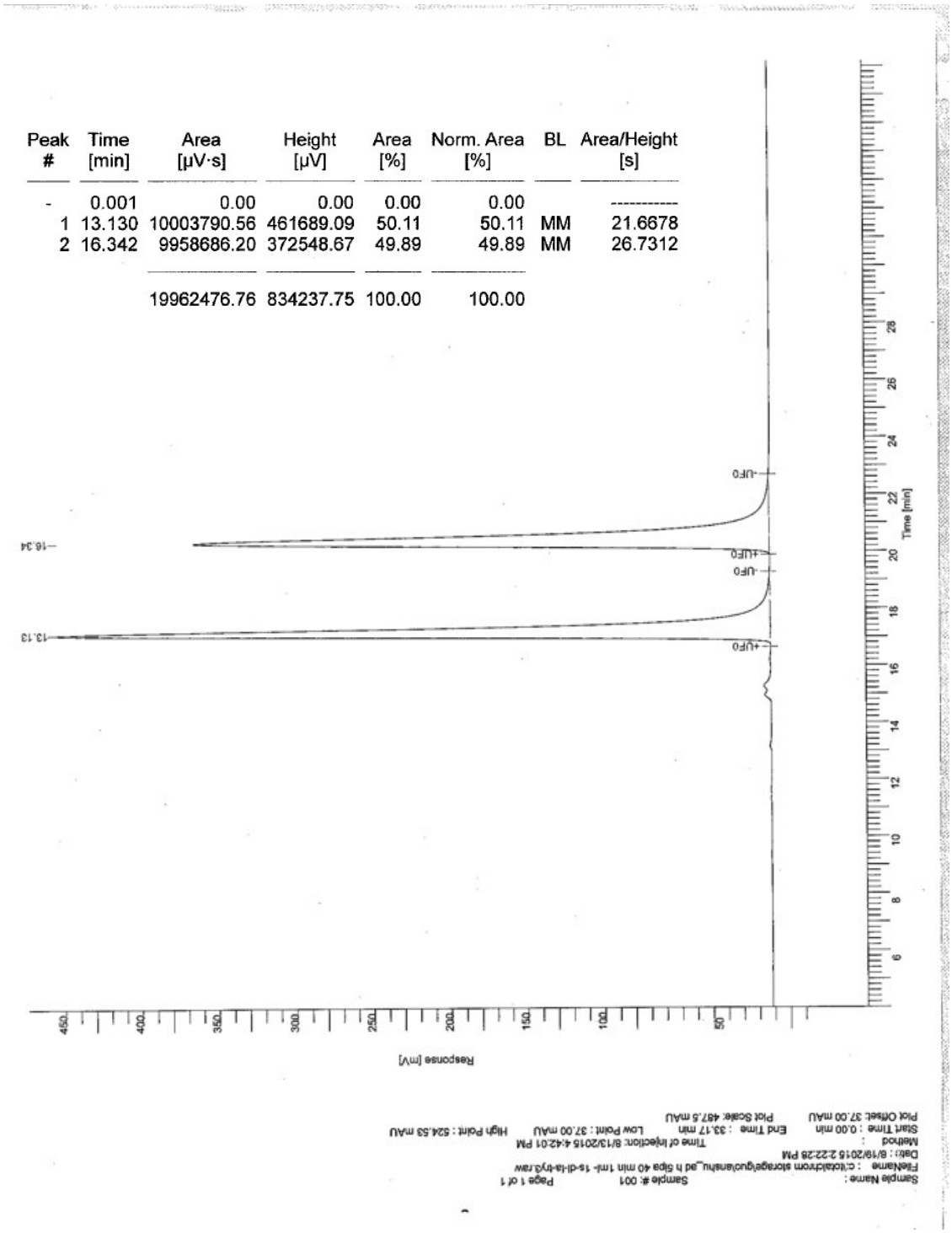

Figure S 8. Chiral phase HPLC chromatogram of **1** prepared from D,L-LA.

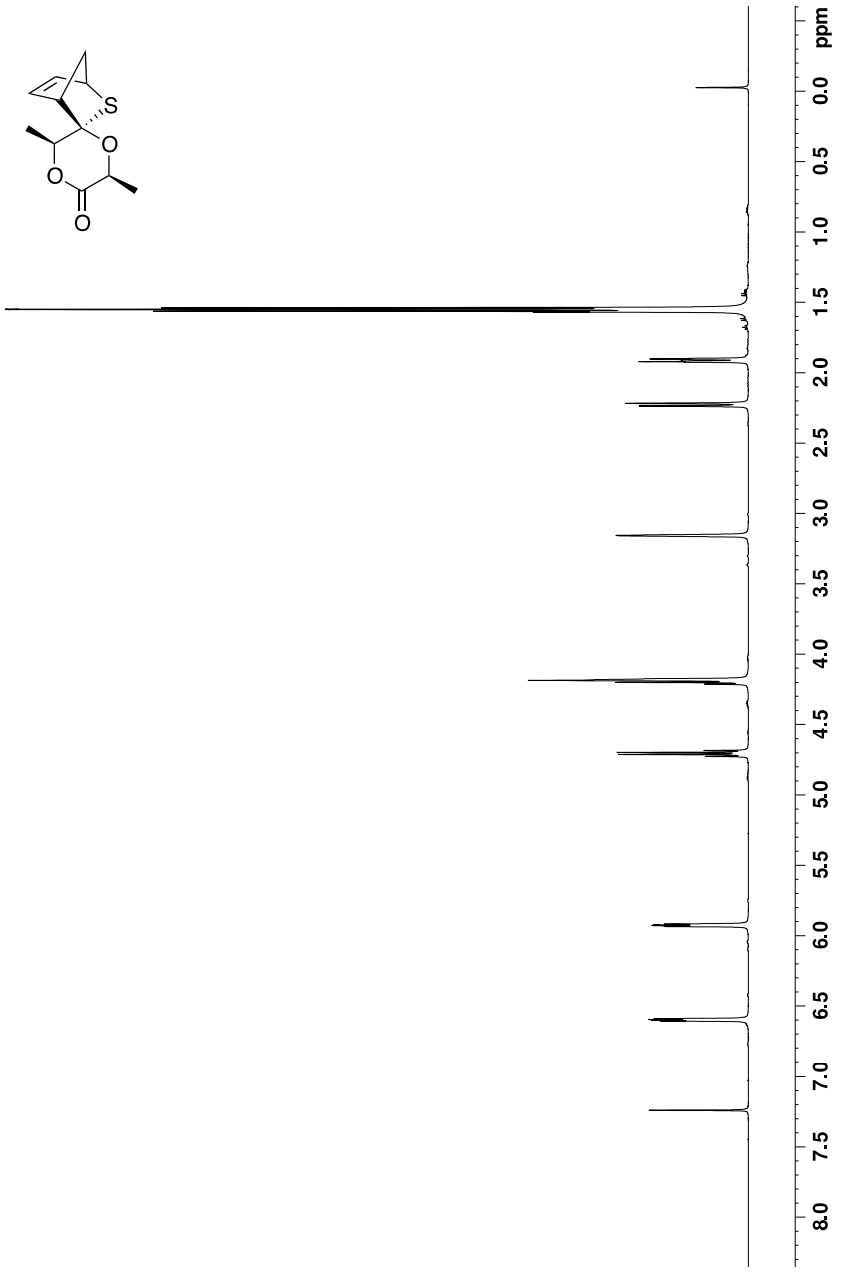

Figure S 9. ^{1}H NMR spectrum of **2** (500 MHz, $CDCl_3$).

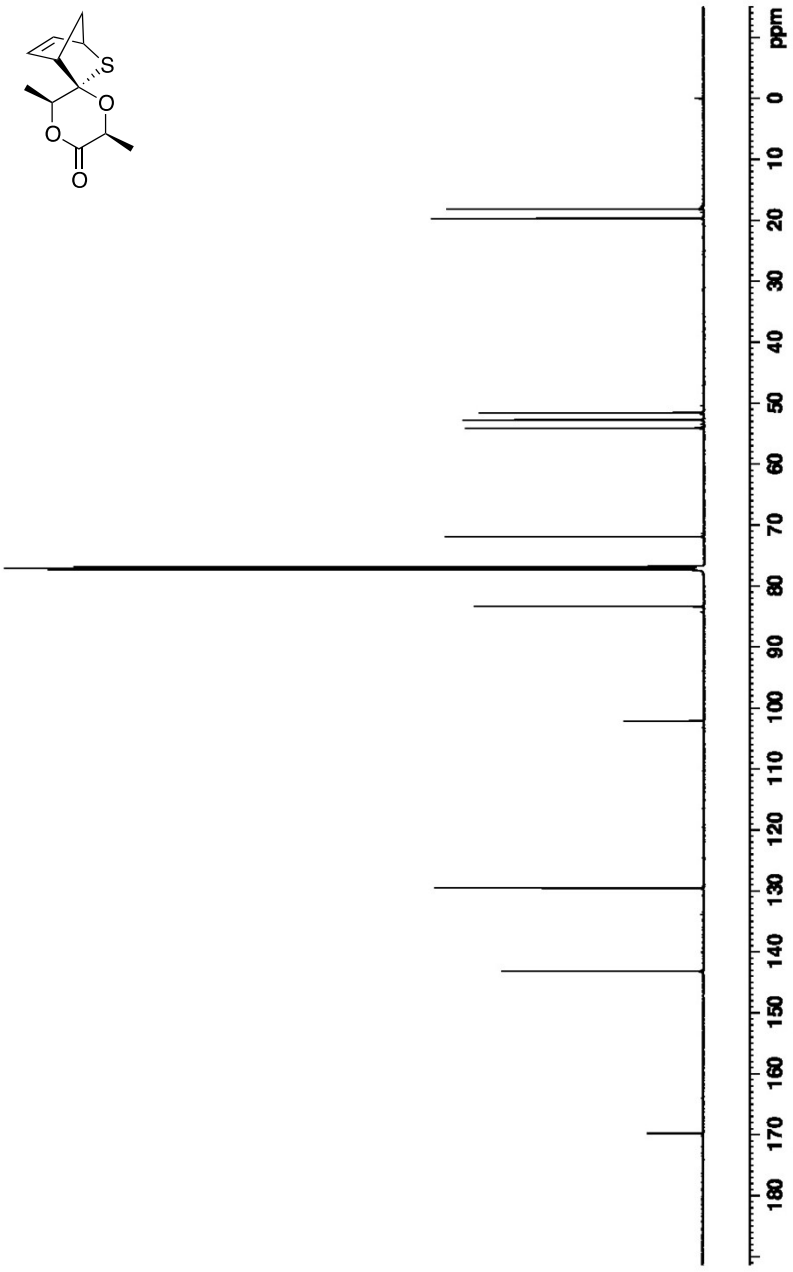

Figure S 10. ^{13}C NMR spectrum of **2** (125 MHz, $CDCl_3$).

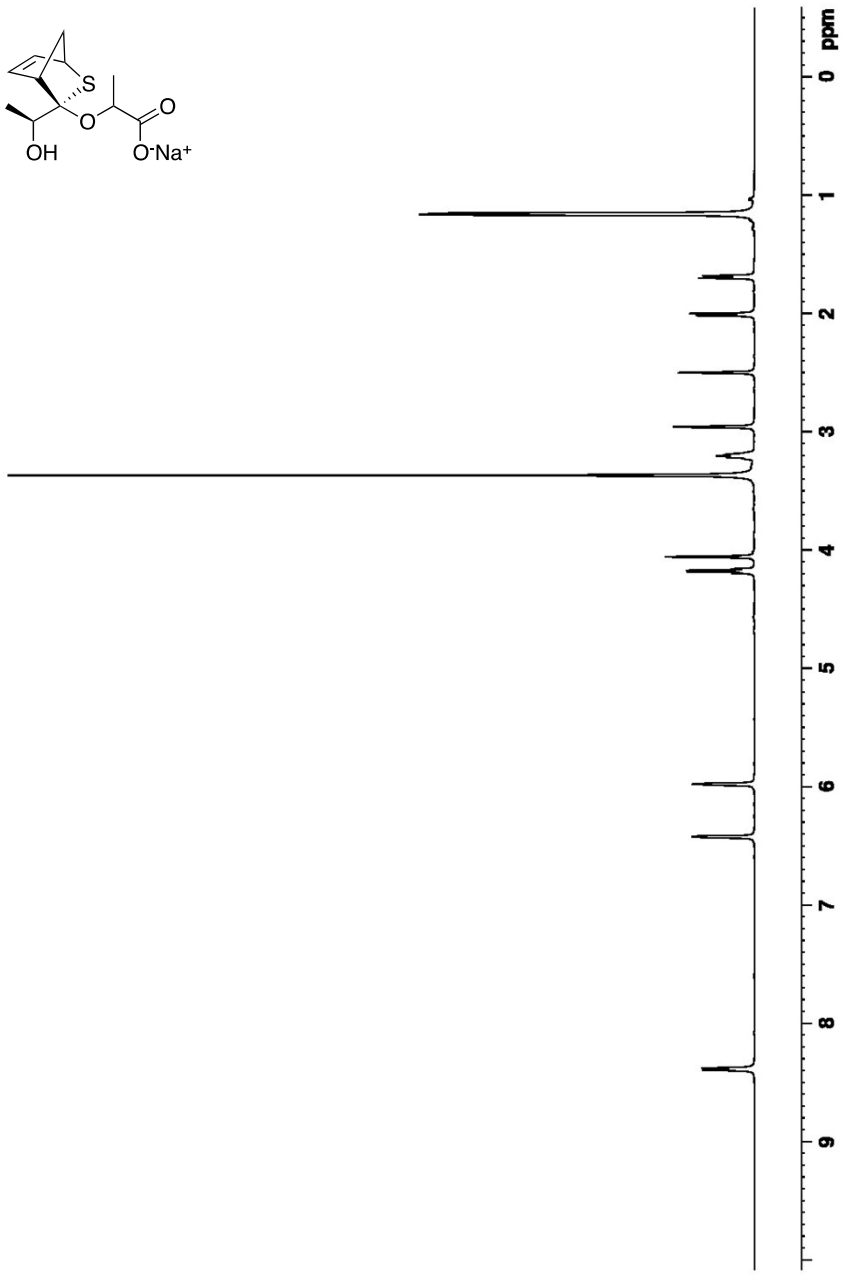

Figure S 11. ^{1}H NMR spectrum of **3** (500 MHz, DMSO-d_6).

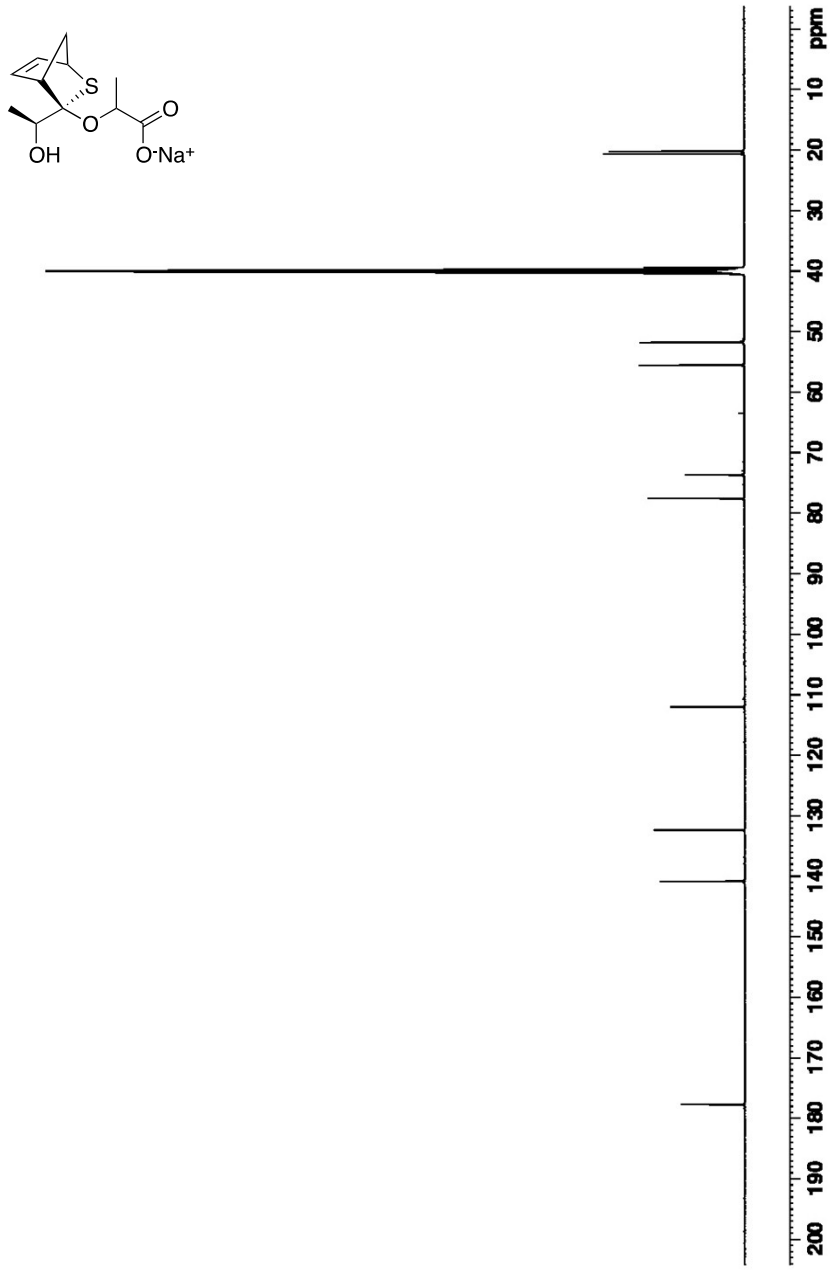

Figure S 12. ^{13}C NMR spectrum of **3** (125 MHz, DMSO-d_6).

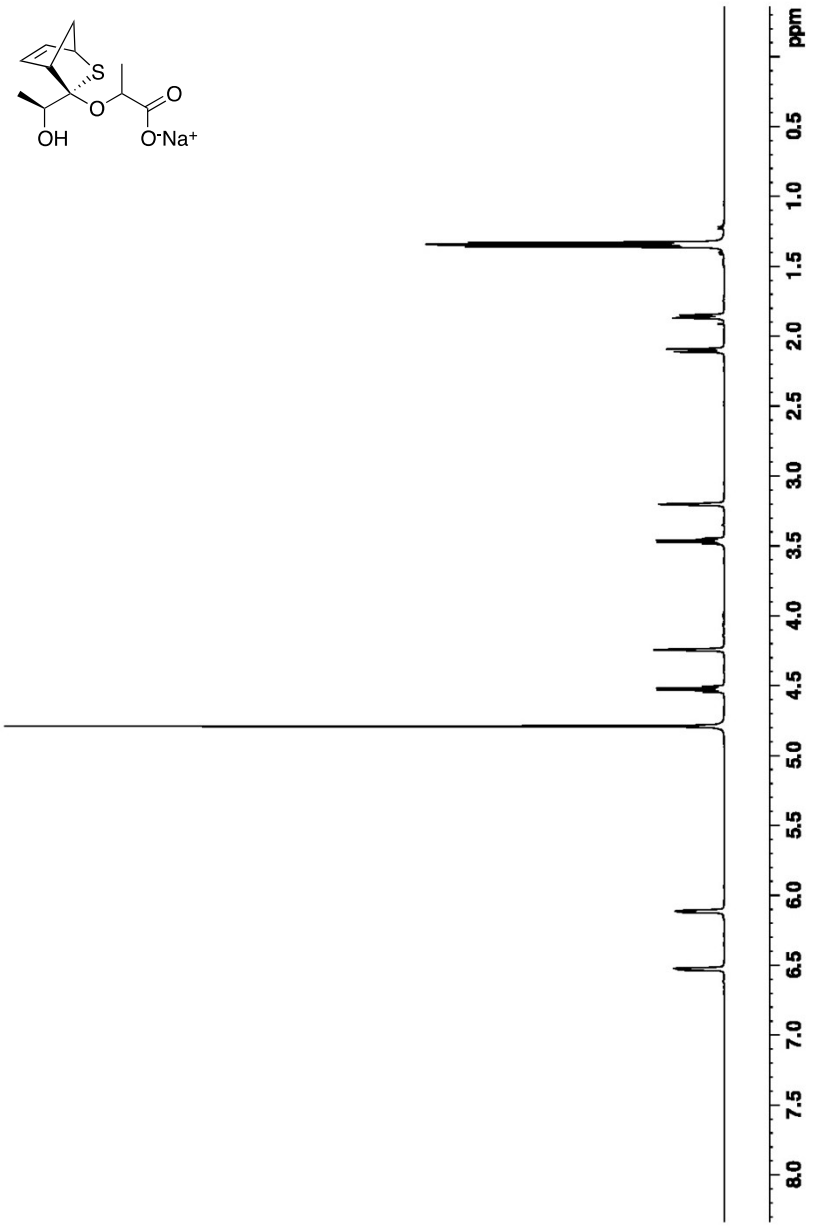

Figure S 13. ^{1}H NMR spectrum of **3** (500 MHz, D_2O).

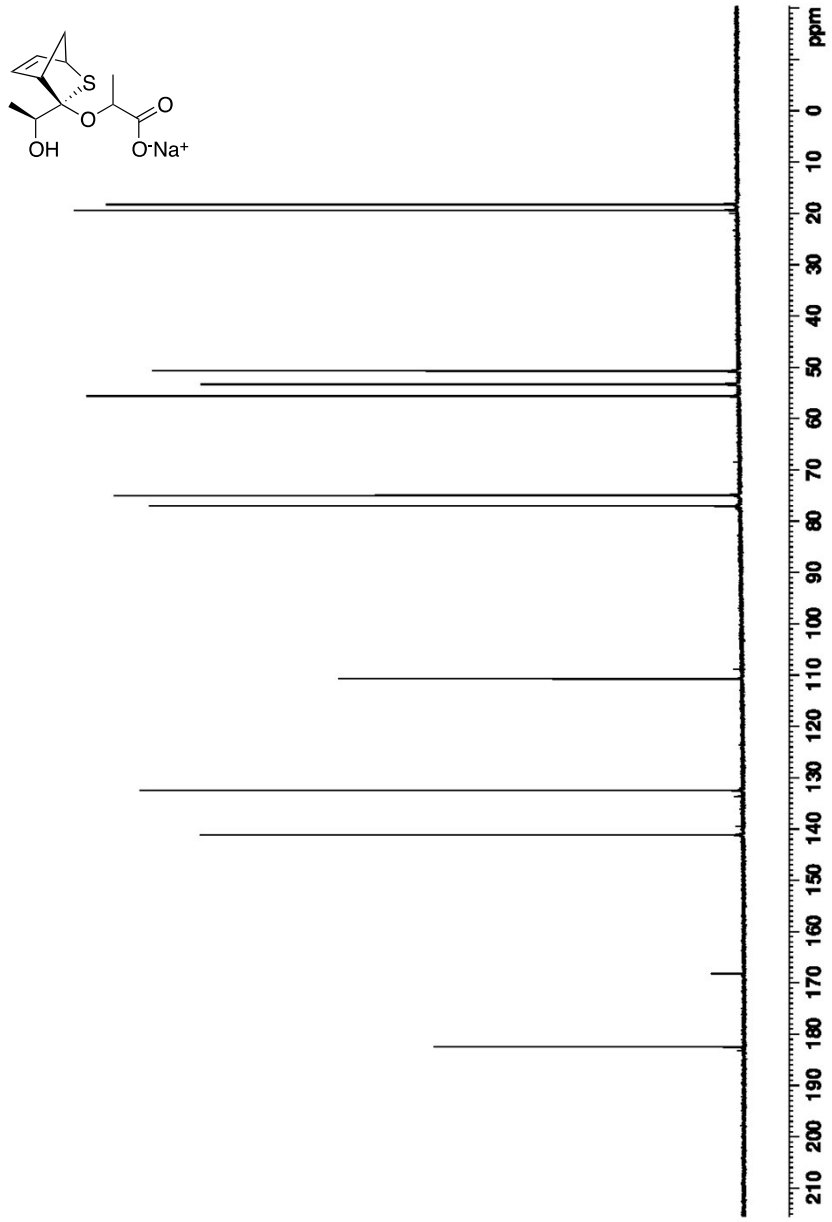

Figure S 14. ^{13}C NMR spectrum of **3** (125 MHz, D_2O).

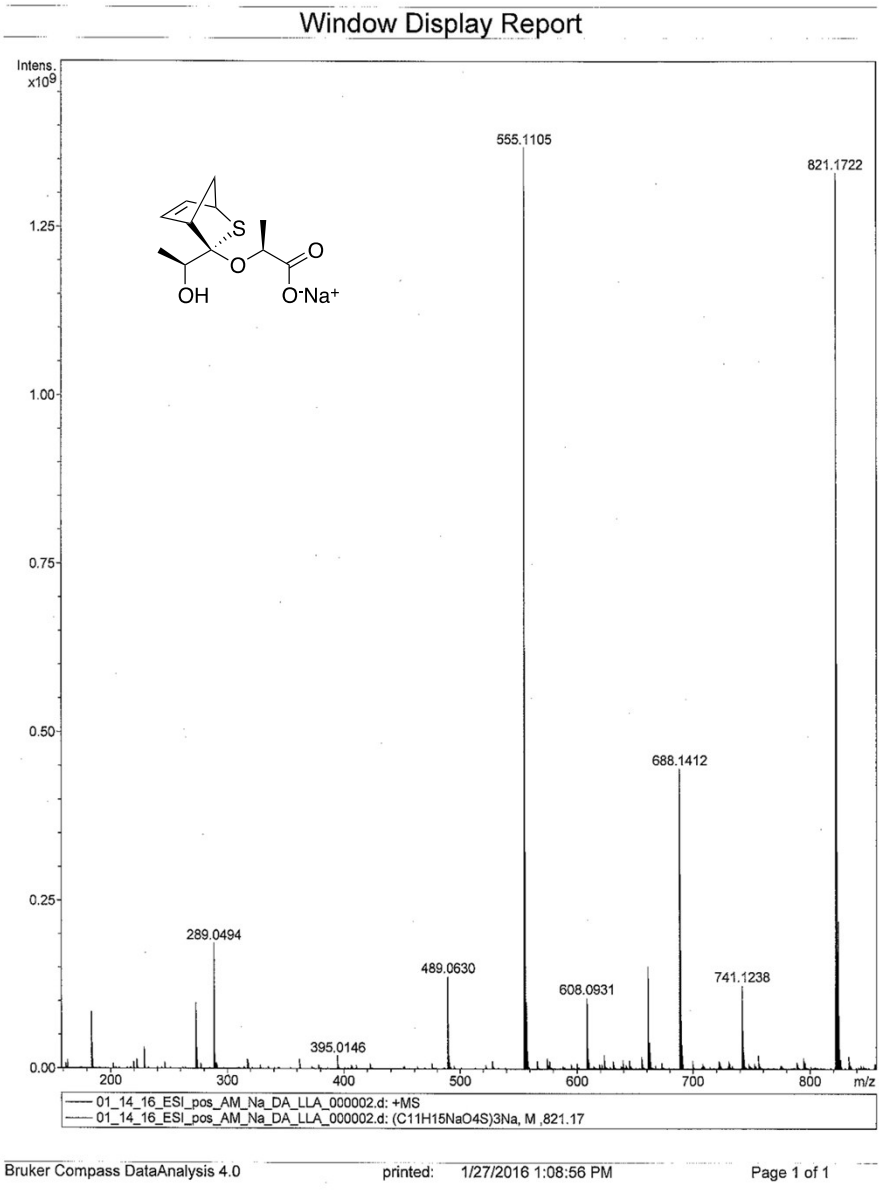

Figure S 15. High-resolution electrospray ionization mass spectrum of **3**.

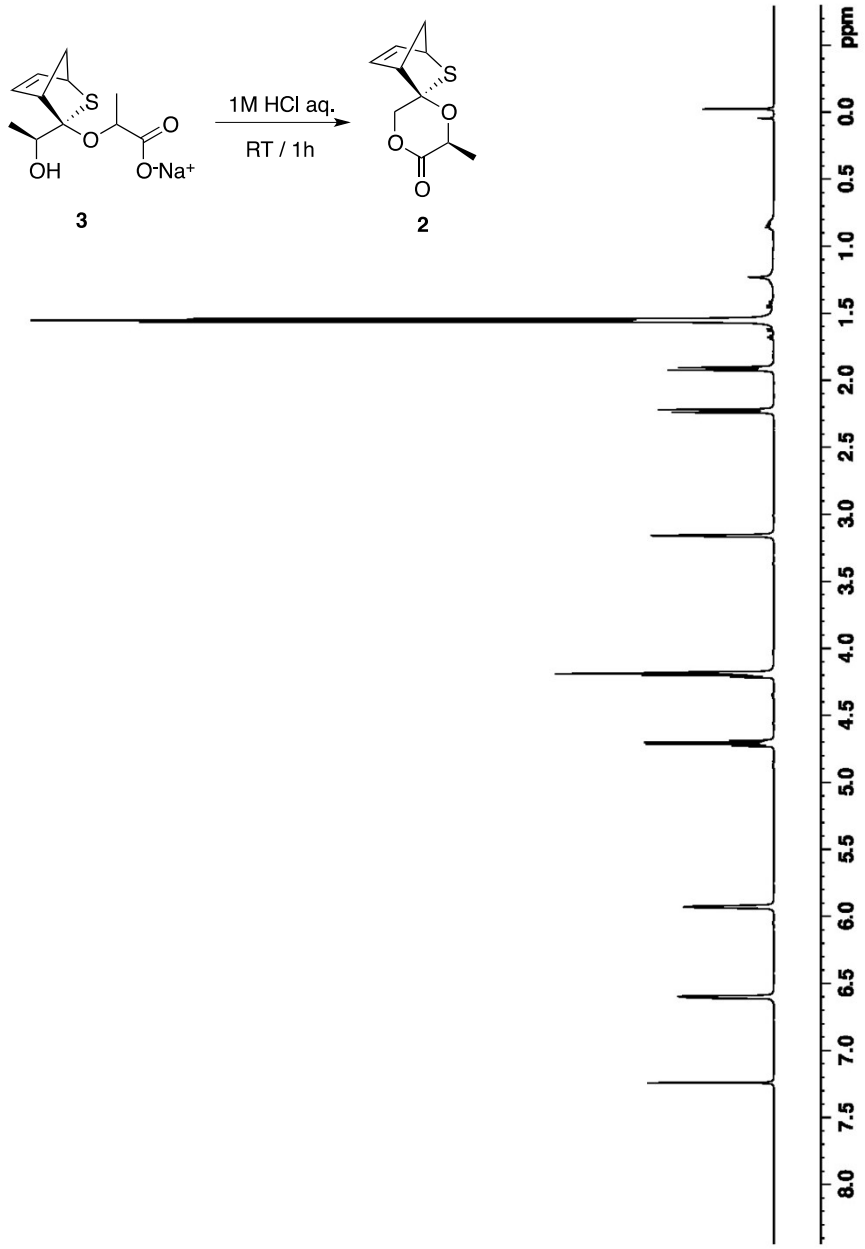

Figure S 16. ^{1}H NMR spectrum of **2** prepared from the cyclization of **3** (500 MHz, $CDCl_3$).

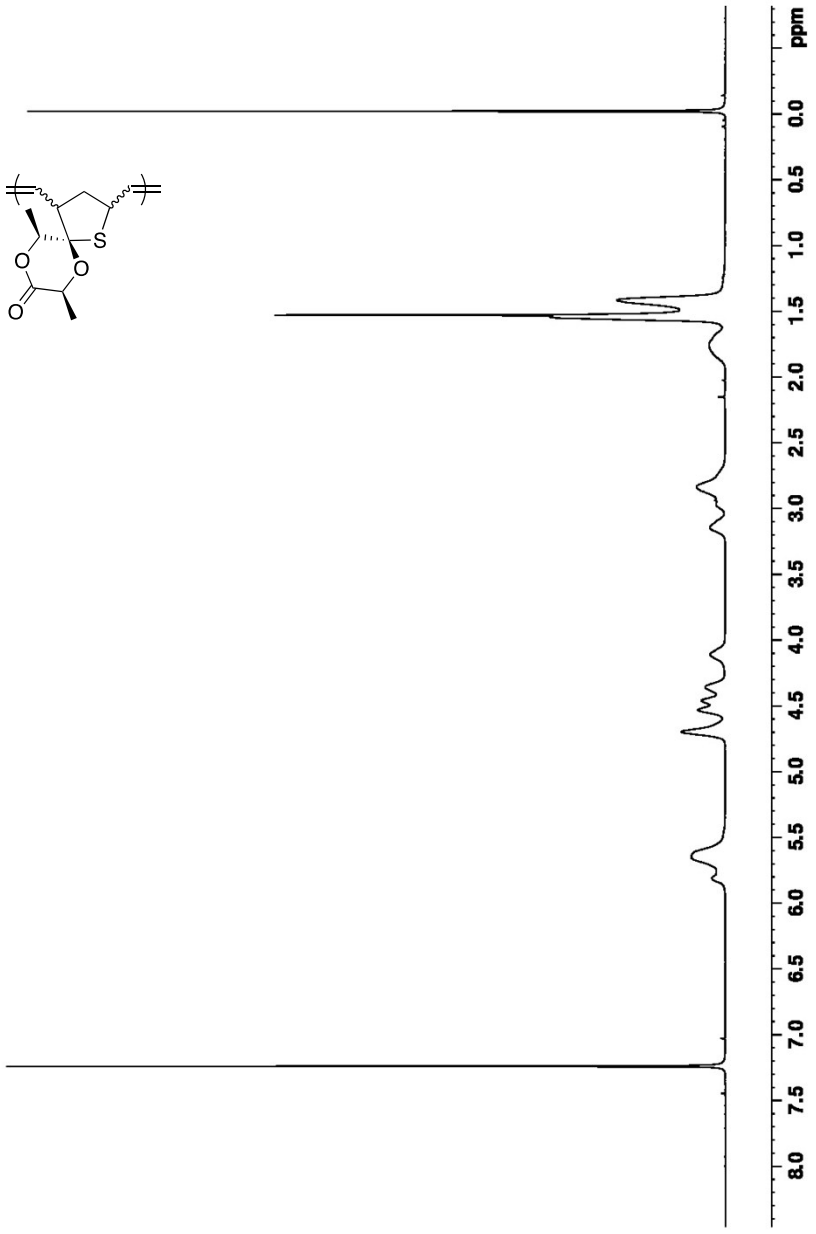

Figure S 17. ^{1}H NMR spectrum of **poly-2a** ($[\mathbf{2}]_0/[\mathrm{Ru}]_0 = 100$, 500 MHz, $CDCl_3$).

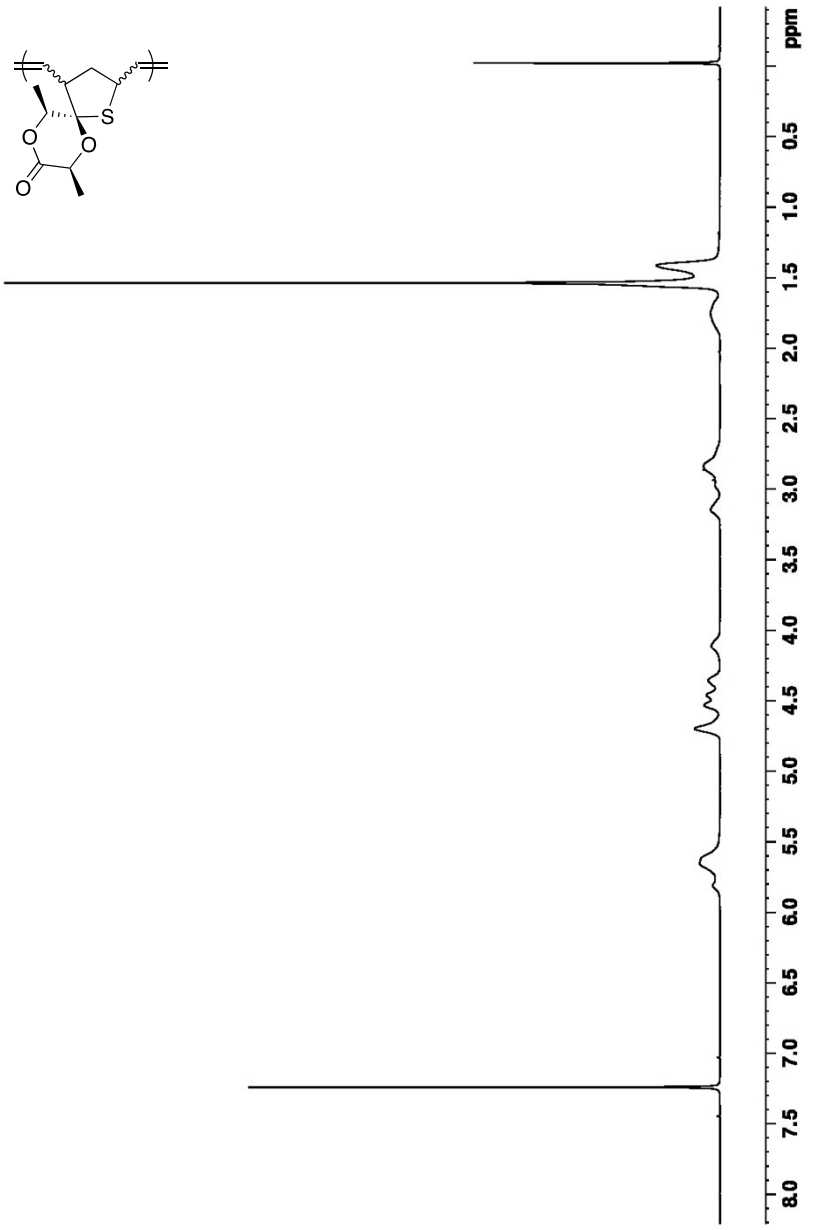

Figure S 18. ^{1}H NMR spectrum of **poly-2a** ($[\mathbf{2}]_0/[\mathrm{Ru}]_0 = 200$, 500 MHz, $CDCl_3$).

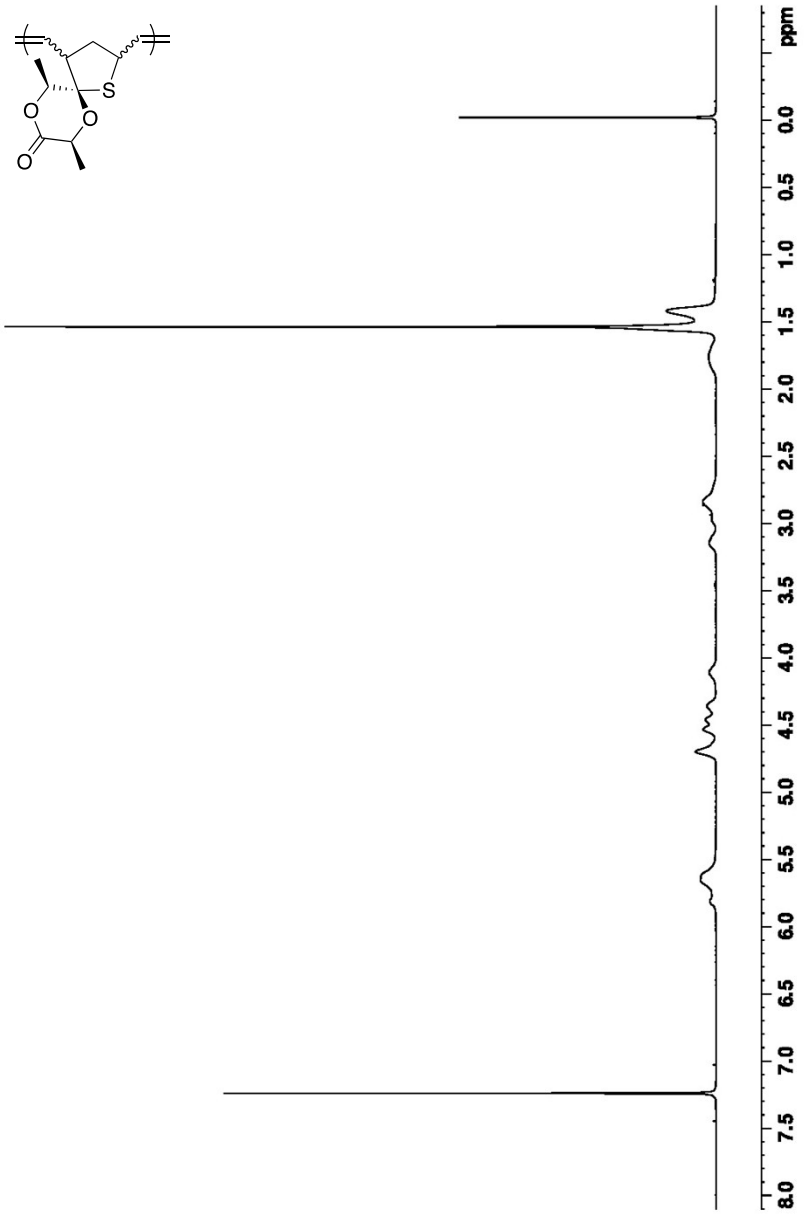

Figure S 19. ^{1}H NMR spectrum of **poly-2a** ($[\mathbf{2}]_0/[\mathrm{Ru}]_0 = 400$, 500 MHz, $CDCl_3$).

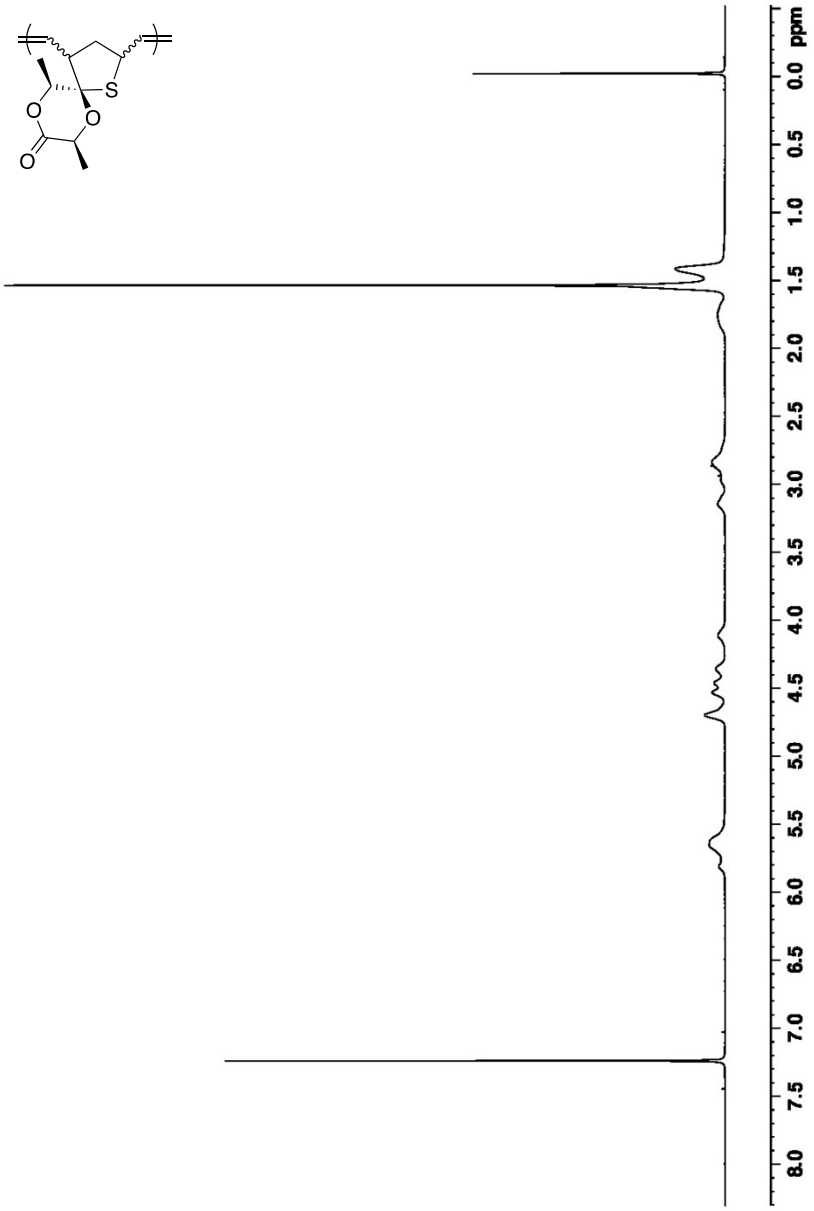

Figure S 20. ^{1}H NMR spectrum of **poly-2a** ($[\mathbf{2}]_0/[\mathrm{Ru}]_0 = 800$, 500 MHz, $CDCl_3$).

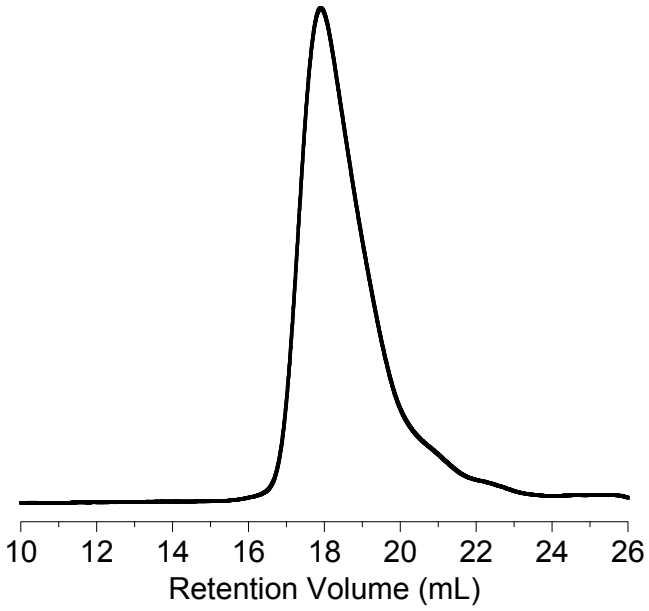

Figure S 21. GPC trace of **poly-2a** ($[\mathbf{2}]_0/[\mathrm{Ru}]_0 = 100$).

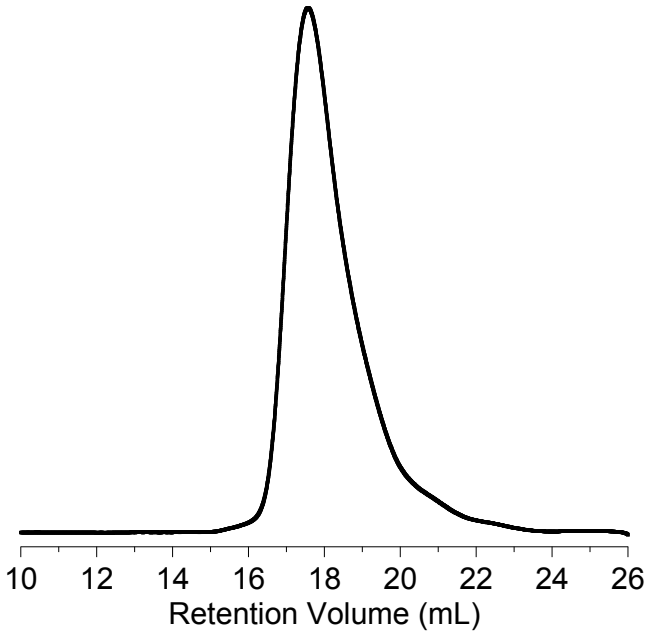

Figure S 22. GPC trace of **poly-2a** ($[\mathbf{2}]_0/[\mathrm{Ru}]_0 = 200$).

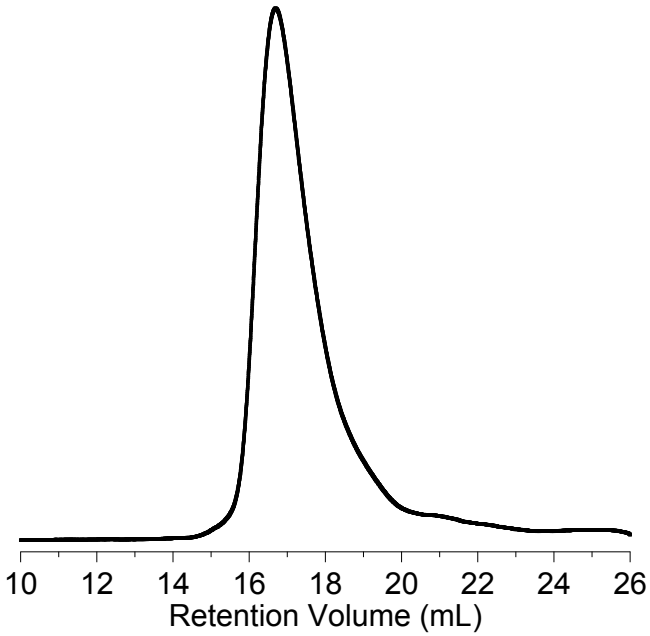

Figure S 23. GPC trace of **poly-2a** ($[\mathbf{2}]_0/[\mathrm{Ru}]_0 = 400$).

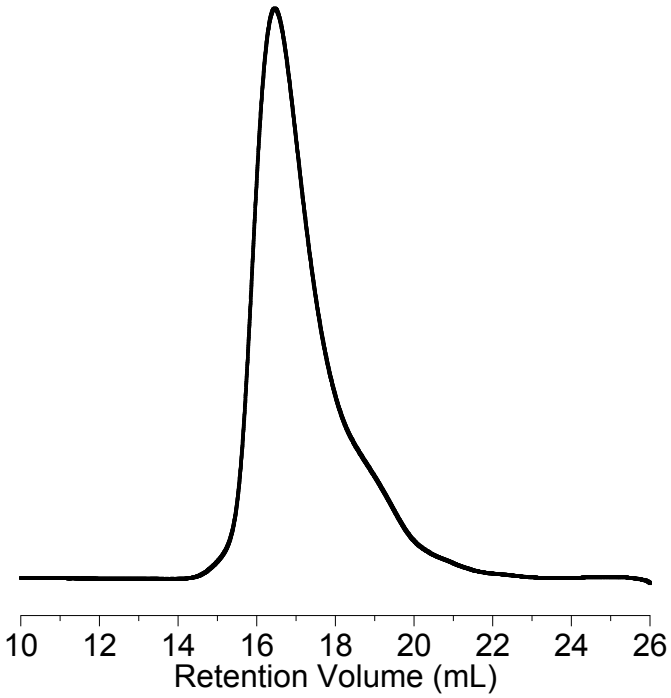

Figure S 24. GPC trace of **poly-2a** ($[\mathbf{2}]_0/[\mathrm{Ru}]_0 = 800$).

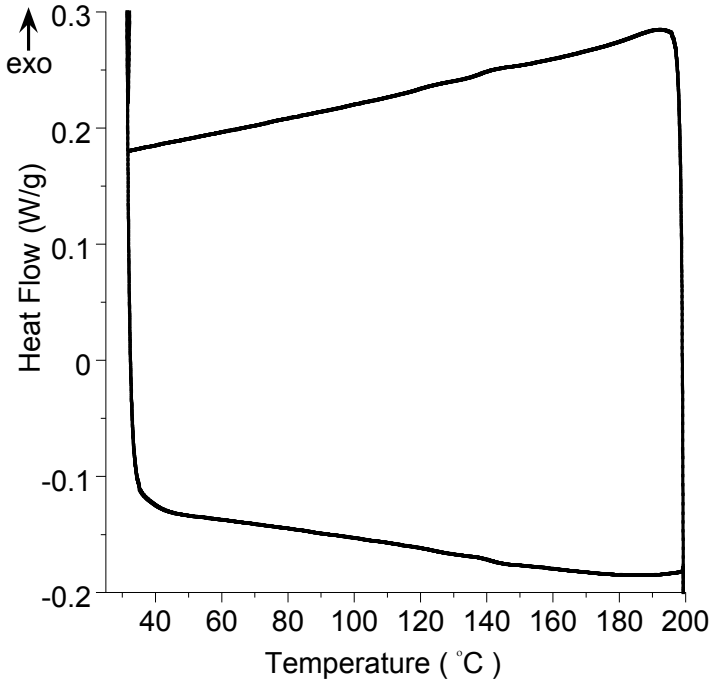

Figure S 25. DSC trace of **poly-2a** ($[\mathbf{2}]_0/[Ru]_0 = 100$). Second scan, ramp rate: 10 °C/min.

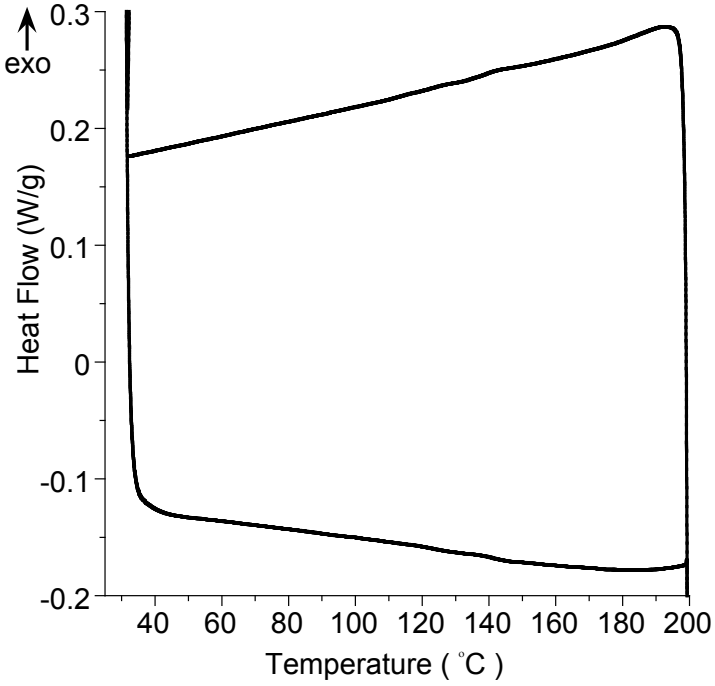

Figure S 26. DSC trace of **poly-2a** ($[\mathbf{2}]_0/[Ru]_0 = 200$). Second scan, ramp rate: 10 °C/min.

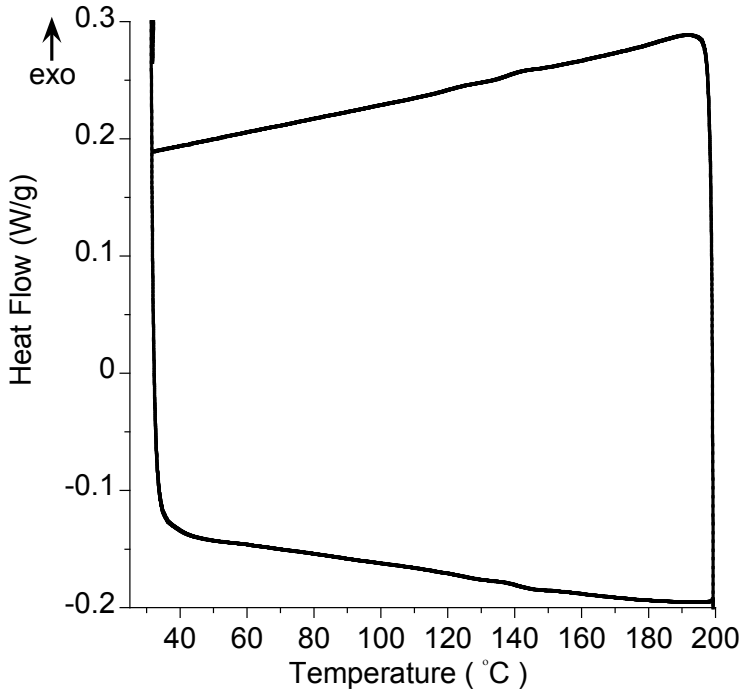

Figure S 27. DSC trace of **poly-2a** ($[\mathbf{2}]_0/[Ru]_0 = 400$). Second scan, ramp rate: 10 °C/min.

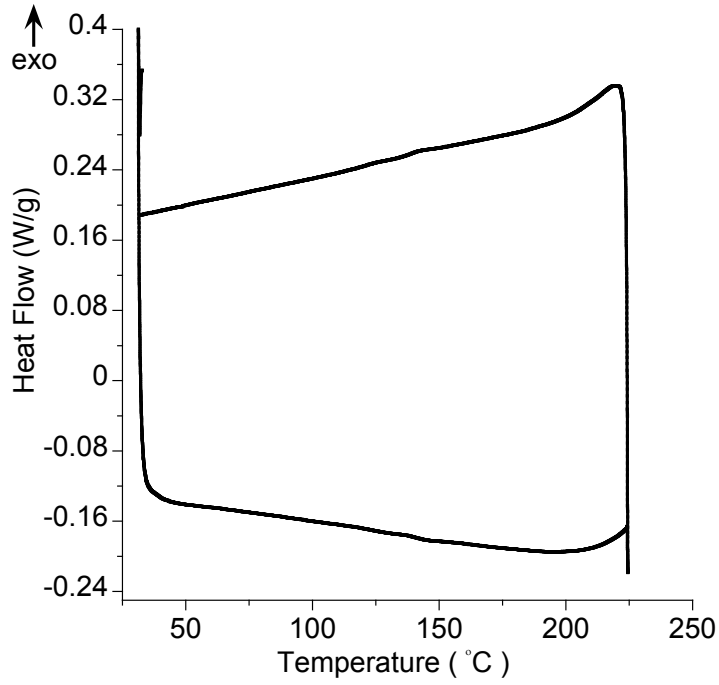

Figure S 28. DSC trace of **poly-2a** ($[\mathbf{2}]_0/[Ru]_0 = 800$). Second scan, ramp rate: 10 °C/min.

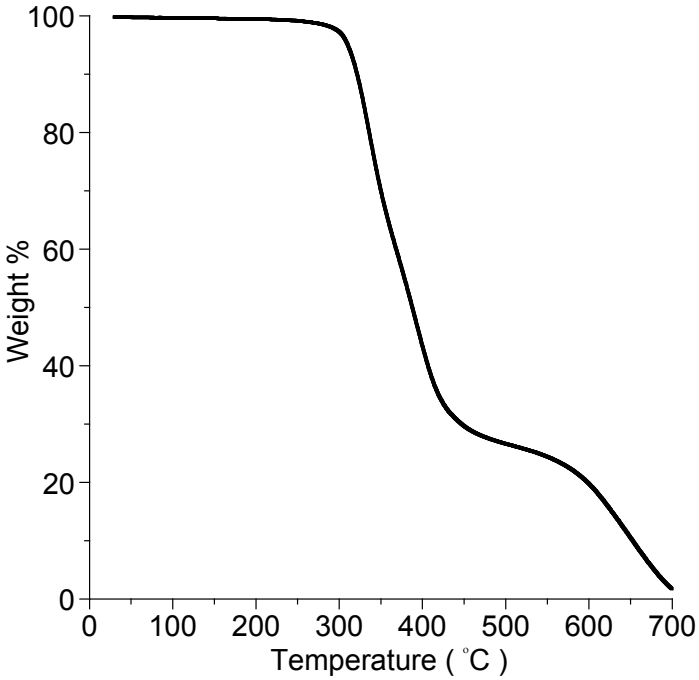

Figure S 29. TGA thermogram of **poly-2a** ($[\mathbf{2}]_0/[Ru]_0 = 100$).

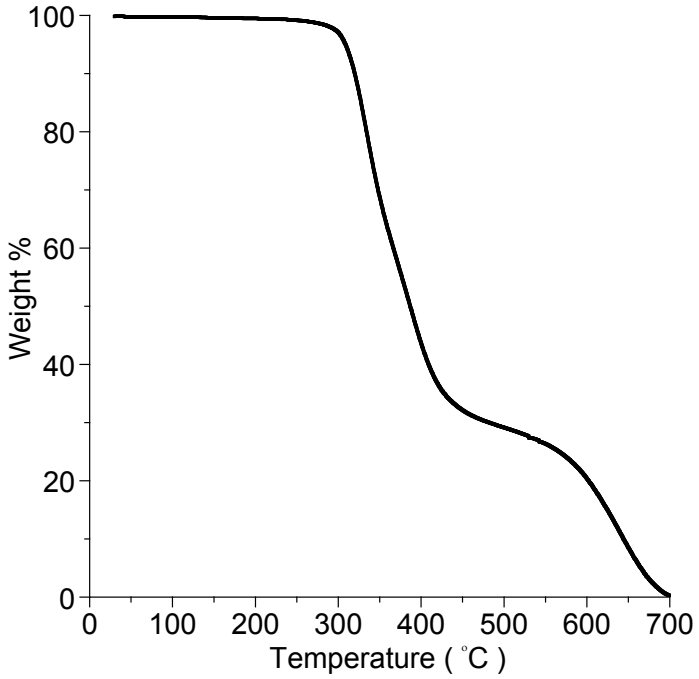

Figure S 30. TGA thermogram of **poly-2a** ($[\mathbf{2}]_0/[Ru]_0 = 200$).

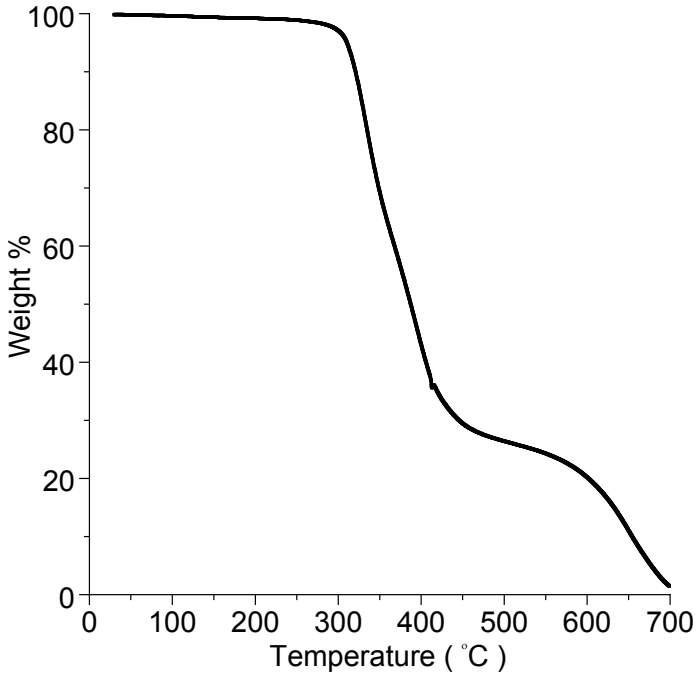

Figure S 31. TGA thermogram of **poly-2a** ($[\mathbf{2}]_0/[Ru]_0 = 400$).

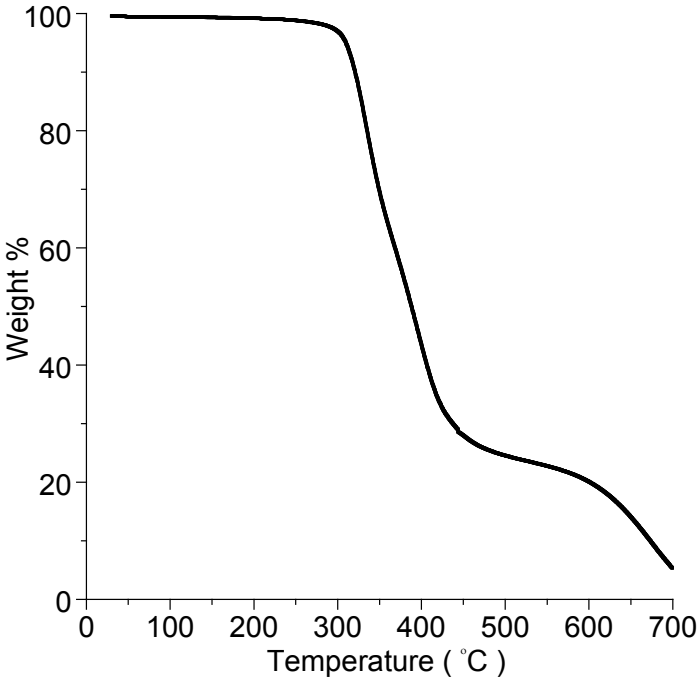

Figure S 32. TGA thermogram of **poly-2a** ($[\mathbf{2}]_0/[Ru]_0 = 800$).

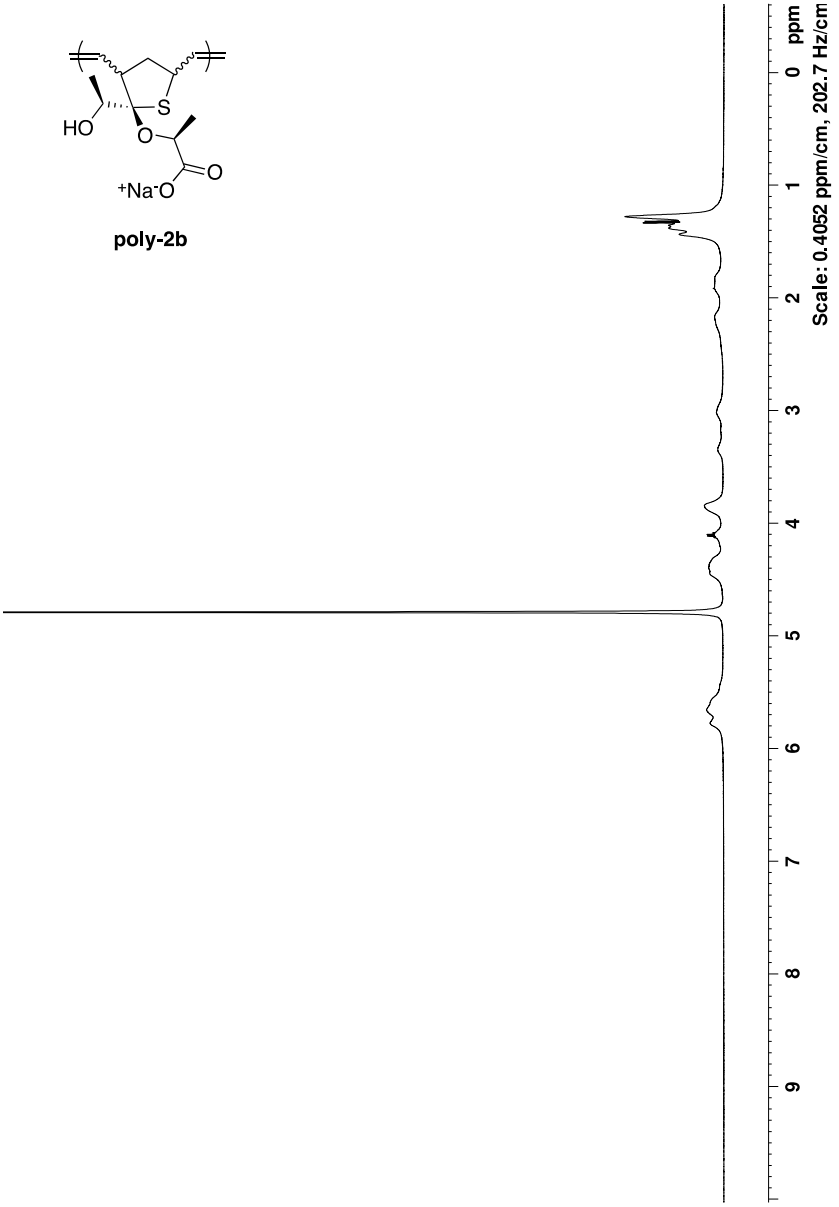

Figure S 33. ^{1}H NMR spectrum of **poly-2b** ($[\mathbf{2}]_0/[\mathrm{Ru}]_0 = 100$, 500 MHz, D_2O).

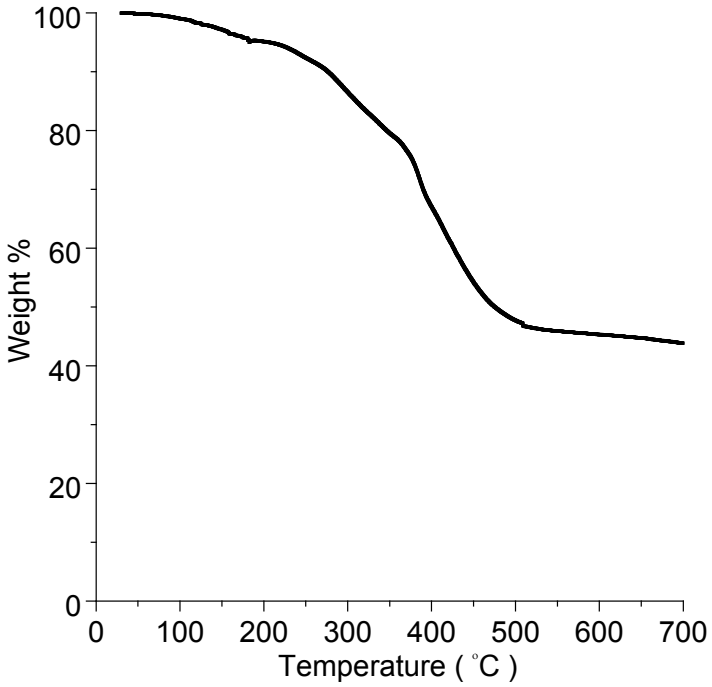

Figure S 34. TGA thermogram of **poly-2b** ($[\mathbf{2}]_0/[Ru]_0 = 100$).

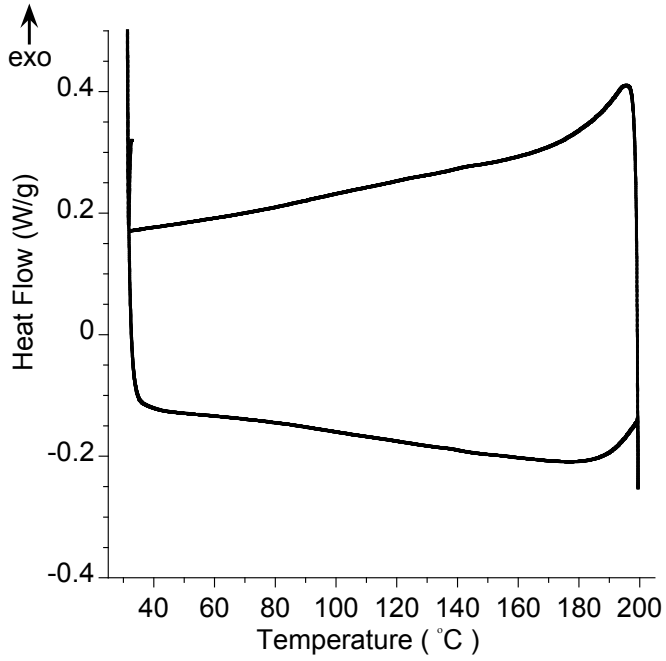

Figure S 35. DSC trace of **poly-2b** ($[\mathbf{2}]_0/[Ru]_0 = 100$). Second scan, ramp rate: 10 °C/min.

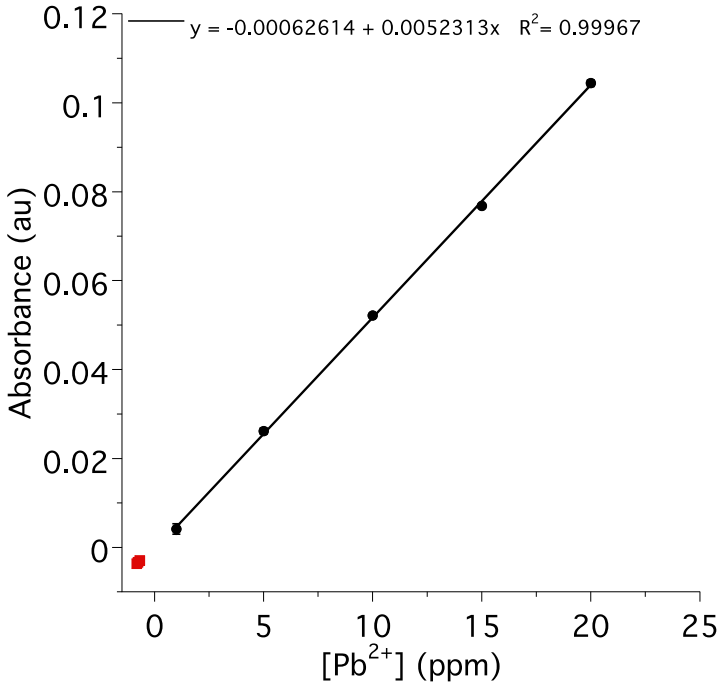

Figure S 36. AA spectroscopy results from filtrate (red squares). Calibration curve (black circles). [**poly-2b**] = *ca*. 0.67 mg/mL; $[Pb^{2+}]_0$, *ca*. 10 ppm. Experiments performed in triplicate.

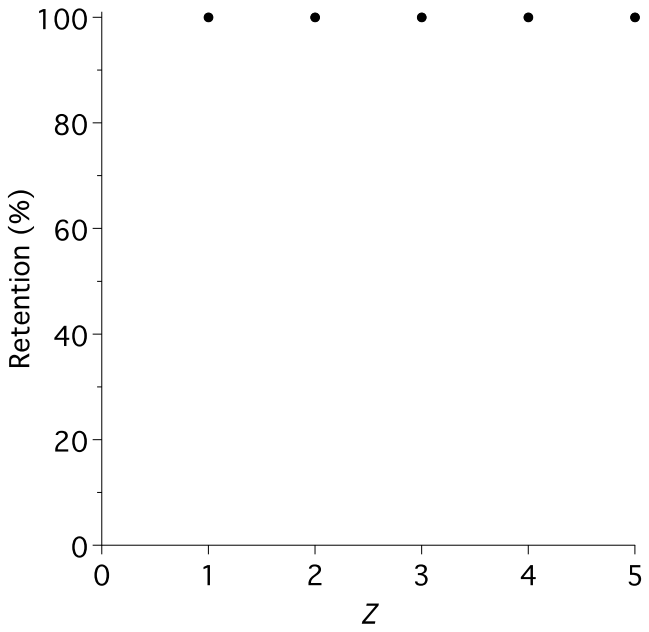

Figure S 37. Retention profile plotted against filtration factor *Z* where $Z = V_f V_0^{-1}$ (V_f = volume of filtrate and V_0 = volume of cell.

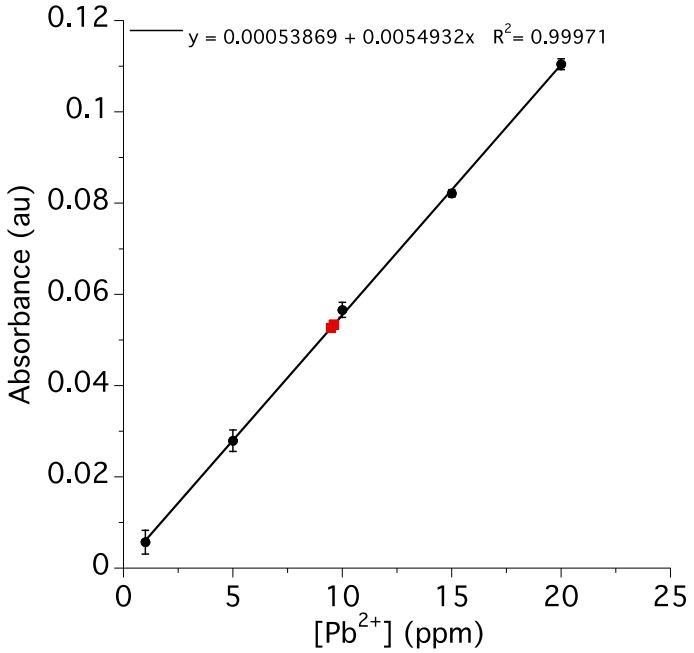

Figure S 38. AA spectroscopy results from filtrate (red squares). Calibration curve (black circles). $[Pb^{2+}]_0$, *ca*. 10 ppm. Experiments performed in triplicate.

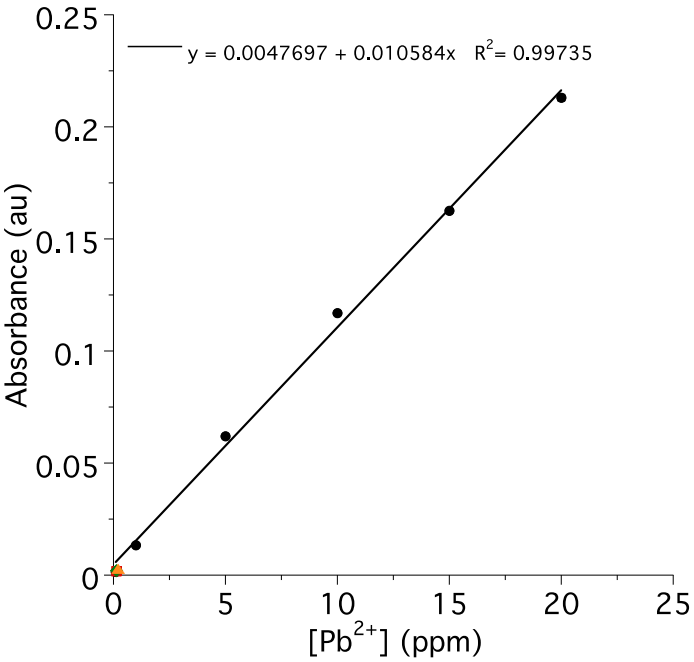

Figure S 39. AA spectroscopy results of filtrates isolated from formulations with $[Pb^{2+}]_0$, *ca*. 8-9 ppm and a) $[Na^{+}]_0$, *ca*. 10 ppm, (red square) b) $[K^{+}]_0$, *ca*. 10 ppm, (green diamond), and $[Ca^{2+}]_0$, *ca*. 10ppm (orange triangle). Calibration curve (black circles). Experiments performed in triplicate.

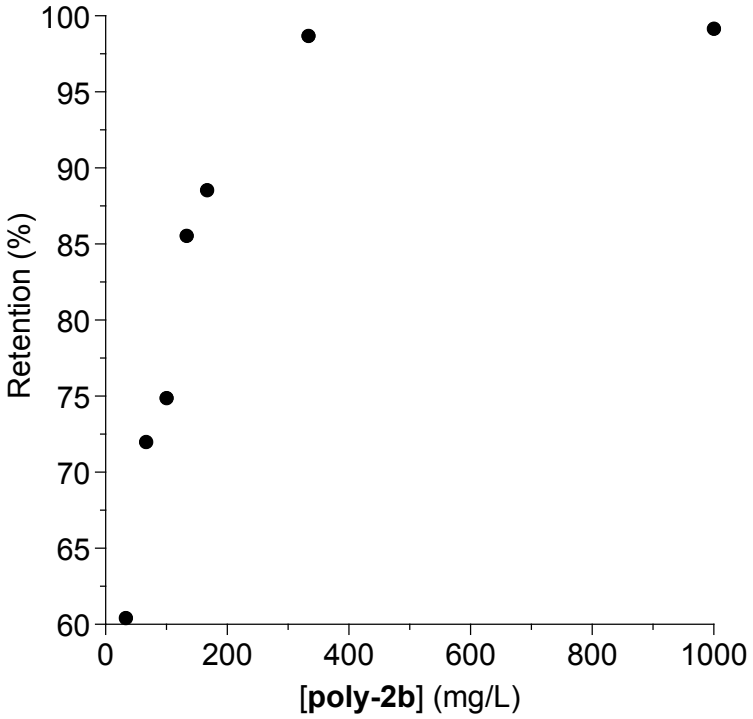

Figure S40. Retention (%) of Pb^{2+} after filtration as a function of [**poly-2b**].

[1] H. E. Gottlieb, V. Kotlyar and A. Nudelman, *J. Org. Chem.* **1997**, *62*, 7512-7515.

[2] a) Bruker (2005). *SAINT*, Version 7.23a. Bruker AXS Inc., Madison, Wisconsin, USA. b) Bruker (2006). *APEX 2*, Version 2.0-2. Bruker AXS Inc., Madison, Wisconsin, USA

[3] a) Sheldrick, G. M. (2008a). *SADABS*. University of Göttingen, Germany. b) Sheldrick, G. M. (2008b). Acta Cryst. A, **64**, 112-122.