Electronic supplementary materials *Mendeleev Commun.*, 2017, **27**, 476–478

Synthesis of vinyl thioethers and bis-thioethenes from calcium carbide and disulfides

Konstantin S. Rodygin, Yuliya V. Gyrdymova and Vladimir V. Zarubaev

Contents

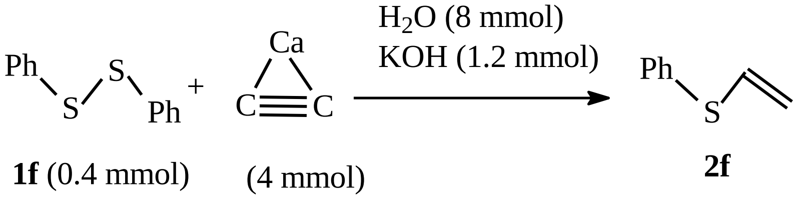
1. Materials and methods

Calcium carbide was purchased from Acros (97+% purity) and powdered prior to use. Solvents were dried and purified according to standard procedures. GC MS was performed using a Shimadzu GC-2010 Ultra coupled to a GCMS-QP2010 with a 'RTX-5ms column' with helium as the carrier gas. HRMS (ESI) was performed using a Bruker microTOF instrument. ^{1}H, ^{13}C and ^{19}F NMR spectra were recorded using a Bruker Avance 400 NMR spectrometer. The data were processed using MestReNova (version 6.0.2) desktop NMR data processing software.

X-ray data of compounds **1e** and **3e** were recorded using an automatic four-circle diffractometer equipped with the CCD-detector and graphite monochromator «Xcalibur Eos». The crystals were kept at 100.0(3) K during data collection.

2. Optimization of the reaction conditions

Table S1. Optimization of the vinylation of diphenyl disulfide **1f**.



Entry	**Solvent**	***T*, °C**	**Reaction time, h**	**Yield of 2f, %**
1	DMSO	80	3	40
2	DMSO	80	24	45
3	DMSO	130	3	41
4	DMSO	100	3	60
5	DMF	100	3	20
6	EtOH	100	3	50
7	DMF[a]	60	0.2	15
8	DMSO[b]	100	0.1	35

[a] Microwave irradiation, 20 Wt. [b] Microwave irradiation, 100 Wt.

3. Synthetic procedures

General procedure. Potassium hydroxide (67 mg, 1.5 mmol), diorganyl disulfide (0.4 mmol) and DMSO (1.5 ml) were placed into a 8 ml pressure vessel, and the mixture was stirred at room temperature for 20 min. Freshly powdered calcium carbide (256 mg, 4 mmol) and water (144 μl, 8 mmol) were added. The vessel was immediately sealed and heated to 100 °C for 3 h. The mixture was allowed to cool down to room temperature and extracted with hexane (3×20 ml). New portions of calcium carbide and water were added into the reaction vessel, it was sealed and heated again. This procedure was repeated twice, and, totally, the product was extracted three times. All the hexane extracts were combined and washed with 10% aqueous solution of KOH (2×10 ml), brine, dried over $MgSO_4$, and concentrated *in vacuo*. The crude material was purified by column chromatography on neutralized silica gel (hexane or/and diethyl ether/hexane as eluents). If necessary, for further purification the products were bulb-to-bulb distilled *in vacuo* and kept cold under argon. In the case of volatile products, it was necessary to use pentane for extraction instead of hexane.

General procedure for large scale experiment. Potassium hydroxide (3.35 g, 60 mmol), bis(4-methylphenyl) disulfide (4.9 g, 40 mmol) and DMSO (100 ml) were stirred at room temperature for 20 min. Powdered calcium carbide (12.8 g, 200 mmol) and water (7.2 ml, 40 mmol) were added, and the mixture was heated to 100 °C with vigorous stirring for 3 h. The mixture was filtred, extracted with hexane (4 × 40 ml). The hexane extract was treated with aqueous alkaline solution (10 ml), dried over $MgSO_4$, and concentrated *in vacuo*. The crude product was analyzed by NMR and GCMS. The individual components were isolated by column chromatography on silica gel.

*Bis[(5,6-epoxy-6,10,10-trimethylbicyclo[7.2.0]undec-2-yl)methyl] disulfide (**1e**).* To a stirred solution of (5,6-epoxy-6,10,10-trimethylbicyclo[7.2.0]undec-2-yl)methanethiol (254 mg, 1 mmol) and 276 mg (2 mmol) K_2CO_3 in EtOH (10 ml) a solution of iodine (140 mg, 0.55 mmol) in EtOH (5 ml) was added dropwise until discoloration of the solution. The mixture was quenched with saturated solution of $Na_2S_2O_3$ (10 ml), extracted with Et_2O (3×10 ml). The combined extracts were washed with $Na_2S_2O_3$, dried over anhydrous Na_2SO_4, filtered and evaporated under reduced pressure. The disulfide was purified on silica gel using $CHCl_3$:Et_2O as an eluent.

4. Spectral data and characterization

*Dodecyl vinyl sulfide **(2a)**.*

Yield - 93 %. ^1H NMR ($CDCl_3$, 400 MHz) δ 6.37 (dd, 1H, *J* = 16.8, 10.2 Hz), 5.14 (dd, 2H, *J* = 16.8, 10.2 Hz), 2.70 (t, 2H, *J* = 7.4 Hz), 1.65 (quin, 2H, *J* = 7.4 Hz), 1.36-1.46 (m, 2H), 1.27 (s, 19H), 0.89 (t, 3H, *J* = 6.8 Hz). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 132.61, 110.32, 31.90, 31.41, 29.64, 29.61, 29.57, 29.49, 29.33, 29.18, 29.05, 28.88, 22.68, 14.10. MS: m/z (% of max intensity) 41 (100), 60 (75), 73 (29), 87 (44), 101 (35), 115 (25), 119 (33), 228 (10). HRMS (ESI): calcd. for $C_{14}H_{28}S$ [M + Ag]$^+$ 335.0957; found 335.0956.

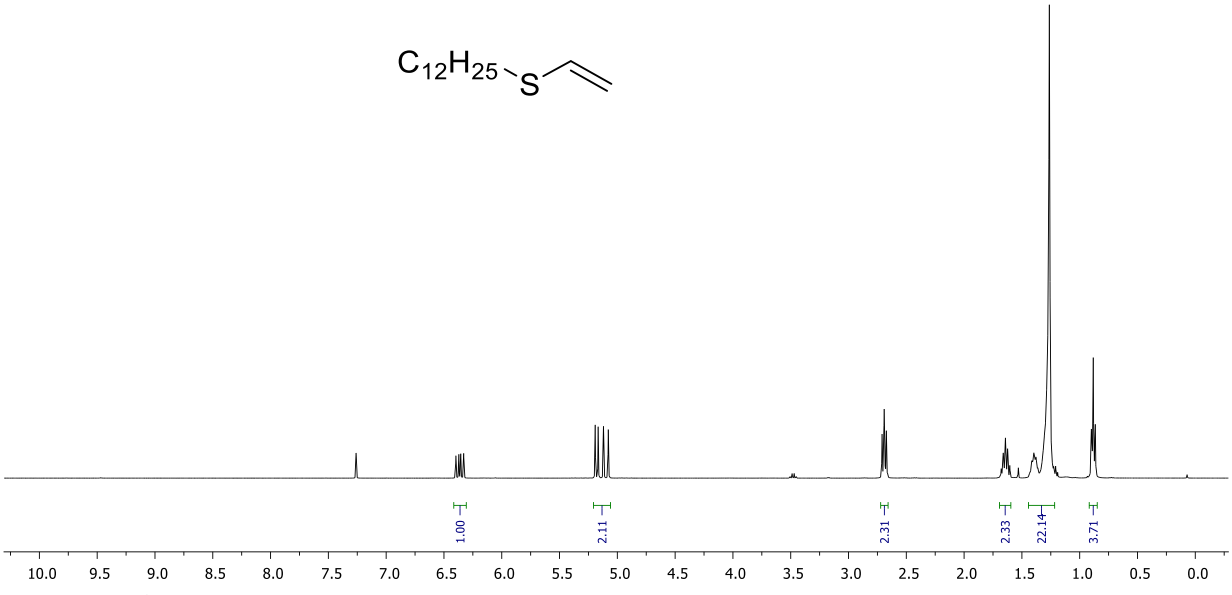


Figure S1. ^1H NMR spectrum of dodecyl vinyl sulfide (**2a**).

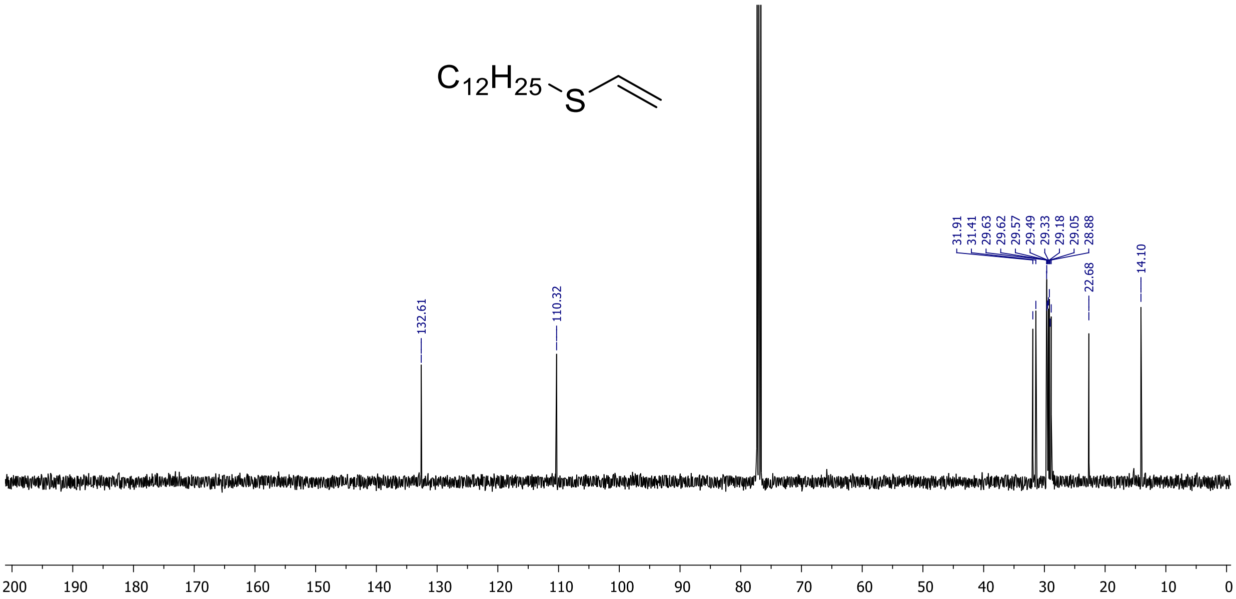


Figure S2. ^{13}C NMR spectrum of dodecyl vinyl sulfide (**2a**).

Hexyl vinyl sulfide ***(2b)***

Yield – 70 %. ^{1}H NMR ($CDCl_3$, 400 MHz) δ 6.37 (dd, 1H, *J* = 16.7, 19.2 Hz), 5.15 (dd, 2H, *J* = 16.8, 10.2 Hz), 2.70 (t, 2H, *J* = 7.4 Hz), 1.65 (quin, 2H, 7.5 Hz), 1.25-1.46 (m, 6H), 0.90 (t, 3H, *J* = 6.9 Hz). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 132.60, 110.31, 31.39, 31.36, 29.00, 28.54, 22.51, 13.98. MS: m/z (% of max intensity) 41 (68), 43 (96), 60 (100), 73 (28), 87 (15), 115 (22), 144 (27). HRMS (ESI): calcd. for $C_8H_{16}S$ $[M + Na]^+$ 167.0865; found 167.0872.

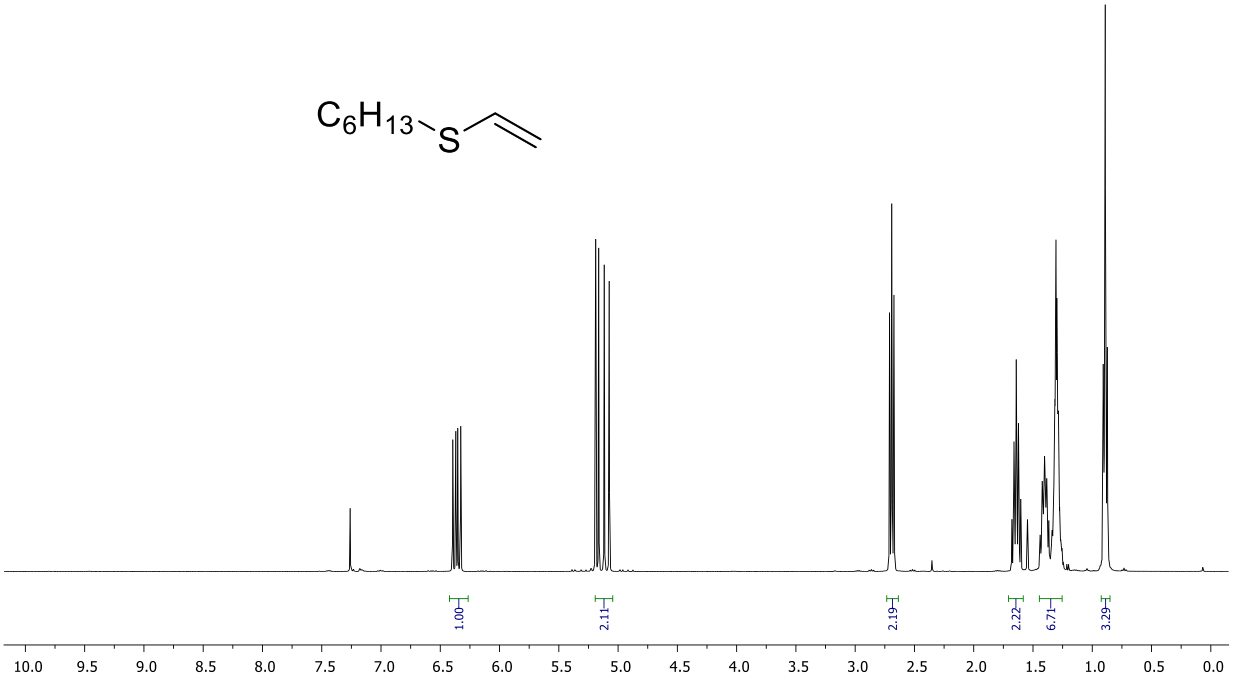


Figure S3. ^{1}H NMR spectrum of hexyl vinyl sulfide (**2b**).

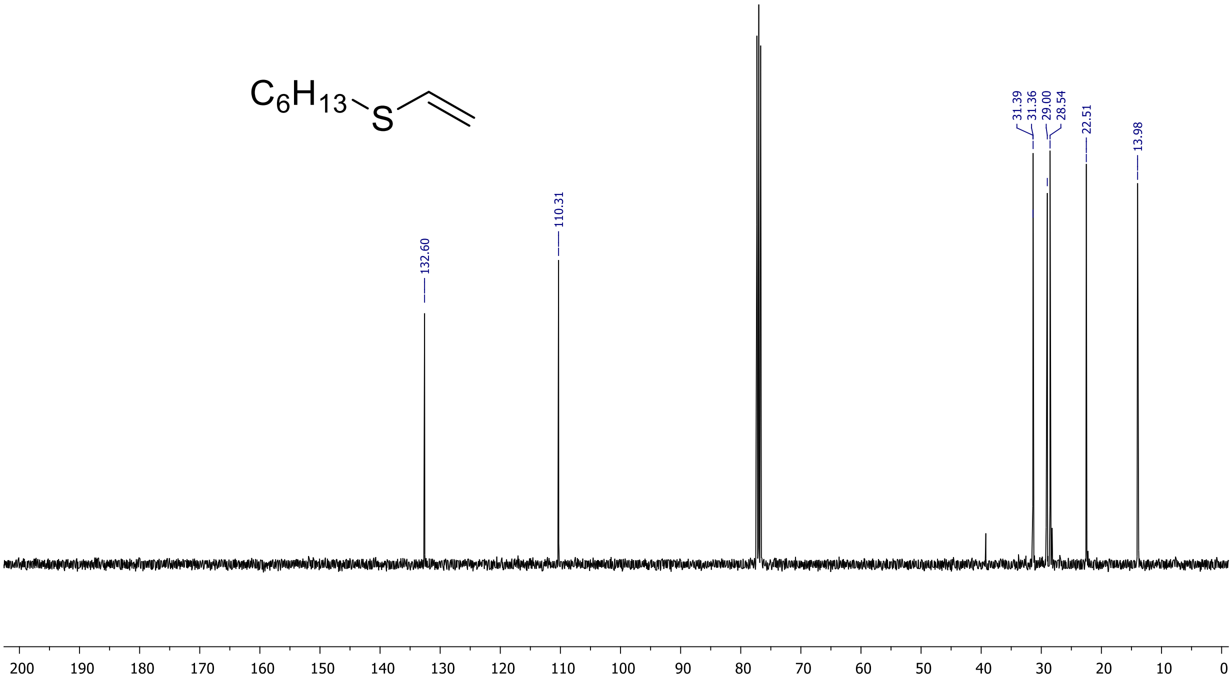


Figure S4. ^{13}C NMR spectrum of hexyl vinyl sulfide (**2b**).

Z-1,2-Bis(hexylthio)ethene ***(3b)***

Yield – 70%. ^{1}H NMR (CDCl$_3$, 400 MHz) δ 0.89 (t, 6H, J = 6.9 Hz), 1.23-1.46 (m, 12H), 1.64 (quin, 4H, J = 7.5 Hz), 2.72 (t, 4H, J = 7.4 Hz), 6.06 (s, 2H). ^{13}C NMR (CDCl$_3$, 100 MHz) δ 13.99, 22.50, 28.25, 30.22, 31.36, 34.29, 123.38. MS: m/z (% of max intensity) 41 (38), 43 (100), 92 (42), 115 (12), 176 (12), 260 (32). HRMS (ESI): calcd. for $C_{14}H_{28}S_2$ [M + Na]$^+$ 283.1525; found 283.1510.

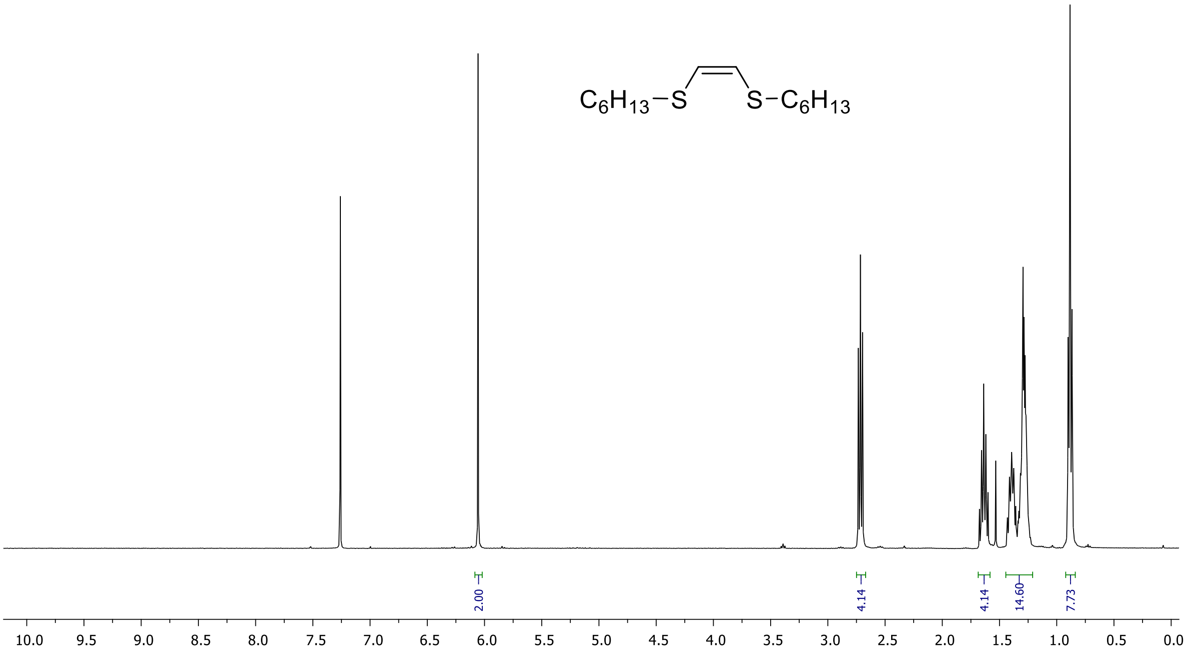


Figure S5. ^{1}H NMR spectrum of *Z*-1,2-bis(hexylthio)ethene (**3b**).

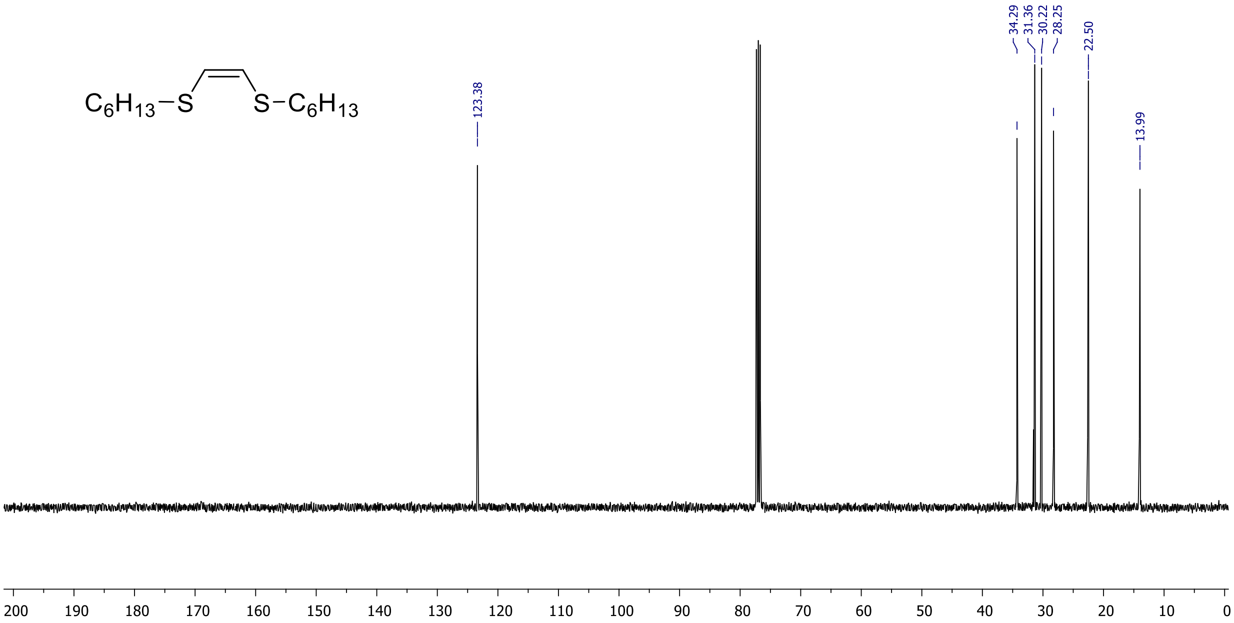


Figure S6. ^{13}C NMR spectrum of *Z*-1,2-bis(hexylthio)ethene (**3b**).

Z-1,2-Bis(buthylthio)ethene ***(3c)***

Yield – 60%. ^{1}H NMR (CDCl$_3$, 400 MHz) δ 6.06 (s, 2H), 2.72 (t, 4H, *J* = 7.4 Hz), 1.67 – 1.58 (quin, 4H, 7.3 Hz), 1.43 (dddd, 2H, *J* = 14.9, 7.4, 7.3 Hz), 0.92 (t, 3H, *J* = 7.3 Hz). ^{13}C NMR (CDCl$_3$, 100 MHz) δ 123.39, 33.97, 32.32, 21.68, 13.60. MS: m/z (% of max intensity) 41 (89), 45 (25), 57 (63), 92 (100), 101 (29), 148 (34), 204 (45). HRMS (ESI): calcd. for $C_{10}H_{20}S_2$ [M + Ag]$^+$ 331.0052; found 331.0052.

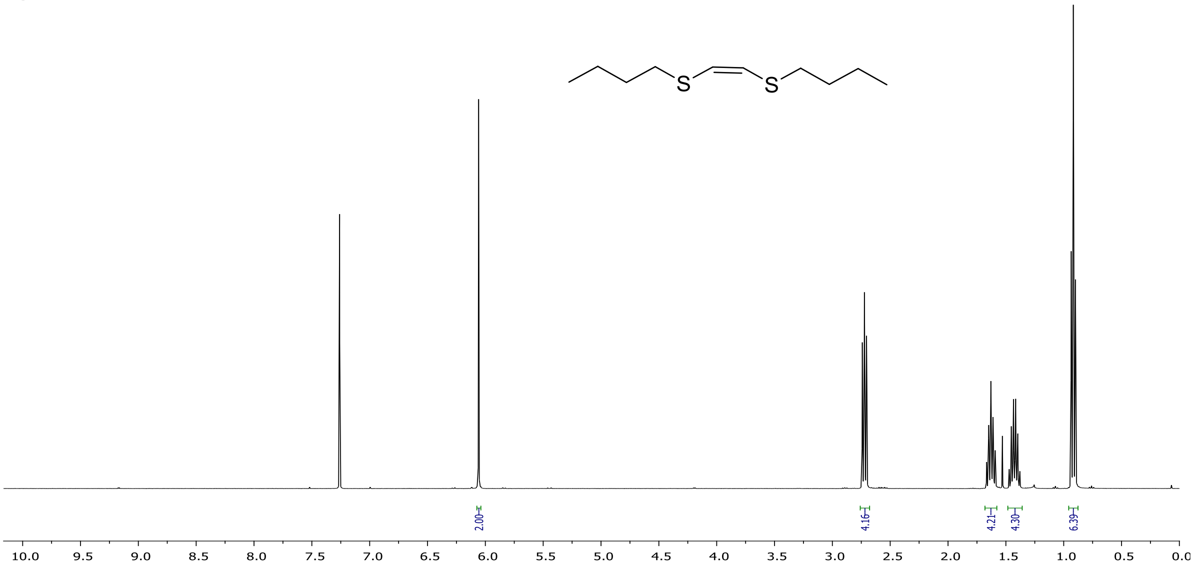


Figure S7. ^{1}H NMR spectrum of *Z*-1,2-bis(buthylthio)ethene (**3c**).

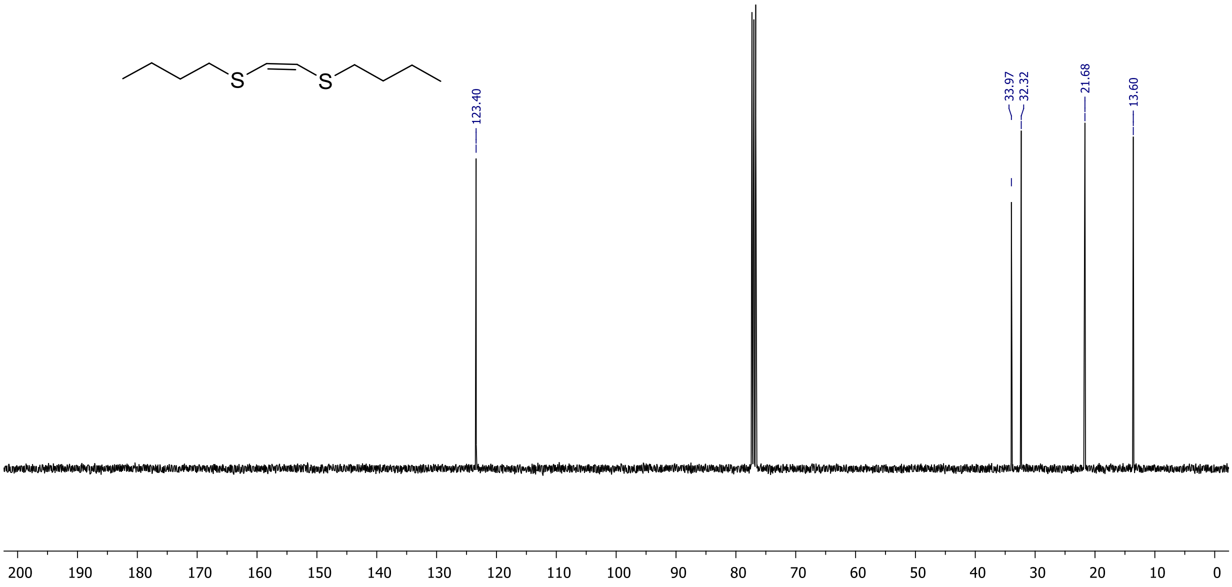


Figure S8. ^{13}C NMR spectrum of *Z*-1,2-bis(buthylthio)ethene (**3c**).

*Cyclohexyl vinyl sulfide (***2d***)*

Yield – 32%. ^{1}H NMR (CDCl$_3$, 400 MHz) δ 6.38 (dd, 1H, *J* = 16.9, 10.0 Hz), 5.21 (dd, 2H, *J* = 13.4, 4.1 Hz), 2.90 (td, 1H, *J* = 10.4, 3.7 Hz), 1.99 (dd, 2H, *J* = 14.7, 9.8 Hz), 1.56-1.66 (m, 2H), 1.19-1.45 (m, 6H). ^{13}C NMR (CDCl$_3$, 100 MHz) δ 131.57, 112.43, 44.28, 33.38, 25.99, 25.70. MS: m/z (% of max intensity) 41 (76), 55 (100), 67 (70), 82 (54), 142 (32). HRMS (ESI): calcd. for $C_8H_{14}S$ [M + Ag]$^+$ 248.9862; found 248.9858.

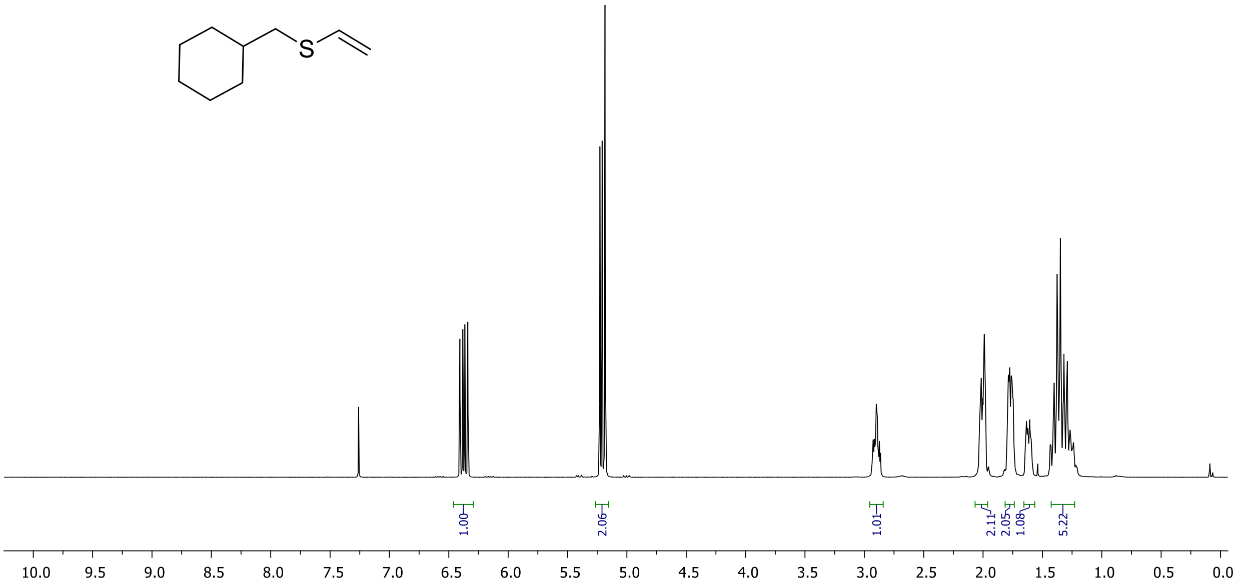


Figure S9. ^{1}H NMR spectrum of cyclohexyl vinyl sulfide (**2d**).

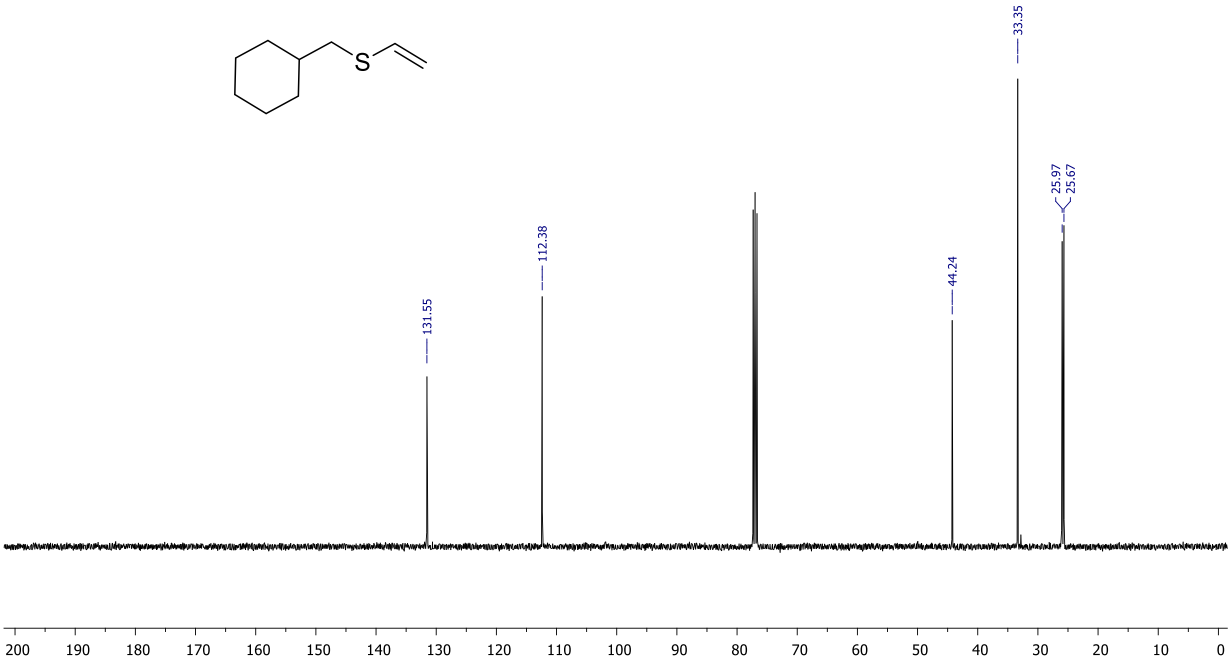


Figure S10. ^{13}C NMR spectrum of cyclohexyl vinyl sulfide (**2d**).

*Z-1,2-Bis(cyclohexylthio)ethene (**3d**)*

Yield – 32%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ 6.14 (s, 2H), 2.83-2.92 (m, 2H, 1.98-2.01 (m, 4H), 1.72-1.80 (m, 4H), 1.54-1.62 (m, 2H), 1.15-1.49 (m, 10H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 123.40, 33.97, 32.32, 21.68, 13.60. HRMS (ESI): calcd. for $C_{14}H_{24}S_2$ $[M + Ag]^+$ 363.0365; found 363.0353.

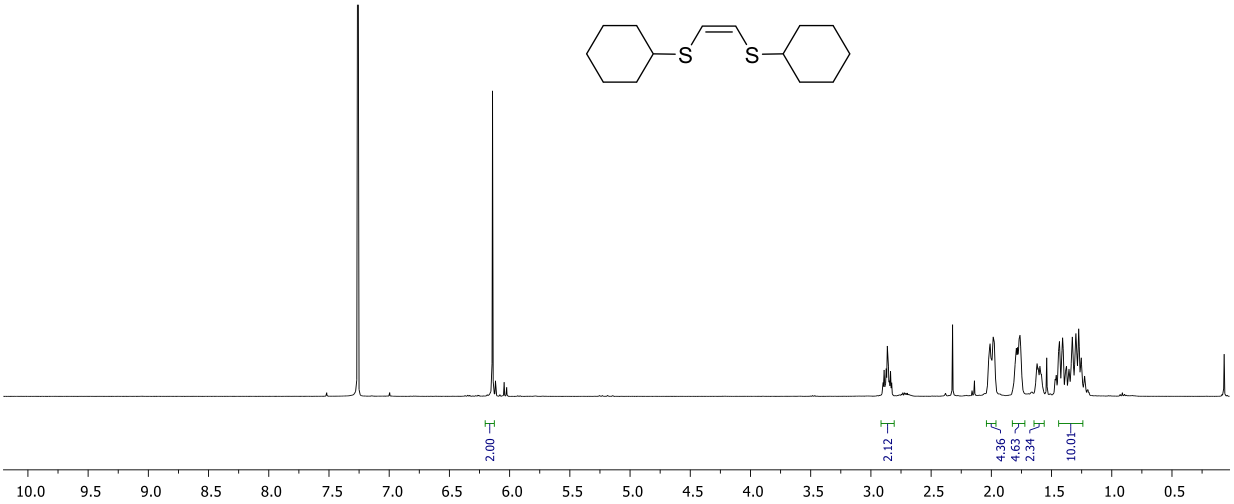


Figure S11. ^{1}H NMR spectrum of *Z*-1,2-bis(cyclohexylthio)ethene (**3d**).

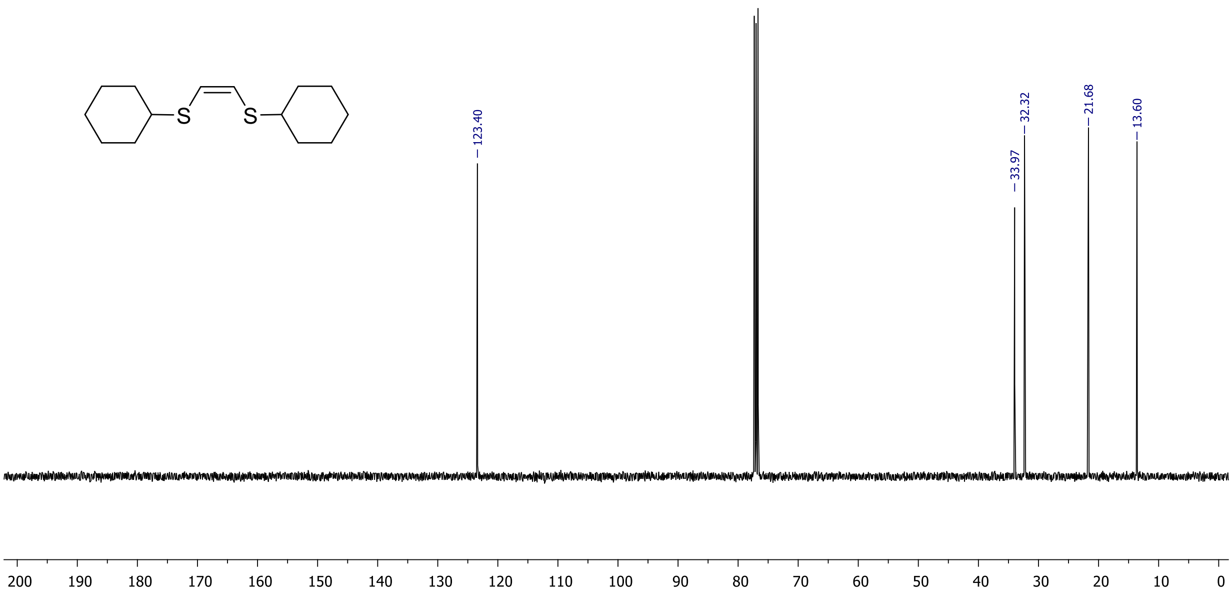


Figure S12. ^{13}C NMR spectrum of *Z*-1,2-bis(cyclohexylthio)ethene (**3d**).

Di(4,5-epoxycaryophyll-9-ylmetyl)disulfide ***(1e)***

Yield – 98 %. $[\alpha]_D^{27}$ – 84.4 (*c* 0.2, $CHCl_3$). IR, sm^{-1}: 1261 (epoxy cycle), 910, 758 (C–S), 794, 686 (S-S). ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.90 (dd, 2H, *J* = 11.4, 3.4 Hz), 2.55 (dd, 2H, *J* = 12.8, 5.9 Hz), 2.35 (dd, 2H, *J* = 12.8, 8.9 Hz), 2.13-2.87 (m, 4H), 2.08 (dd, 2H, *J* = 12.6, 2.6 Hz), 1.82-1.93 (m, 2H), 1.55-1.82 (m, 8H), 1.33–1.53 (m, 4H), 1.29 (s, 6H), 1.14–1.29 (m, 4H), 0.99–1.09 (m, 2H), 0.98 (s, 6H), 0.96 (s, 6H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 65.34, 60.18, 46.18, 44.72, 44.17, 38.36, 38.22, 34.60, 24.23, 29.90, 28.85, 27.24, 23.78, 21.14, 14.47. MS: m/z (% of max intensity) 41 (60), 43 (100), 69 (80), 95 (84), 107 (33), 253 (65), 506 (20). MW 506.46.

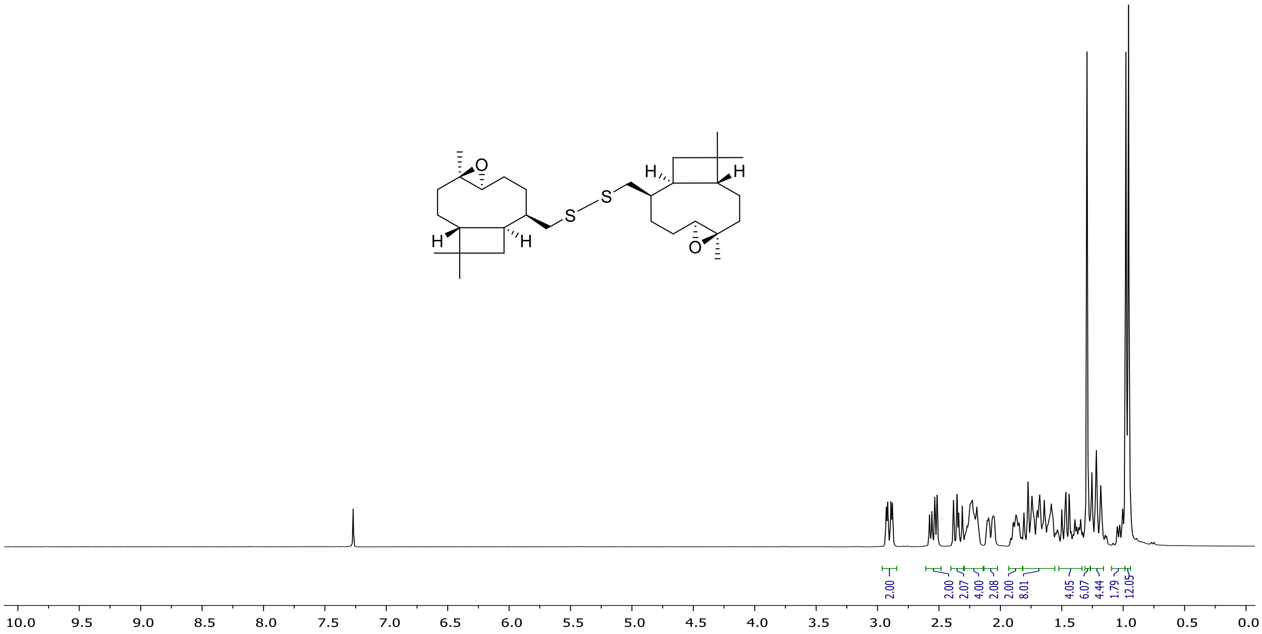


Figure S13. ^{1}H NMR spectrum of di(4,5-epoxycaryophyll-9-ylmetyl)disulfide **(1e)**.

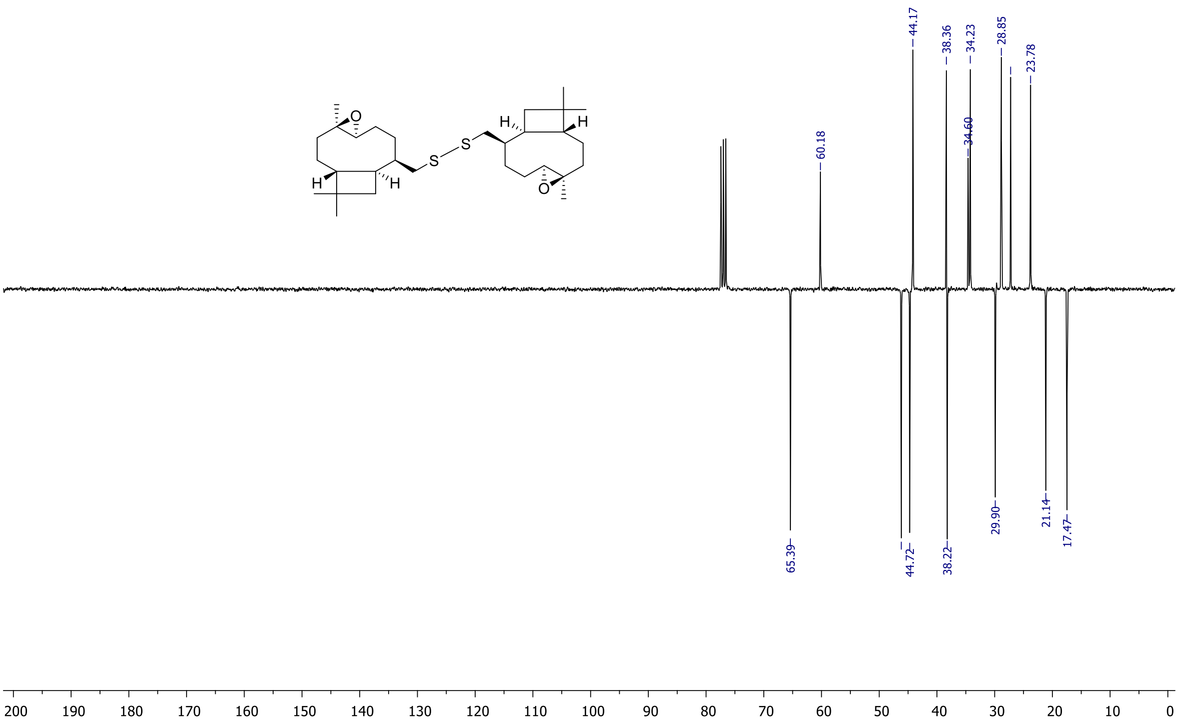


Figure S14. *J* mod ^{13}C NMR spectrum of di(4,5-epoxycaryophyll-9-ylmetyl)disulfide **(1e)**.

*((1R,4R,6R,9R,10S)-4,12,12-trimethyl-9-((vinylthio)methyl)-5-oxatricyclo[8.2.0.0^{4,6}]dodecane (((4,5-epoxycaryophyll-9-yl)methyl vinyl sulfide) (**2e**)*

Yield – 45%. ^{1}H NMR (CDCl$_3$, 400 MHz) δ 6.32 (dd, 1H, *J* = 16.8, 10.1 Hz), 5.14 (dd, 2H, *J* = 17.9, 10.4 Hz), 2.89 (dd, 1H, *J* = 11.4, 3.5 Hz), 2.55 (dd, 1H, *J* = 12.4, 6.0 Hz), 2.41 (dd, 1H, *J* = 12.7, 8.5 Hz), 2.18-2.32 (m, 2H), 2.03-2.10 (m, 1H), 1.58-1.82 (m, 5H), 1.48-1.54 (m, 2H), 1.30-1.43 (m, 1H), 1.24 (s, 3H), 1.15-1.29 (m, 3H), 0.99-1.04 (m, 2H), 0.98 (s, 3H), 0.96 (s, 3H). ^{13}C NMR (CDCl$_3$, 100 MHz) δ 132.29, 110.86, 62.45, 60.21, 46.15, 44.85, 38.38, 36.99, 34.59, 34.08, 29.93, 28.91, 27.20, 24.18, 21.14, 17.44. MS: m/z (% of max intensity) 41 (83), 43 (100), 67 (48), 79 (40), 93 (47), 107 (25), 121 (13), 252 (12), 280 (5). HRMS (ESI): calcd. for $C_{17}H_{28}S$ [M + Na]$^+$ 303.1753; found 303.1742.

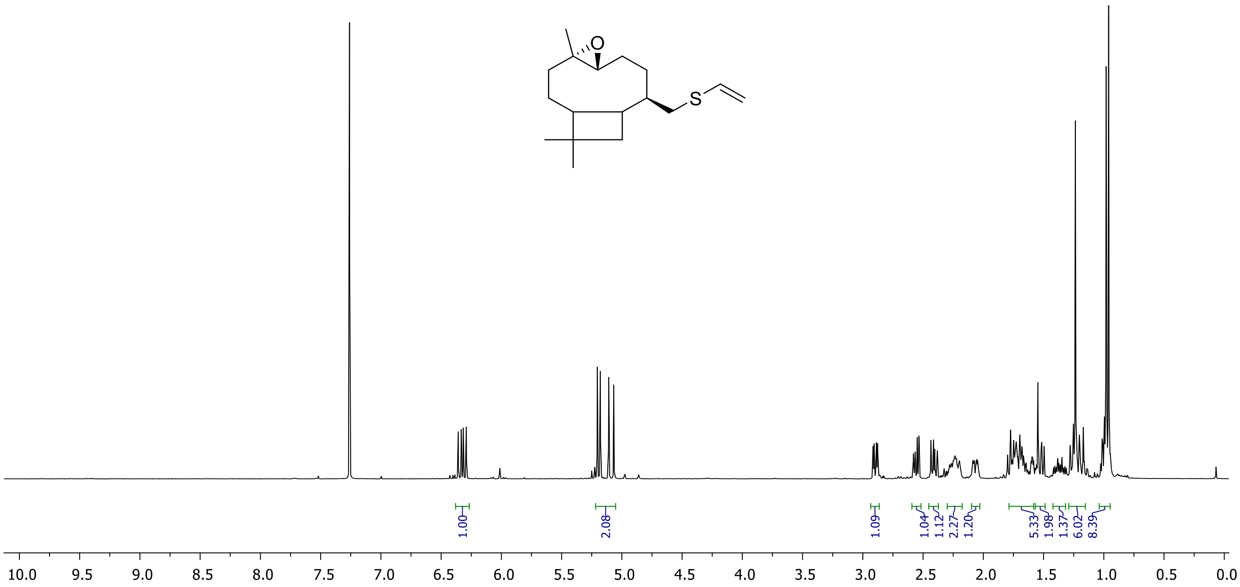


Figure S15. ^{1}H NMR spectrum of (4,5-epoxycaryophyll-9-yl)methyl vinyl sulfide (**2e**).

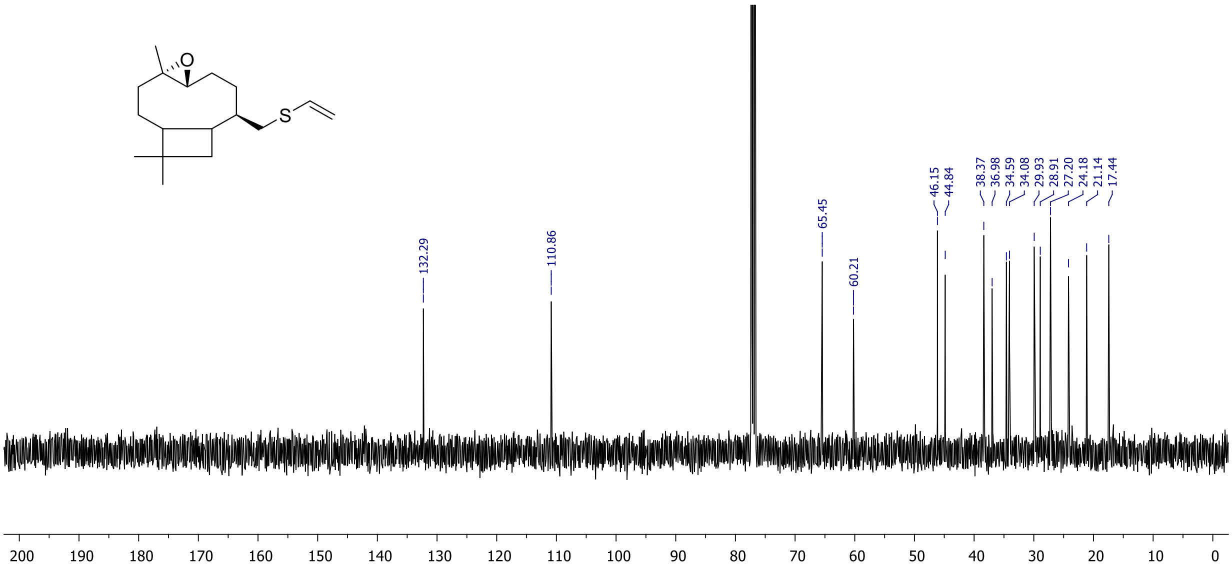


Figure S16. ^{13}C NMR spectrum of (4,5-epoxycaryophyll-9-yl)methyl vinyl sulfide (**2e**).

*Z-1,2-Bis((((1R,4R,6R,9R,10S)-4,12,12-trimethyl-5-oxatricyclo[8.2.0.0^{4,6}]dodec-9-yl)methyl)thio)ethen (Z-1,2-bis((4,5-epoxycaryophyll-9-ylmethyl)thio)ethene) (**3e**)*

Yield – 50%. ^{1}H NMR (CDCl$_3$, 400 MHz) δ 6.01 (s, 2H), 2.89 (dd, 2H, *J* = 11.4, 3.6 Hz), 2.59 (dd, 2H, *J* = 12.3, 6.0 Hz), 2.43 (dd, 2H, *J* = 12.6, 8.5 Hz), 2.16-2.33 (4H, m), 2.03-2.10 (m, 2H), 1.57-1.81 (m, 12H), 1.50 (dd, 2H, *J* = 9.8, 8.0 Hz), 1.29-1.41 (m, 2H), 1.16-1.27 (m, 4H), 1.24 (s, 6H), 0.97 (s, 6H), 0.95 (s, 6H). ^{13}C NMR (CDCl$_3$, 400 MHz) δ 123.83, 65.43, 60.16, 46.16, 44.66, 39.95, 39.52, 38.28, 34.59, 34.13, 29.93, 28.94, 27.20, 23.81, 21.16, 17.46. MS: m/z (% of max intensity) 55 (100), 81 (95), 95 (68), 105 (40), 121 (24), 122 (12), 221 (8), 321 (24), 532 (52). HRMS (ESI): calcd. for $C_{32}H_{52}S_2$ $[M + H]^+$ 533.3487; found 533.3282.

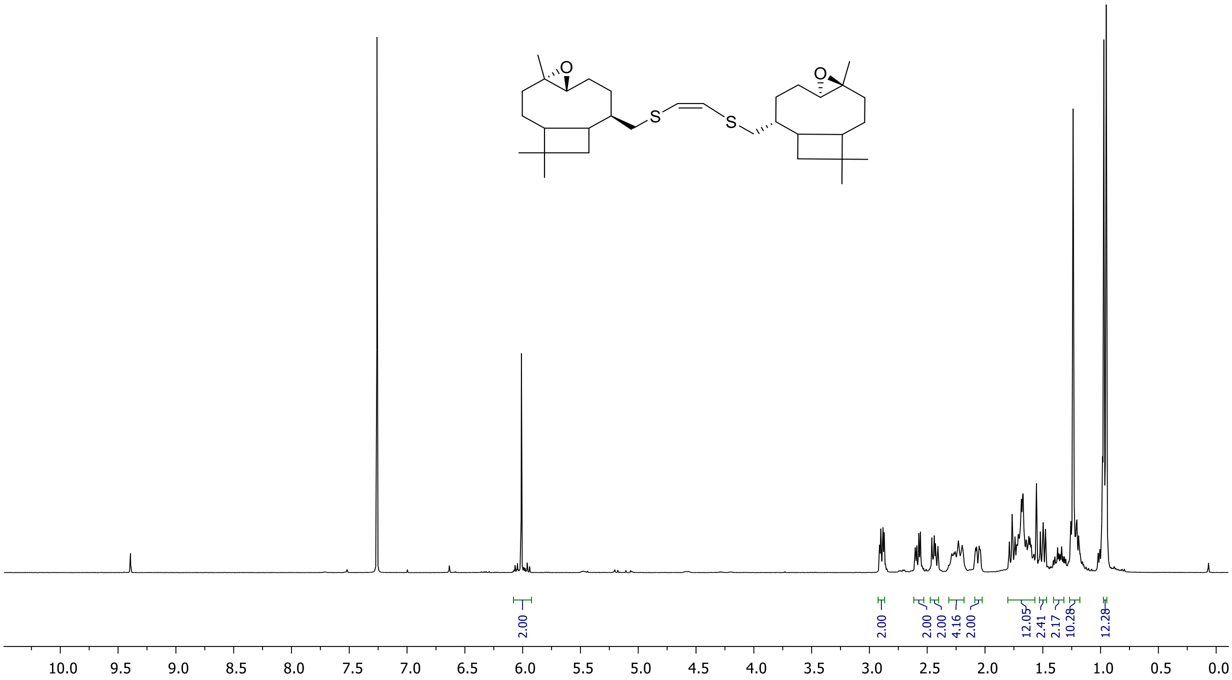


Figure S17. ^{1}H NMR spectrum of *Z*-1,2-bis((4,5-epoxycaryophyll-9-ylmethyl)thio)ethene (**3e**).

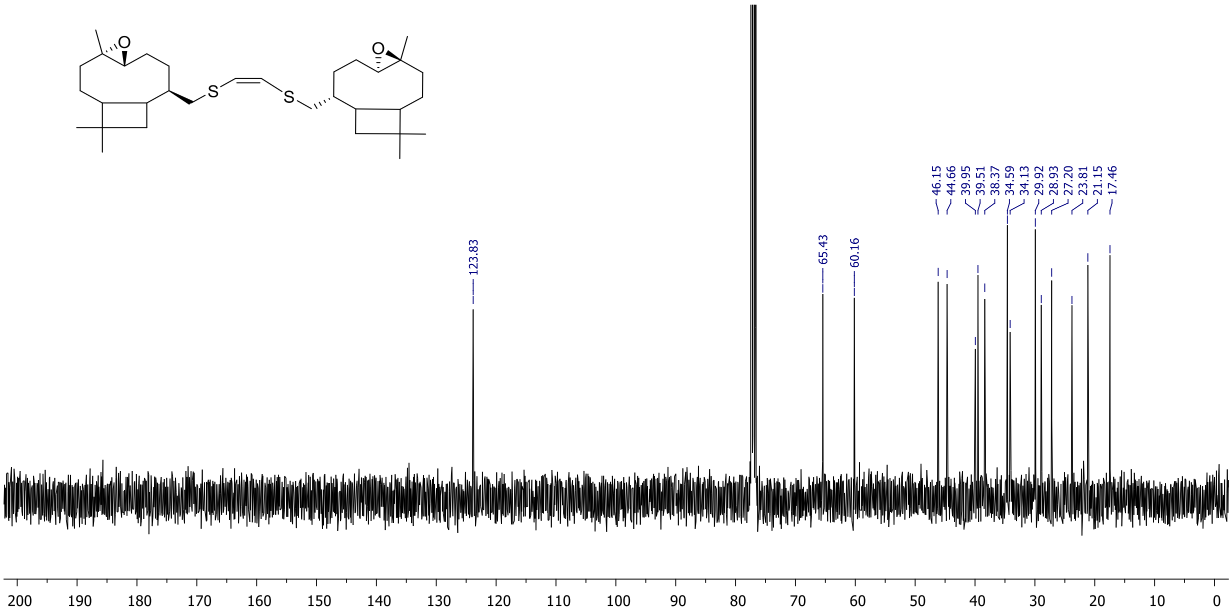


Figure S18. ^{13}C NMR spectrum of *Z*-1,2-bis((4,5-epoxycaryophyll-9-ylmethyl)thio)ethene (**3e**).

Phenyl vinyl sulfide ***(2f)***

Yield – 93%. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.44 – 7.26 (m, 5H), 6.55 (dd, 1H, *J* = 6.6, 9.6 Hz), 5.36 (dd, 2H, *J* = 13.3, 4.7 Hz). ^{13}C NMR (100 MHz, CDCl$_3$) δ 34.27, 131.89, 130.52, 129.12, 127.11, 115.46. MS: m/z (% of max intensity) 39 (24), 51 (24), 64 (23), 91 (96), 109 (11), 135 (100), 136 (92). HRMS (ESI): calcd. for C_8H_8S [M + Ag]$^+$ 242.9392; found 242.9391.

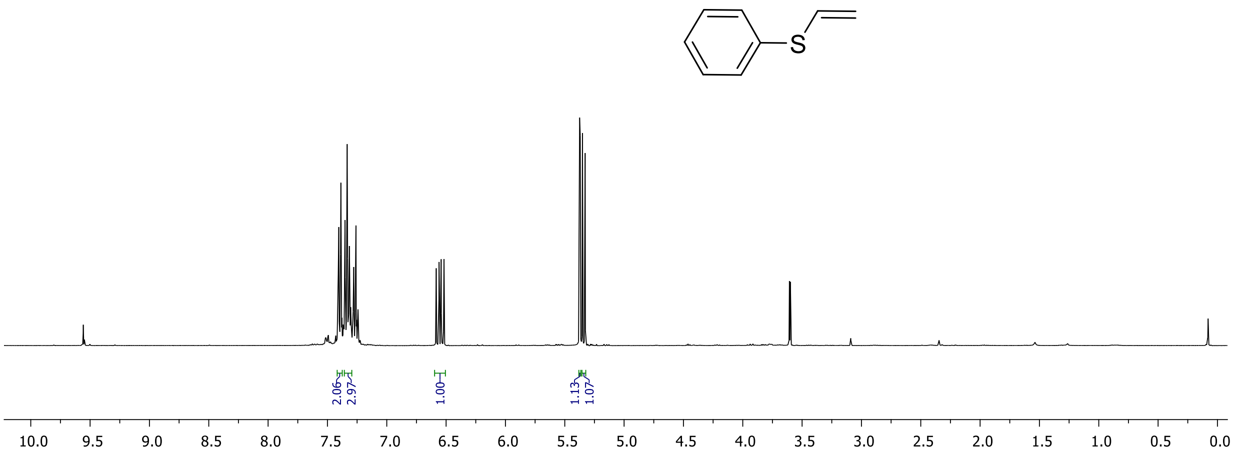


Figure S19. ^{1}H NMR spectrum of phenyl vinyl sulfide (**2f**).

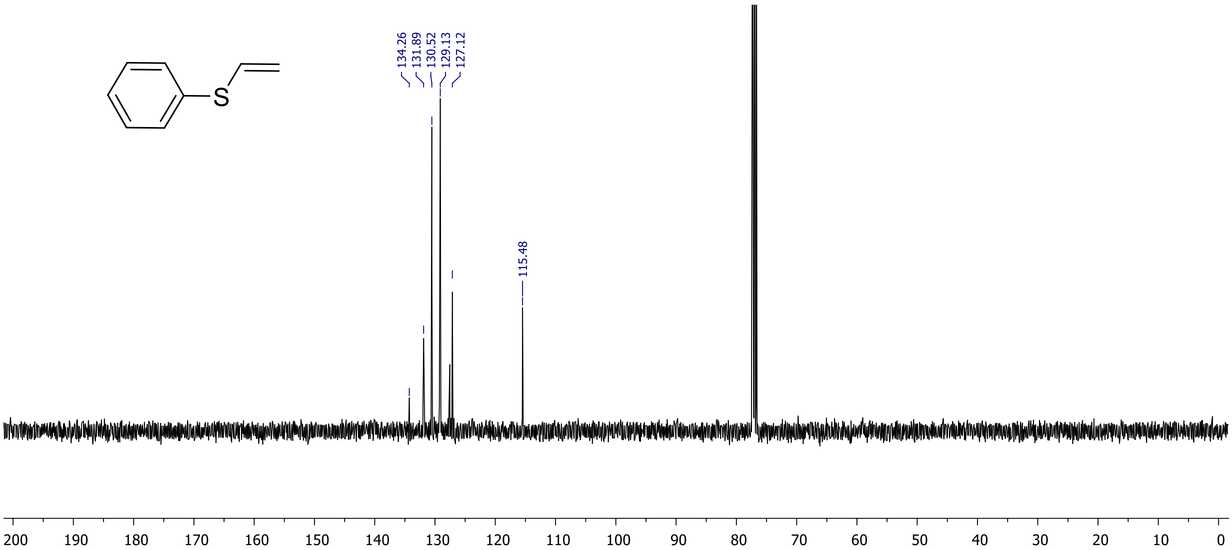


Figure S20. ^{13}C NMR spectrum of phenyl vinyl sulfide (**2f**).

4-Methylphenyl vinyl sulfide ***(2g)***

Yield – 69%. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 – 7.25 (d, 2H, *J* = 8.1 Hz), 7.15 – 7.09 (d, 2H, *J* = 7.9 Hz), 6.48 (dd, 1H, *J* = 16.6, 9.6 Hz), 5.24 (dd, 2H, *J* = 17.3, 13.1 Hz), 2.30 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.44, 132.71, 131.29, 130.19, 129.93, 114.17, 21.07. MS: m/z (% of max intensity) 39 (32), 69 (31), 77 (32), 91 (72), 105 (46), 135 (100), 150 (93). HRMS (ESI): calcd. for $C_9H_{10}S$ $[M + Ag]^+$ 256.9549; found 256.9542.

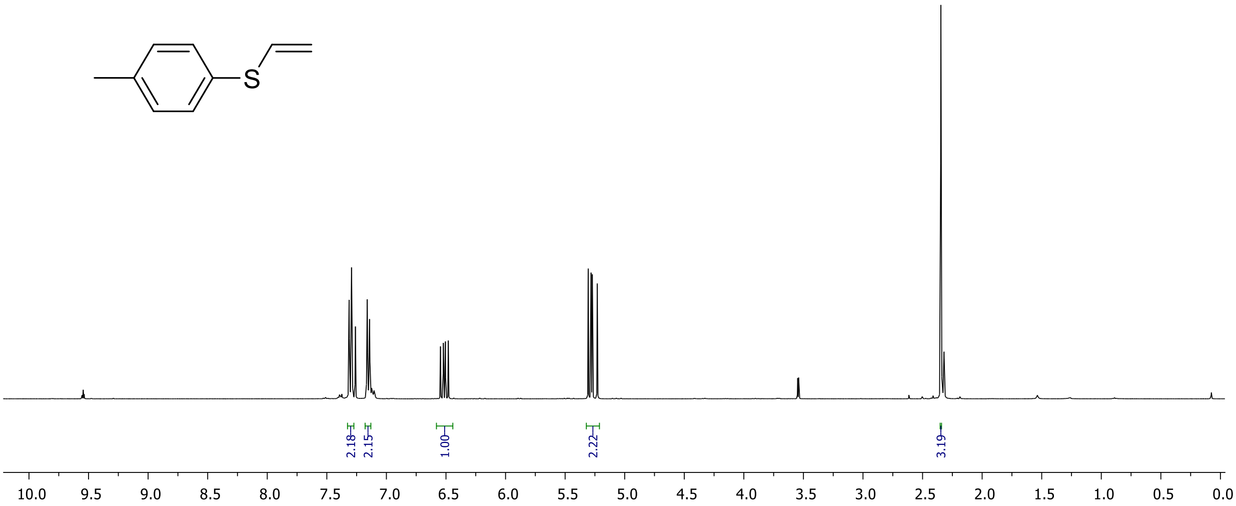


Figure S21. ^{1}H NMR spectrum of 4-methylphenyl vinyl sulfide (**2g**).

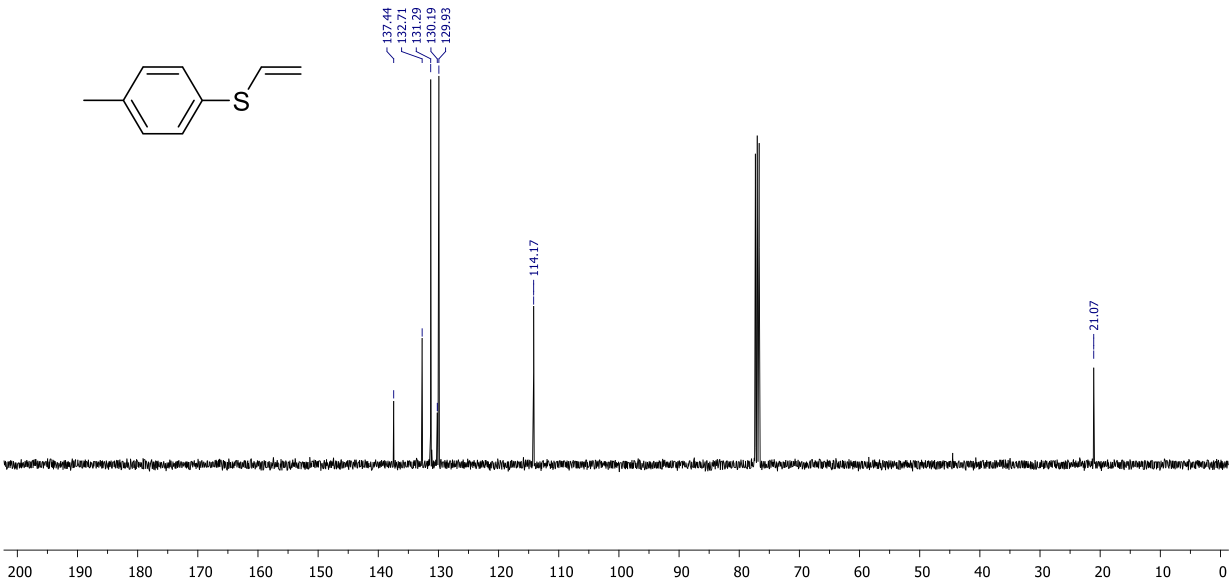


Figure S22. ^{13}C NMR spectrum of 4-methylphenyl vinyl sulfide (**2g**).

4-Chlorophenyl vinyl sulfide ***(2h)***

Yield – 60 %. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31 (s, 4H), 6.54 – 6.44 (dd, 1H, *J* = 16.6, 9.5 Hz), 5.37 (dd, 2H, *J* = 17.4, 10.32 Hz). ^{13}C NMR (100 MHz, $CDCl_3$) δ 133.26, 132.80, 131.76, 131.30, 129.29, 116.24. MS: m/z (% of max intensity) 50 (120), 67 (18), 75 (27), 91 (53), 108 (32), 125 (26), 135 (100), 170 (42). HRMS (ESI): calcd. for C_8H_7ClS $[M + Ag]^+$ 276.9002; found 276.8983.

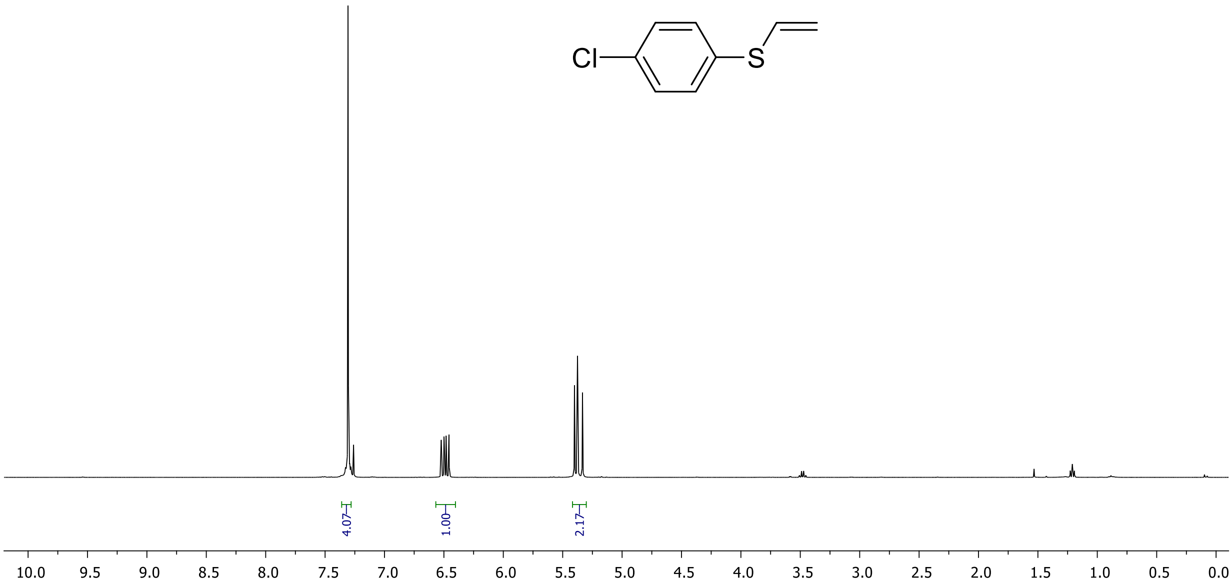


Figure S23. ^{1}H NMR spectrum of 4-chlorophenyl vinyl sulfide (**2h**).

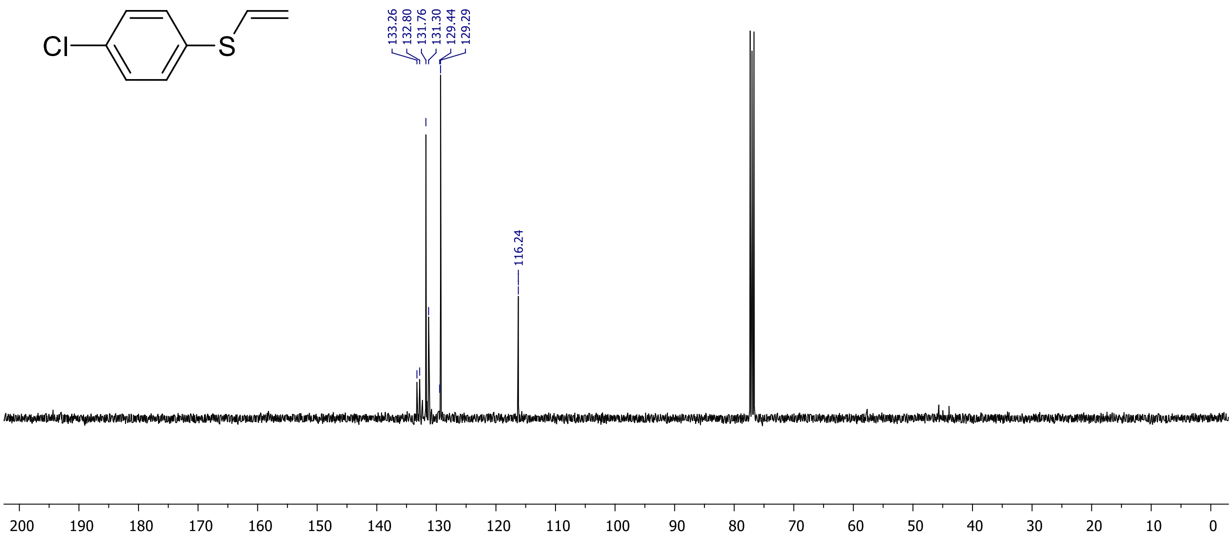


Figure S24. ^{13}C NMR spectrum of 4-chlorophenyl vinyl sulfide (**2h**).

4-Fluorophenyl vinyl sulfide ***(2i)***

Yield – 66 %. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.43 – 7.34 (m, 1H), 7.10 – 6.98 (m, 1H), 6.52 – 6.40 (dd, 1H, *J* = 16.5, 9.6 Hz), 5.28 (dd, 1H, *J* = 19.5, 9.8 Hz). ^{13}C NMR (100 MHz, CDCl$_3$) δ 162.32 (d, *J* = 248.0 Hz), 133.43 (d, *J* = 8.8 Hz), 132.38, 132.05 (d, *J* = 8.1 Hz), 128.77 (d, *J* = 2.9 Hz), 125.30, 116.30 (d, *J* = 22.0 Hz), 114.57. ^{19}F NMR (376 MHz, CDCl$_3$) δ -114.08. MS: m/z (% of max intensity) 45 (15), 57 (25), 83 (51), 109 (100), 153 (94), 154 (98).

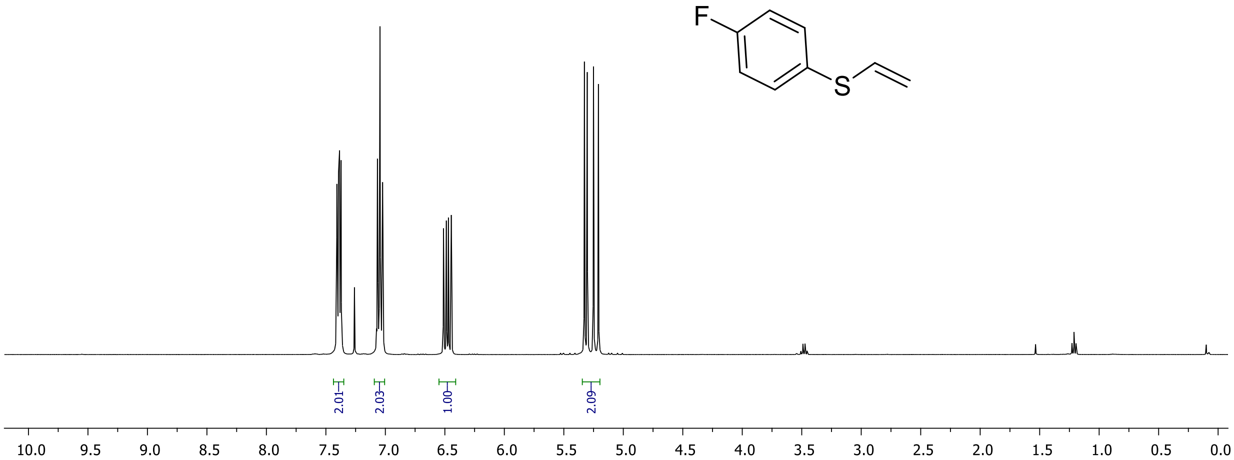


Figure S25. ^{1}H NMR spectrum of 4-fluorophenyl vinyl sulfide (**2i**).

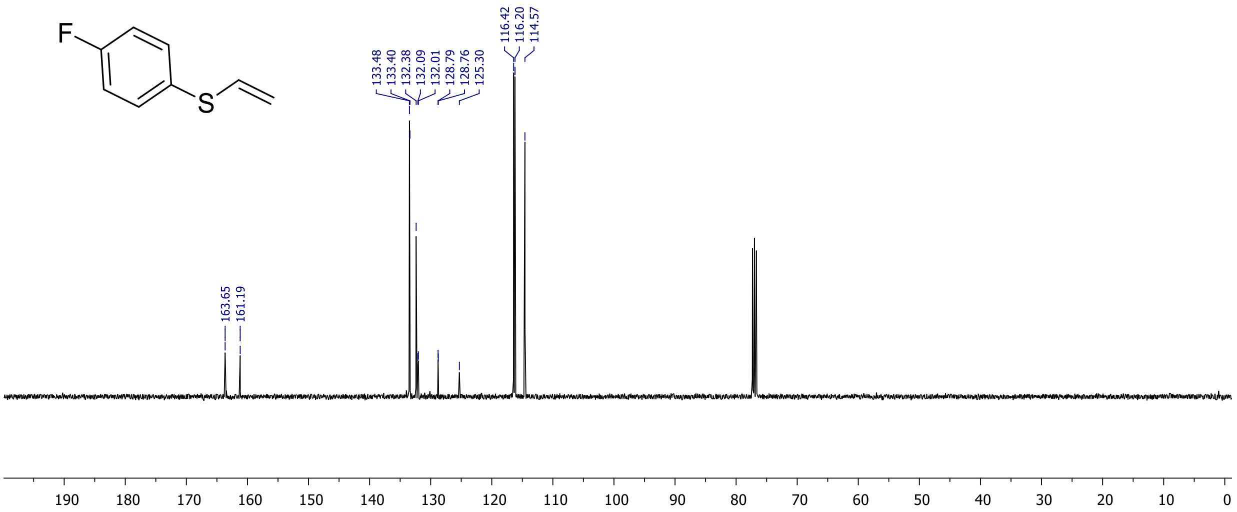


Figure S26. ^{13}C NMR spectrum of 4-fluorophenyl vinyl sulfide (**2i**).

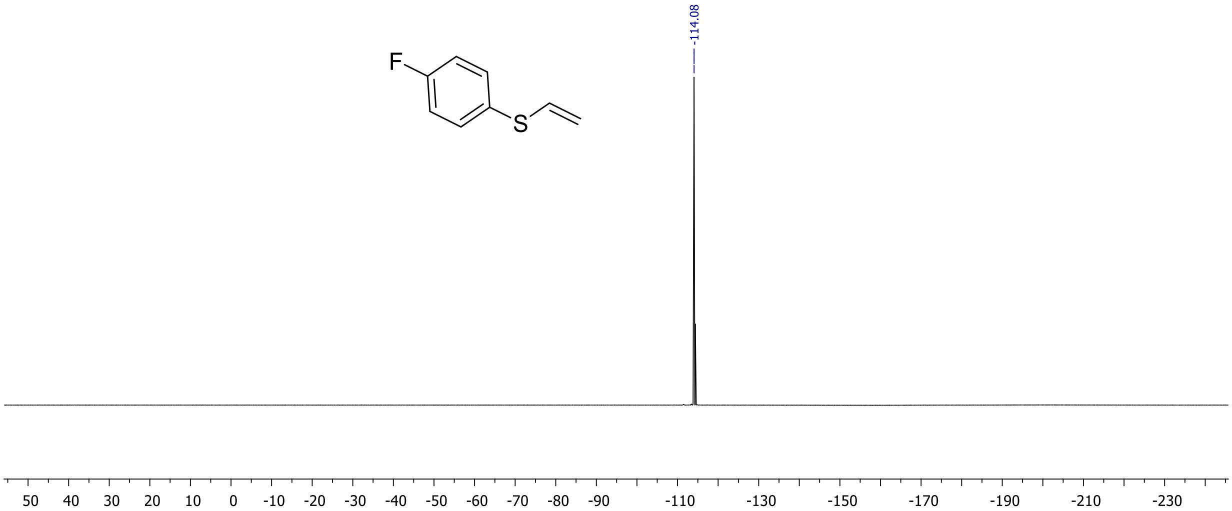


Figure S27. ^{19}F NMR spectrum of 4-fluorophenyl vinyl sulfide (**2i**).

3-Methylphenyl vinyl sulfide ***(2j)***

Yield – 21 %. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.21 – 7.25 (m, 3H), 7.08 (d, 1H, *J* = 6.9 Hz), 6.56 (dd, 1H, *J* = 16.6, 9.6 Hz), 5.36 (dd, 2H, *J* = 13.1, 3.5 Hz), 2.36 (s, 3H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 138.96, 133.97, 132.05, 131.04, 128.93, 127.95, 127.50, 115.24, 21.25. MS: m/z (% of max intensity) 39 (49), 45 (30), 65 (45), 77 (37), 91 (90), 105 (57), 115 (20), 135 (100), 150 (95). HRMS (ESI): calcd. for $C_9H_{10}S$ [M + Ag]$^+$ 256.9549; found 256.9538.

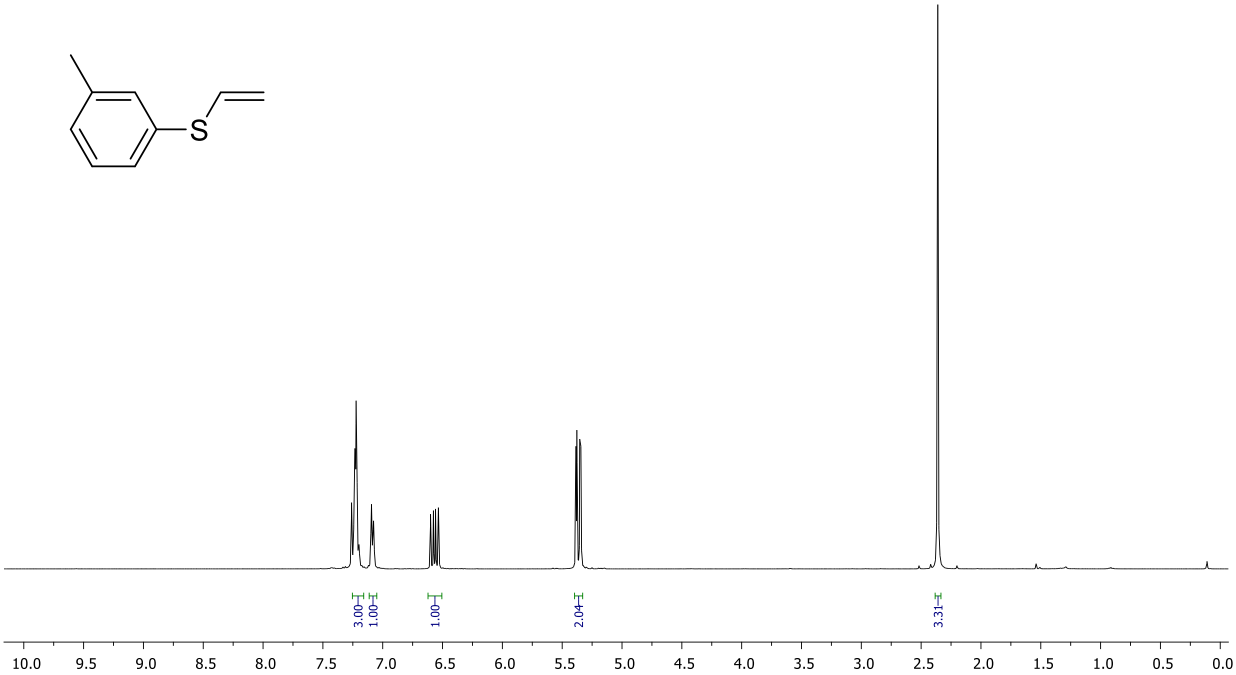


Figure S28. ^{1}H NMR spectrum of 3-methylphenyl vinyl sulfide (**2j**).

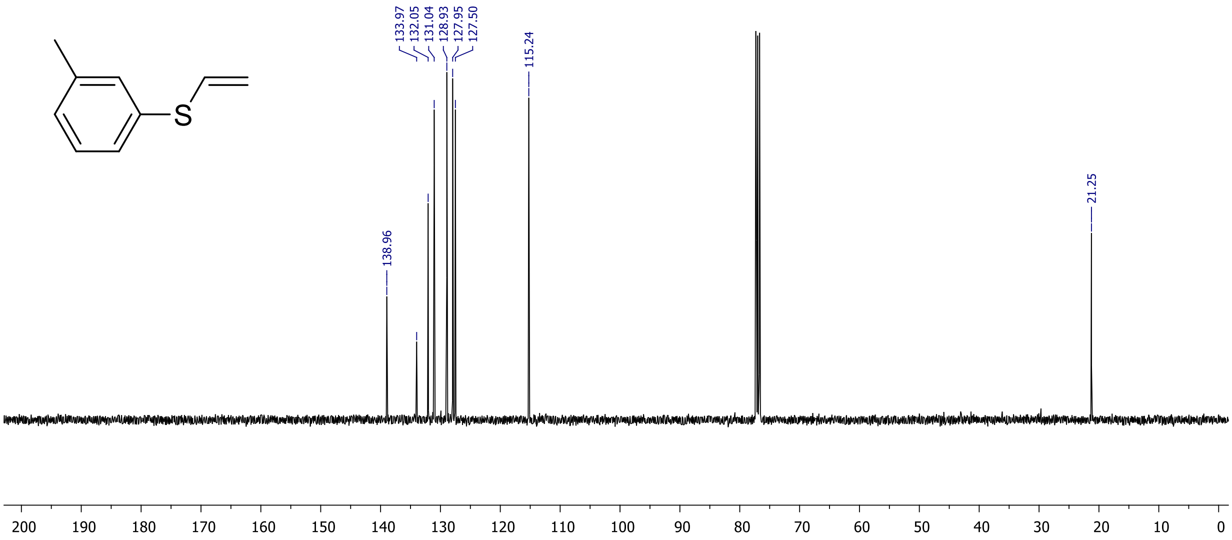


Figure S29. ^{13}C NMR spectrum of 3-methylphenyl vinyl sulfide (**2j**).

Z-1,2-Bis(3-methylphenylthio)ethene ***(3j)***

Yield – 63 %. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20 – 7.25 (m, 3H), 7.06 (ddd, 1H, *J* = 3.8, 1.5 Hz), 6.51 (s, 2H), 2.35 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.98, 134.99, 130.08, 128.94, 127.75, 126.54, 124.85, 21.30. HRMS (ESI): calcd. for $C_{16}H_{16}S_2$ $[M + Ag]^+$ 378.9739; found 378.9727.

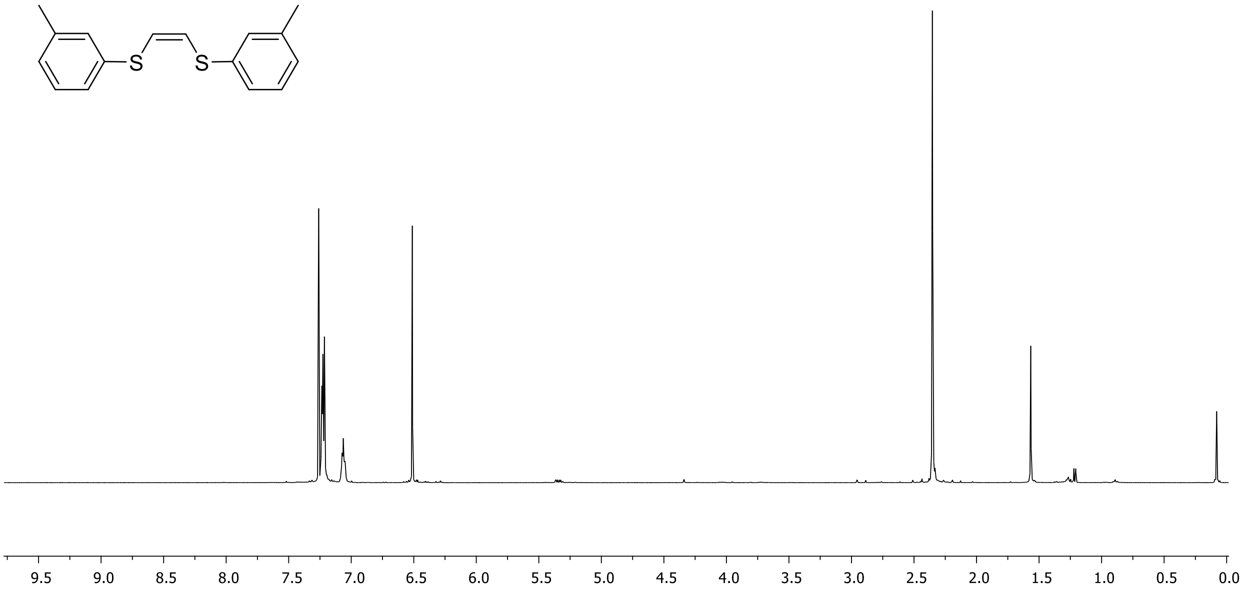


Figure S30. ^{1}H NMR spectrum of *Z*-1,2-*bis*(3-methylphenylthio)ethene (**3j**).

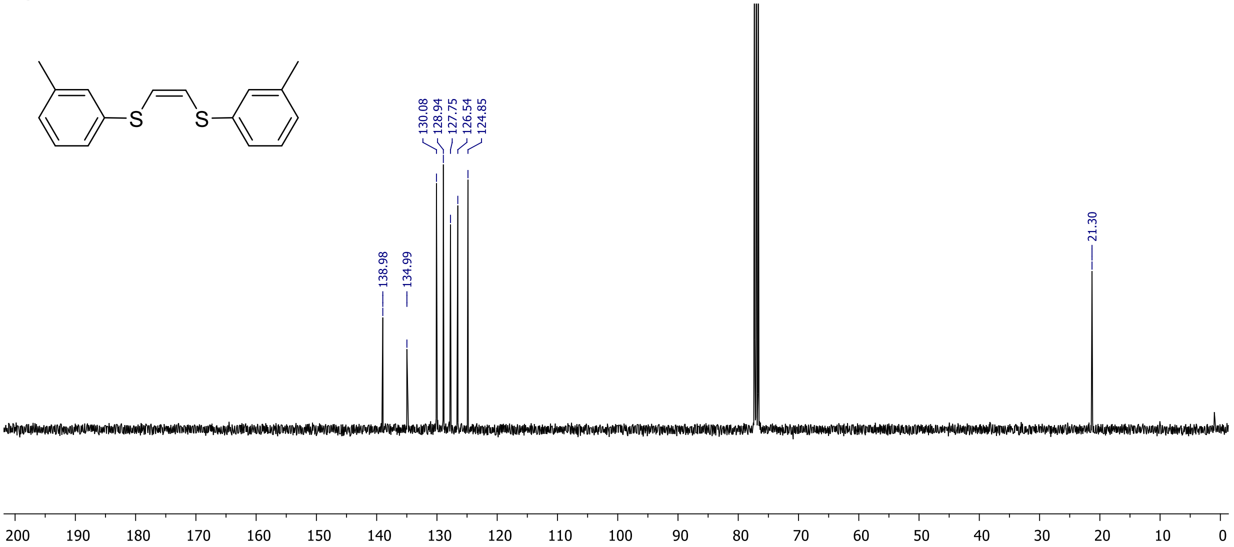


Figure S31. ^{13}C NMR spectrum of *Z*-1,2-*bis*(3-methylphenylthio)ethen (**3j**).

*2-Pyridyl vinyl sulfide **(2k)***

Yield – 92 %. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.46 (ddd, 1H, *J* = 5.0, 1.5, 1.0 Hz), 7.52 (ddd, 1H, *J* = 7.7, 1.8 Hz), 7.19 (d, 1H, *J* = 8.1 Hz), 7.11 (dd, 1H, *J* = 17.1, 9.8 Hz), 7.04 (ddd, 1H, *J* = 7.4, 4.9, 1.0 Hz), 5.59 (d, 1H, *J* = 17.1 Hz). 5.52 (d, 1H, *J* = 10.2 Hz). ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.71, 149.81, 136.43, 128.03, 122.14, 120.22, 117.05. MS: m/z (% of max intensity) 39 (35), 51 (60), 67 (59), 79 (64), 136 (100), 137 (65). HRMS (ESI): calcd. for C_7H_7NS $[M + Ag]^+$ 243.9345; found 243.9355.

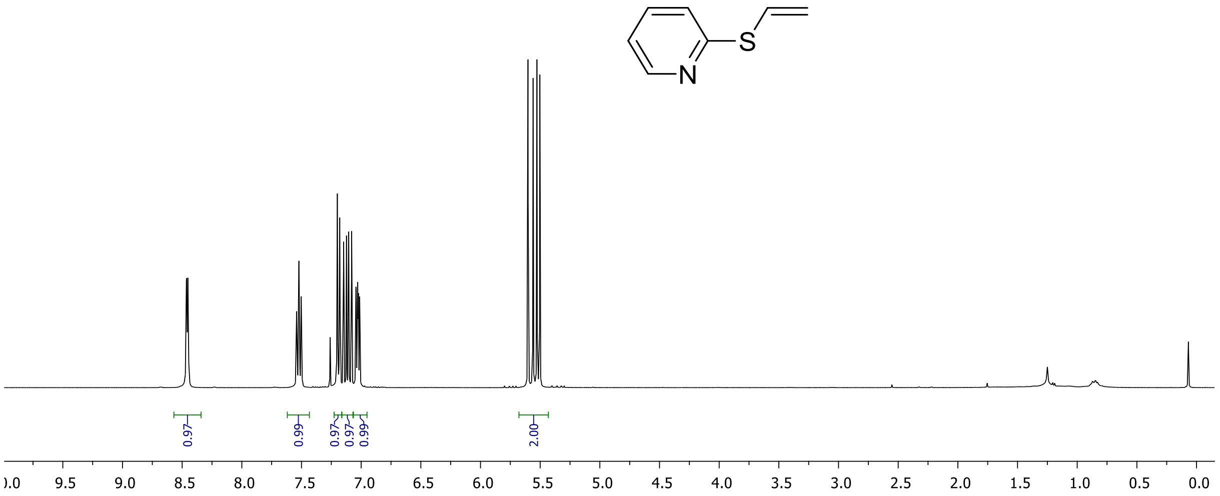


Figure S32. ^{1}H NMR spectrum of vinyl sulfide (**2k**).

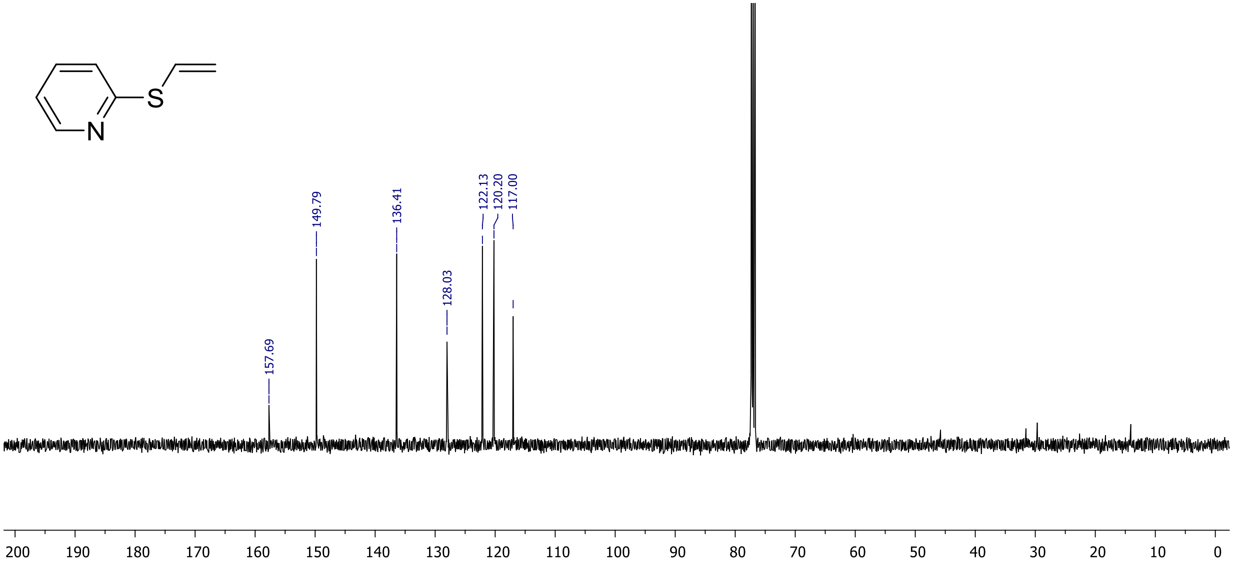


Figure S33. ^{13}C NMR spectrum of vinyl sulfide (**2k**).

Phenyl vinyl selenide ***(5)***

Yield – 28 %. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.49 – 7.56 (m, 2H), 7.28 – 7.36 (m, 3H), 6.85 (dd, 1H, 16.9, 9.5 Hz), 5.79 (d, 1H, 9.5 Hz), 5.55 (d, 1H, 17.0 Hz). ^{13}C NMR (100 MHz, CDCl$_3$) δ 133.08, 129.29, 129.24, 127.67, 127.49, 119.39. MS: m/z (% of max intensity) 39 (23), 51 (76), 77 (100), 91 (35), 104 (78), 157 (13), 181 (28), 183 (23), 184 (48). HRMS (ESI): calcd. for C_8H_8Se $[M + Ag]^+$ 290.8839; found 290.8837.

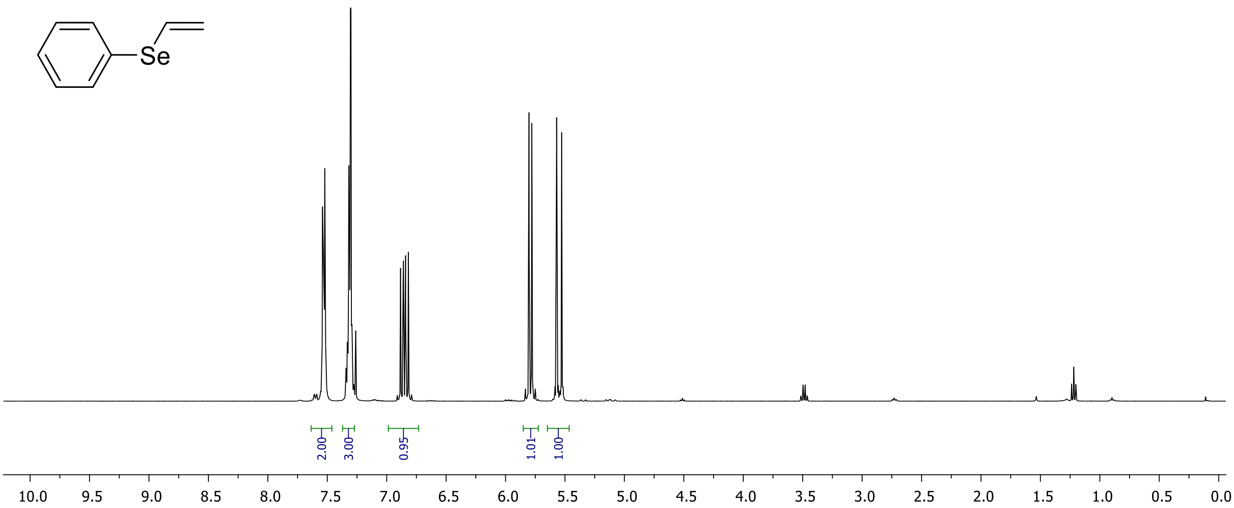


Figure S34. ^{1}H NMR spectrum of phenyl vinyl selenide (**5**).

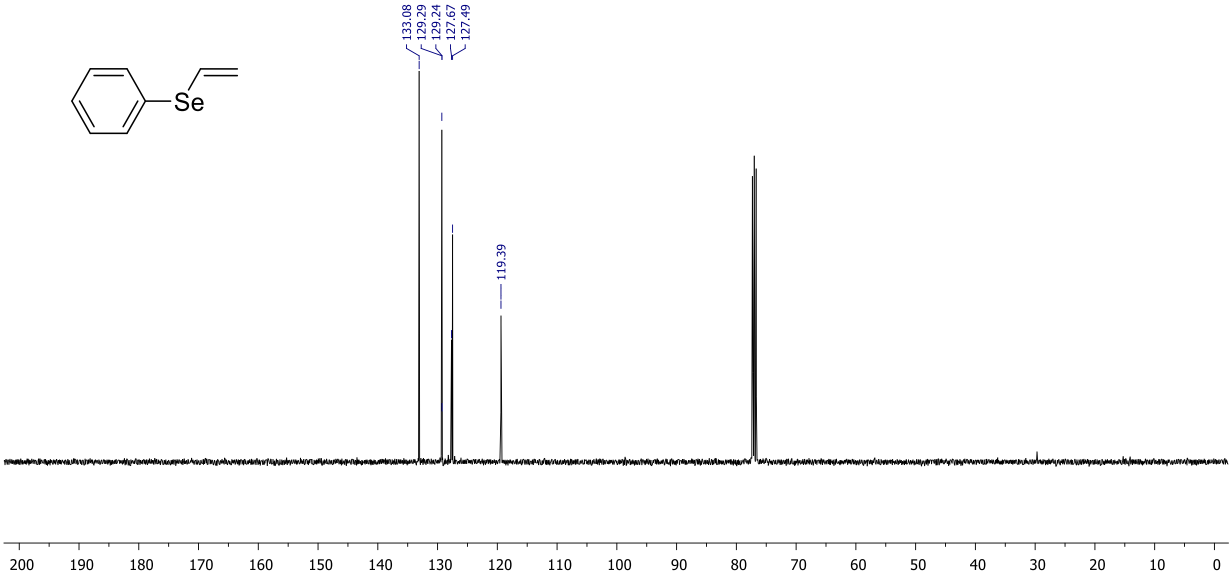


Figure S35. ^{13}C NMR spectrum of phenyl vinyl selenide (**5**).

Z-1,2-Bis(phenylselenyl)ethene ***(6)***

Yield – 35 %. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.46-7.51 (m, 2H), 7.28-7.35 (m, 3H), 6.90 (s, 2H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 134.35, 132.40, 129.89, 129.30, 127.50, 122.20. MS: m/z (% of max intensity) 39 (11), 51 (37), 65 (13), 77 (100), 91 (24), 102 (35), 153 (15), 157 (65), 183 (78), 336 (28), 338 (32), 340 (32). HRMS (ESI): calcd. for $C_{14}H_{12}Se_2$ [M + Ag]$^+$ 446.8320; found 446.8307.

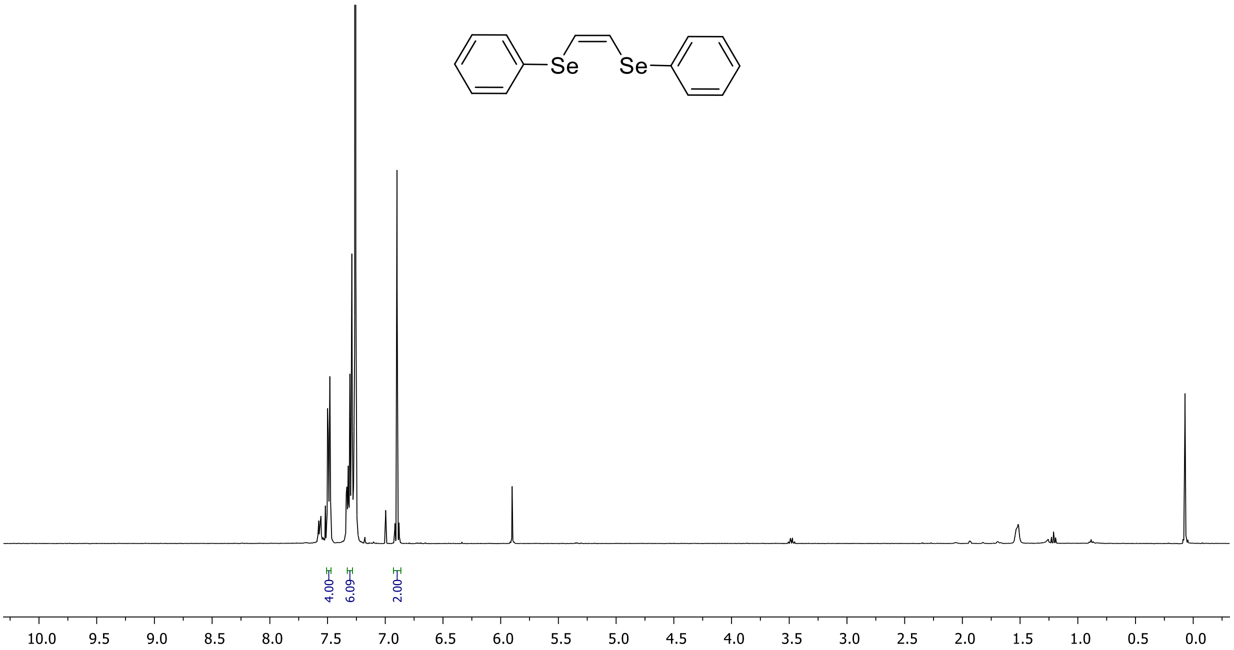


Figure S36. ^{1}H NMR spectrum of *Z*-1,2-bis(phenylselenyl)ethene (**6**).

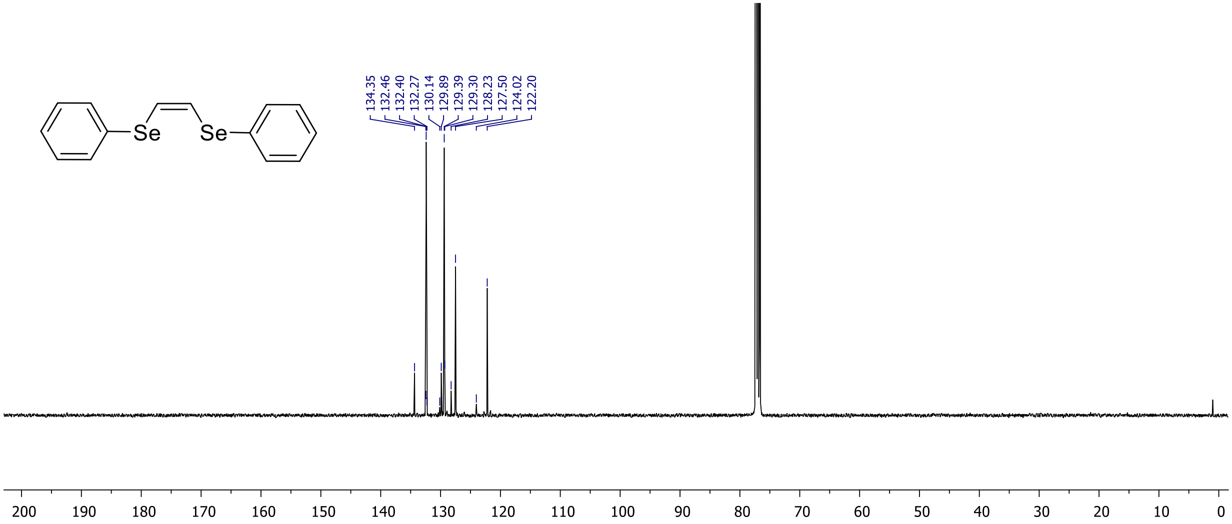


Figure S37. ^{13}C NMR spectrum of *Z*-1,2-bis(phenylselenyl)ethene (**6**).

5. X-ray data of *bis*((4,5-epoxycaryophyll-9-ylmethyl)thio)ethene (3e)

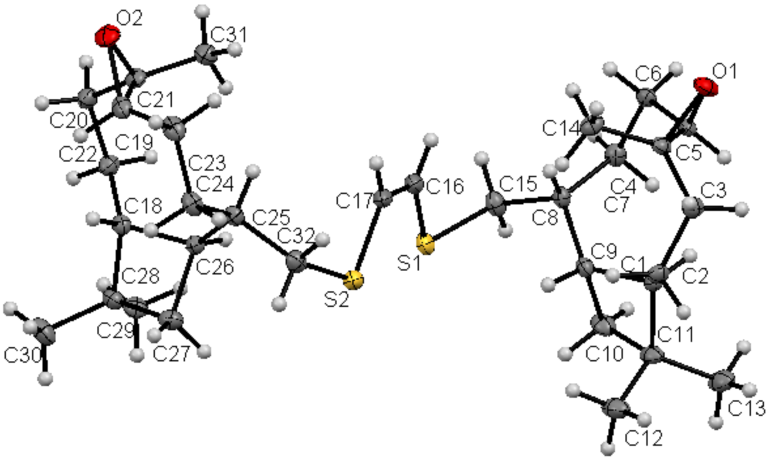


Figure 1. ORTEP representation of the compound (**3e**) with thermal ellipsoids at 50% probability

Crystal structure determination of compound 3e. The crystal data of **3e** have been deposited in CCDC with number 1502546.

Crystal Data for $C_{32}H_{52}O_2S_2$ (M =532.85 g/mol): monoclinic, space group $P2_1$ (no. 4), a = 11.8086(3) Å, b = 8.9786(2) Å, c = 14.7740(4) Å, β = 98.854(3)°, V = 1547.75(7) Å^3, Z = 2, T = 100.0(3) K, μ(MoKα) = 0.198 mm^{-1}, $Dcalc$ = 1.143 g/cm^3, 19755 reflections measured (5.326° ≤ 2Θ ≤ 54.996°), 7132 unique (R_{int} = 0.0271, R_{sigma} = 0.0351) which were used in all calculations. The final R_1 was 0.0343 (I > 2σ(I)) and wR_2 was 0.0794 (all data). Goodness-of-fit on F^2 - 1.037; Largest diff. peak/hole: 0.30/-0.16 eÅ^{-3}; Flack parameter - 0.01(2).

Table S2. Fractional Atomic Coordinates (×10^4) and Equivalent Isotropic Displacement Parameters (Å^2×10^3) for compound 3e. U_{eq} is defined as 1/3 of of the trace of the orthogonalised U_{IJ} tensor.

Atom	*x*	*y*	*z*	U(eq)
S1	50.4(5)	4995.6(7)	7081.5(4)	21.02(14)
S2	2727.8(5)	5326.7(6)	6866.7(4)	19.56(13)
C4	81.6(18)	10232(3)	9105.8(14)	15.5(4)
O2	5852.4(14)	329(2)	9812.8(11)	24.5(4)
O1	-374.1(15)	10692.1(19)	9930.0(11)	21.0(4)
C32	4239(2)	4913(3)	7198.9(16)	19.8(5)
C28	3781.3(18)	356(3)	6045.7(15)	17.7(5)
C29	2503.6(19)	35(3)	5776.4(15)	20.9(5)
C6	-1617(2)	8423(3)	9376.3(16)	17.2(5)

C12	-585(2)	10004(4)	5436.5(16)	27.7(6)
C11	-1475.8(19)	9974(3)	6082.5(14)	20.1(5)
C20	4330(2)	-914(3)	8669.1(16)	20.1(5)
C1	-943.5(18)	10010(3)	7123.1(14)	14.6(4)
C21	4785.3(19)	481(3)	9163.5(15)	18.3(5)
C22	5876(2)	1062(3)	8940.4(17)	19.6(5)
C3	269(2)	11452(3)	8438.7(16)	18.3(5)
C16	1153(2)	5194(3)	8019.5(15)	21.8(5)
C15	-1162(2)	5636(3)	7601.5(18)	21.6(5)
C13	-2390(2)	11151(3)	5799.9(18)	28.6(6)
C27	4049(2)	2046(3)	6010.4(16)	19.4(5)
C5	-1115.3(19)	9914(3)	9208.1(14)	15.7(4)
C18	4168.1(18)	449(3)	7108.2(15)	15.2(4)
C26	3905.3(19)	2151(3)	7035.4(15)	14.6(5)
C19	3600(2)	-564(3)	7737.3(16)	17.9(5)
C25	4521.6(19)	3385(3)	7644.8(16)	15.8(4)
C24	5839(2)	3241(3)	7908.1(17)	19.6(5)
C17	2252(2)	5285(3)	7936.9(15)	21.3(5)
C30	4472(2)	-688(3)	5530.9(18)	26.4(6)
C2	159(2)	10871(3)	7448.3(16)	17.4(5)
C7	-2054(2)	7661(3)	8455.8(17)	18.1(5)
C23	6204(2)	2661(3)	8888.1(17)	21.4(5)
C10	-1877(2)	8360(3)	6245.6(17)	22.7(5)
C9	-937.9(19)	8280(3)	7101.2(15)	15.8(5)
C31	3917(2)	1444(3)	9535.0(17)	20.3(5)
C14	1049.5(19)	9129(3)	9324.3(16)	19.3(5)
C8	-1068.1(19)	7271(3)	7912.3(16)	15.5(5)

Table S3. Anisotropic Displacement Parameters (Å^2×10^3) for compound 3e. The Anisotropic displacement factor exponent takes the form: $-2\pi^2[h^2a^{*2}U_{11}+2hka^*b^*U_{12}+\ldots]$.

Atom	U_{11}	U_{22}	U_{33}	U_{23}	U_{13}	U_{12}
S1	27.5(3)	16.4(3)	19.6(3)	-3.4(2)	5.1(2)	4.3(2)
S2	25.3(3)	18.1(3)	15.5(3)	1.3(2)	3.7(2)	4.2(2)
C4	19.8(10)	15.2(11)	11.7(9)	-2.4(9)	2.8(8)	-1.9(10)
O2	23.8(8)	27.5(10)	19.2(8)	0.4(8)	-6.7(6)	3.5(8)
O1	29.1(9)	20.9(9)	14.0(8)	-5.0(7)	6.3(7)	-5.4(7)
C32	22.5(11)	17.0(11)	20.8(11)	-1.5(10)	5.9(9)	-2.9(10)
C28	17.5(10)	21.1(12)	14.8(10)	-2.3(10)	3.4(8)	-0.2(10)
C29	20.7(11)	23.5(12)	17.3(11)	-3.0(11)	-0.6(8)	-3.4(11)
C6	16.2(11)	18.9(11)	17.7(11)	1.3(10)	6.6(9)	0.8(9)
C12	24.8(12)	42.2(17)	16.0(11)	2.6(13)	2.8(9)	4.2(13)
C11	17.8(10)	28.8(13)	12.8(10)	2.1(11)	-0.3(8)	3.6(11)
C20	24.1(12)	16.2(11)	19.3(12)	1.4(10)	1.5(10)	1.5(10)
C1	15.9(10)	16.0(11)	12.0(9)	1.2(9)	2.2(8)	2.2(9)
C21	17.4(10)	20.7(12)	15(1)	0.7(10)	-3.0(8)	3.7(10)
C22	15.6(11)	23.3(13)	18.3(11)	-4.2(10)	-2.4(9)	4.5(10)
C3	22.0(12)	15.6(11)	16.9(11)	0.1(9)	1.8(9)	-3.2(10)
C16	31.3(12)	19.2(13)	15.6(10)	0.2(10)	5.9(9)	8.5(11)
C15	21.7(11)	17.6(12)	26.6(13)	-4.2(10)	7(1)	-0.9(10)
C13	25.1(13)	39.3(17)	21.0(13)	7.3(12)	2(1)	9.3(12)
C27	19.4(11)	23.4(13)	15.4(11)	0.2(10)	3.3(9)	-3.2(10)
C5	19(1)	16.9(11)	11.5(9)	-2.0(9)	3.1(8)	3.1(9)
C18	13.7(10)	15.6(11)	15.8(10)	-1.8(9)	0.8(8)	-0.6(9)
C26	13.5(10)	15.5(11)	14.8(11)	0.5(9)	2.4(8)	-0.1(9)
C19	20.0(11)	15.1(11)	17.4(11)	-0.7(9)	-0.7(9)	-1.5(9)
C25	14.7(10)	16.5(11)	16.7(11)	-1.4(10)	3.9(8)	-1.4(9)
C24	16.6(11)	19.7(12)	23.0(12)	-5.7(10)	4.2(9)	-2.9(10)
C17	31.2(12)	18.7(12)	13.5(10)	0.7(10)	2.3(9)	8.3(11)

C30	24.5(12)	31.1(14)	24.7(13)	-11.2(12)	6.8(10)	-0.8(11)
C2	21.1(11)	15.6(11)	15.5(11)	3.2(9)	3.2(9)	-1.8(9)
C7	15.2(10)	17.0(12)	22.6(12)	-0.4(9)	4.5(9)	-2.1(9)
C23	14.5(11)	25.9(14)	22.7(13)	-6.8(10)	-1.0(9)	-0.4(10)
C10	20.3(12)	29.2(14)	17.3(12)	-5.3(11)	-1.6(9)	-0.2(11)
C9	15.6(10)	16.7(11)	15.2(11)	-3.2(10)	2.4(9)	1.3(9)
C31	20.6(11)	21.3(12)	19.0(12)	-1.1(10)	3.1(9)	-0.6(10)
C14	16.0(11)	21.6(12)	19.0(12)	3.3(10)	-1.1(9)	-2.2(10)
C8	14.6(10)	13.4(11)	18.8(11)	-1.5(9)	3.6(9)	-0.2(9)

Table S4. Bond Lengths for compound 3e.

Atom	**Atom**	**Length/Å**	**Atom**	**Atom**	**Length/Å**
S1	C16	1.759(2)	C11	C10	1.555(4)
S1	C15	1.819(2)	C20	C21	1.507(3)
S2	C32	1.815(2)	C20	C19	1.540(3)
S2	C17	1.758(2)	C1	C2	1.527(3)
C4	O1	1.464(3)	C1	C9	1.554(3)
C4	C3	1.512(3)	C21	C22	1.473(3)
C4	C5	1.472(3)	C21	C31	1.507(3)
C4	C14	1.509(3)	C22	C23	1.492(4)
O2	C21	1.468(3)	C3	C2	1.540(3)
O2	C22	1.451(3)	C16	C17	1.324(3)
O1	C5	1.451(3)	C15	C8	1.537(3)
C32	C25	1.537(3)	C27	C26	1.552(3)
C28	C29	1.527(3)	C18	C26	1.560(3)
C28	C27	1.553(4)	C18	C19	1.527(3)
C28	C18	1.568(3)	C26	C25	1.538(3)
C28	C30	1.521(3)	C25	C24	1.550(3)
C6	C5	1.500(3)	C24	C23	1.537(3)

C6	C7	1.539(3)	C7	C8	1.553(3)
C12	C11	1.526(3)	C10	C9	1.549(3)
C11	C1	1.569(3)	C9	C8	1.529(3)
C11	C13	1.523(4)			

Table S5. Bond Angles for compound 3e.

Atom	**Atom**	**Atom**	**Angle/°**	**Atom**	**Atom**	**Atom**	**Angle/°**
C16	S1	C15	99.82(11)	C22	C21	C31	123.1(2)
C17	S2	C32	100.92(11)	O2	C22	C21	60.26(15)
O1	C4	C3	116.6(2)	O2	C22	C23	121.5(2)
O1	C4	C5	59.20(13)	C21	C22	C23	126.5(2)
O1	C4	C14	111.74(18)	C4	C3	C2	111.99(19)
C5	C4	C3	116.53(19)	C17	C16	S1	123.42(18)
C5	C4	C14	123.9(2)	C8	C15	S1	113.76(16)
C14	C4	C3	115.62(19)	C26	C27	C28	88.48(17)
C22	O2	C21	60.61(14)	C4	C5	C6	126.9(2)
C5	O1	C4	60.67(13)	O1	C5	C4	60.13(13)
C25	C32	S2	115.98(16)	O1	C5	C6	121.14(19)
C29	C28	C27	111.9(2)	C26	C18	C28	87.67(17)
C29	C28	C18	113.25(18)	C19	C18	C28	119.32(19)
C27	C28	C18	87.24(18)	C19	C18	C26	121.61(19)
C30	C28	C29	109.7(2)	C27	C26	C18	87.55(17)
C30	C28	C27	117.3(2)	C25	C26	C27	120.15(19)
C30	C28	C18	115.9(2)	C25	C26	C18	126.44(19)
C5	C6	C7	109.72(19)	C18	C19	C20	115.33(19)
C12	C11	C1	113.68(18)	C32	C25	C26	109.89(19)
C12	C11	C10	111.7(2)	C32	C25	C24	108.97(19)
C13	C11	C12	110.1(2)	C26	C25	C24	116.96(19)
C13	C11	C1	114.5(2)	C23	C24	C25	112.91(19)

C13	C11	C10	118.0(2)	C16	C17	S2	122.51(18)
C10	C11	C1	87.32(18)	C1	C2	C3	114.41(19)
C21	C20	C19	111.9(2)	C6	C7	C8	112.43(19)
C2	C1	C11	120.83(18)	C22	C23	C24	109.7(2)
C2	C1	C9	120.41(19)	C9	C10	C11	88.43(18)
C9	C1	C11	87.77(18)	C10	C9	C1	88.06(18)
O2	C21	C20	116.5(2)	C8	C9	C1	125.09(19)
O2	C21	C22	59.13(14)	C8	C9	C10	121.4(2)
O2	C21	C31	112.25(19)	C15	C8	C7	110.16(19)
C20	C21	C31	116.2(2)	C9	C8	C15	110.07(19)
C22	C21	C20	116.4(2)	C9	C8	C7	116.5(2)

Table S6. Hydrogen Atom Coordinates (Å×10^4) and Isotropic Displacement Parameters (Å^2×10^3) for compound 3e.

Atom	***x***	***y***	***z***	**U(eq)**
H32A	4610	4982	6658	24
H32B	4572	5676	7624	24
H29A	2070	714	6090	31
H29B	2346	-969	5943	31
H29C	2292	158	5127	31
H6A	-2246	8548	9722	21
H6B	-1039	7805	9733	21
H12A	-254	10981	5438	42
H12B	-946	9759	4827	42
H12C	6	9290	5637	42
H20A	3868	-1457	9047	24
H20B	4968	-1545	8574	24
H1	-1533	10341	7478	18
H22	6201	433	8502	23
H3A	1027	11875	8616	22

H3B	-289	12237	8467	22
H16	955	5236	8604	26
H15A	-1857	5514	7164	26
H15B	-1229	5014	8127	26
H13A	-2041	12119	5834	43
H13B	-2952	11113	6204	43
H13C	-2753	10964	5183	43
H27A	4818	2265	5895	23
H27B	3482	2608	5603	23
H5	-1664	10576	8840	19
H18	5000	309	7241	18
H26	3084	2267	7053	18
H19A	3401	-1496	7420	21
H19B	2892	-100	7847	21
H25	4200	3377	8218	19
H24A	6126	2569	7482	24
H24B	6187	4208	7850	24
H17	2793	5330	8465	26
H30A	4335	-1700	5695	40
H30B	5273	-465	5690	40
H30C	4243	-559	4884	40
H2A	200	11711	7042	21
H2B	807	10227	7400	21
H7A	-2594	8317	8088	22
H7B	-2458	6756	8569	22
H23A	7027	2766	9060	26
H23B	5833	3242	9312	26
H10A	-2652	8298	6384	27
H10B	-1763	7665	5765	27

H9	-228	7981	6885	19
H31A	3641	935	10029	30
H31B	3288	1645	9057	30
H31C	4270	2365	9755	30
H14A	1698	9613	9675	29
H14B	1260	8754	8765	29
H14C	807	8319	9672	29
H8	-353	7356	8345	19

Experimental

A suitable crystal of $C_{32}H_{52}O_2S_2$ **(3e)** was mounted on a **Xcalibur, Eos** diffractometer. The crystal was kept at 100.0(3) K during data collection. Using Olex2,[1] the structure was solved with the ShelXS[2] structure solution program using Direct Methods and refined with the ShelXL[3] refinement package using Least Squares minimization.

6. X-ray data of di(4,5-epoxycaryophyll-9-ylmetyl)disulfide (1e)

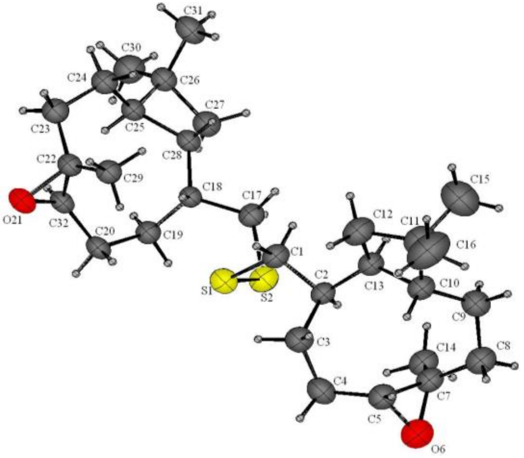


Figure 1. ORTEP representation of the compound (**1e**) with thermal ellipsoids at 50% probability

Crystal structure determination of compound 1e. The crystal data of disulfide **1e** have been deposited in CCDC with number 1506283.

Crystal Data for $C_{30}H_{50}O_2S_2$, (M =506.82 g/mol): monoclinic, space group $P2_1$ (no. 4), a = 8.6814(6) Å, b = 10.7581(8) Å, c = 16.3612(10) Å, β = 101.852(6)°, V = 1495.48(17) Å^3, T = 295(2), Z = 2, μ(Mo Kα) = 0.201 mm^{-1}, $Dcalc$ = 1.126 g/cm^3, 7570 reflections measured ($4.56 \leq 2\Theta \leq 56.54°$), 6214 unique ($R_{\text{int}}$ = 0.0296) which were used in all calculations. The final wR_2 was 0.1054 (all data) and R_1 was 0.0505 (>2sigma(I)). Goodness-of-fit on F^2 - 1.000; Largest diff. peak/hole: 0.17/-0.20 eÅ^{-3}; Flack parameter - 0.01(7).

Table S7. Fractional Atomic Coordinates (×10^4) and Equivalent Isotropic Displacement Parameters (Å^2×10^3) for compound 1e. U_{eq} is defined as 1/3 of of the trace of the orthogonalised U_{IJ} tensor.

Atom	*x*	*y*	*z*	U(eq)
S1	7670.2(10)	7170.6(8)	3639.7(5)	61.6(2)
S2	9685.4(10)	6547.1(9)	4374.8(6)	66.8(3)
O6	11496(3)	6521(3)	833.9(14)	81.4(7)
O21	4382(3)	9126.8(19)	5682.2(14)	66.0(6)
C1	7018(4)	5884(3)	2938.3(18)	56.9(8)
C2	7949(3)	5725(3)	2249.9(16)	46.0(7)
C3	7706(4)	6847(3)	1658.1(19)	64.4(9)
C4	9235(4)	7351(3)	1452(2)	70.6(10)
C5	9894(4)	6455(4)	930(2)	62.8(9)
C7	10967(4)	5434(3)	1225.2(19)	58.1(9)
C8	10762(4)	4267(4)	725(2)	71.8(10)
C9	9541(4)	3402(3)	981(2)	68.8(10)
C10	7976(3)	4000(3)	1018.3(18)	57.6(9)
C11	6465(4)	3210(4)	877(2)	83.7(13)
C12	5867(4)	4070(4)	1502(2)	76.9(11)
C13	7585(4)	4446(3)	1856.8(19)	52.4(8)
C14	11806(4)	5293(4)	2123.6(19)	68.2(10)
C15	6757(6)	1889(5)	1213(3)	123.7(19)
C16	5487(5)	3204(6)	-8(3)	133(2)
C17	9082(3)	5714(3)	5227.2(19)	56.3(8)
C18	7917(3)	6396(3)	5646.4(18)	44.1(7)
C19	8478(3)	7687(3)	5977.9(19)	52.1(8)
C20	7293(3)	8713(3)	5672(2)	54.9(8)
C22	4490(3)	7772(3)	5696(2)	52.2(8)
C23	3743(3)	7122(3)	6328(2)	61.2(8)
C24	4510(4)	5872(3)	6611(2)	59.6(9)
C25	6301(4)	5905(3)	6867.6(17)	48.3(7)
C26	7188(4)	4942(3)	7505.5(19)	57.4(8)
C27	8539(4)	4986(3)	7019(2)	66.3(9)
C28	7365(3)	5515(3)	6258.4(17)	49.5(7)
C29	4149(3)	7219(3)	4835.9(18)	57.3(8)
C30	7612(4)	5371(4)	8409(2)	80.5(11)
C31	6376(5)	3687(3)	7462(2)	80.5(11)
C32	5862(4)	8538(3)	6034(2)	51.4(7)

Table S8. Anisotropic Displacement Parameters (Å^2×10^3) for compound 1e. The Anisotropic displacement factor exponent takes the form: $-2\pi^2[h^2a^{*2}U_{11}+...+2hka\times b\times U_{12}]$

Atom	U_{11}	U_{22}	U_{33}	U_{23}	U_{13}	U_{12}
S1	71.4(5)	67.8(6)	49.8(4)	-5.7(4)	22.3(4)	7.6(5)
S2	48.2(4)	92.3(7)	63.7(5)	-13.3(5)	20.0(4)	-5.6(5)

O6	79.4(16)	108(2)	63.9(15)	17.4(15)	31.5(13)	-20.6(16)
O21	73.6(15)	50.5(14)	75.3(15)	4.8(12)	18.5(13)	22.1(12)
C1	49.4(17)	79(2)	44.4(16)	-8.6(17)	14.6(14)	-4.5(17)
C2	43.9(17)	64(2)	31.9(14)	1.0(14)	12.2(13)	1.8(16)
C3	69(2)	77(3)	47.2(17)	10.4(16)	13.7(16)	22.7(19)
C4	93(3)	63(2)	59(2)	22.7(19)	22.2(19)	2(2)
C5	64(2)	81(2)	44.9(18)	11.8(19)	15.6(16)	-8(2)
C7	48.9(18)	84(2)	45.8(17)	5.2(18)	19.6(15)	-7.0(18)
C8	62(2)	100(3)	59(2)	-10(2)	25.7(18)	7(2)
C9	70(2)	76(2)	65(2)	-27(2)	24.7(18)	-5(2)
C10	53.5(18)	80(2)	41.1(16)	-15.3(16)	13.7(15)	-14.1(18)
C11	74(3)	115(4)	67(2)	-38(2)	24(2)	-38(3)
C12	55(2)	117(3)	62(2)	-19(2)	19.6(18)	-25(2)
C13	51.7(18)	68(2)	39.2(16)	-4.4(16)	14.1(15)	-5.8(17)
C14	53.0(19)	95(3)	55.3(19)	8.0(19)	8.0(16)	-3.2(19)
C15	142(4)	110(4)	136(4)	-48(3)	67(3)	-67(3)
C16	80(3)	240(7)	79(3)	-72(4)	12(2)	-58(3)
C17	42.5(17)	69(2)	55.2(18)	-5.2(17)	4.1(14)	5.0(16)
C18	38.8(15)	48.3(18)	43.6(15)	-6.8(14)	4.9(13)	3.3(14)
C19	45.0(17)	60(2)	51.0(18)	-7.6(15)	8.6(14)	-6.9(16)
C20	62(2)	42.2(18)	59.3(19)	-6.7(15)	9.8(17)	-10.1(16)
C22	47.0(17)	50.7(19)	58.5(19)	2.5(15)	10.1(15)	10.4(15)
C23	49.3(17)	69(2)	67(2)	2.0(19)	16.2(16)	5.2(18)
C24	54.0(19)	63(2)	61.6(19)	8.4(17)	10.9(16)	-3.2(17)
C25	52.1(18)	48.5(19)	43.1(17)	1.9(15)	6.9(14)	5.0(16)
C26	66(2)	59(2)	44.8(17)	5.1(15)	6.3(16)	4.1(18)
C27	67(2)	70(2)	59(2)	13.7(18)	8.3(18)	21.0(19)
C28	55.9(18)	46.6(18)	44.7(16)	-2.0(14)	7.1(15)	2.2(15)
C29	46.5(16)	63(2)	59.0(18)	-0.4(18)	2.5(15)	0.2(17)
C30	92(3)	98(3)	47.8(19)	1.8(19)	6.7(19)	4(2)
C31	106(3)	60(2)	71(2)	13.8(19)	8(2)	0(2)
C32	61.8(19)	41.8(17)	49.5(19)	-3.2(15)	8.9(16)	9.2(17)

Table S9. Bond Lengths for disulfide 1e.

Atom	Atom	Length/Å	Atom	Atom	Length/Å
S1	S2	2.0230(13)	C11	C15	1.526(6)
S1	C1	1.813(3)	C11	C16	1.521(6)
S2	C17	1.823(3)	C12	C13	1.539(4)
O6	C5	1.433(4)	C17	C18	1.521(4)
O6	C7	1.453(4)	C18	C19	1.534(4)
O21	C22	1.460(4)	C18	C28	1.525(4)
O21	C32	1.442(4)	C19	C20	1.522(4)
C1	C2	1.525(4)	C20	C32	1.493(4)
C2	C3	1.535(4)	C22	C23	1.501(4)

C2	C13	1.524(4)
C3	C4	1.534(4)
C4	C5	1.479(5)
C5	C7	1.458(5)
C7	C8	1.489(5)
C7	C14	1.508(4)
C8	C9	1.532(5)
C9	C10	1.516(4)
C10	C11	1.540(4)
C10	C13	1.555(4)
C11	C12	1.547(5)
C22	C29	1.501(4)
C22	C32	1.460(4)
C23	C24	1.529(4)
C24	C25	1.525(4)
C25	C26	1.557(4)
C25	C28	1.549(4)
C26	C27	1.547(4)
C26	C30	1.520(4)
C26	C31	1.518(5)
C27	C28	1.546(4)

Table S10. Bond Angles for disulfide 1e.

Atom	Atom	Atom	Angle/°
C1	S1	S2	104.04(11)
C17	S2	S1	105.57(10)
C5	O6	C7	60.7(2)
C32	O21	C22	60.43(18)
C2	C1	S1	114.2(2)
C1	C2	C3	110.6(2)
C13	C2	C1	108.5(2)
C13	C2	C3	117.0(2)
C4	C3	C2	113.8(2)
C5	C4	C3	110.6(3)
O6	C5	C4	122.0(3)
O6	C5	C7	60.3(2)
C7	C5	C4	126.6(3)
O6	C7	C5	59.0(2)
O6	C7	C8	116.8(3)
O6	C7	C14	112.2(3)
C5	C7	C8	117.2(3)
C5	C7	C14	123.1(3)
C8	C7	C14	115.5(3)
C7	C8	C9	111.9(3)
C10	C9	C8	115.5(3)
C9	C10	C11	120.1(3)
C9	C10	C13	121.8(3)
C11	C10	C13	88.2(2)
C10	C11	C12	87.8(3)
C15	C11	C10	112.8(3)
C15	C11	C12	111.8(3)
C16	C11	C10	115.9(3)
C16	C11	C12	115.8(4)
C16	C11	C15	111.0(4)
C2	C13	C12	119.8(3)
C12	C13	C10	87.6(2)
C18	C17	S2	115.5(2)
C17	C18	C19	113.8(2)
C17	C18	C28	108.9(3)
C28	C18	C19	116.7(2)
C20	C19	C18	113.4(2)
C32	C20	C19	109.9(2)
O21	C22	C23	116.1(3)
O21	C22	C29	112.4(3)
O21	C22	C32	59.17(19)
C29	C22	C23	115.5(3)
C32	C22	C23	115.9(3)
C32	C22	C29	124.5(3)
C22	C23	C24	113.3(3)
C25	C24	C23	114.8(3)
C24	C25	C26	120.3(3)
C24	C25	C28	121.7(3)
C28	C25	C26	88.5(2)
C27	C26	C25	87.6(2)
C30	C26	C25	115.9(3)
C30	C26	C27	115.7(3)
C31	C26	C25	113.5(3)
C31	C26	C27	113.4(3)
C31	C26	C30	109.4(3)
C28	C27	C26	89.0(2)
C18	C28	C25	124.3(3)
C18	C28	C27	120.9(3)
C27	C28	C25	87.9(2)
O21	C32	C20	122.1(3)

C13	C12	C11	88.6(2)	O21	C32	C22	60.41(19)
C2	C13	C10	125.9(3)	C22	C32	C20	127.0(3)

Table S11. Torsion Angles for disulfide 1e.

A	**B**	**C**	**D**	**Angle/°**
S1	S2	C17	C18	-48.1(2)
S1	C1	C2	C3	-65.0(3)
S1	C1	C2	C13	165.4(2)
S2	S1	C1	C2	-75.4(2)
S2	C17	C18	C19	-55.4(3)
S2	C17	C18	C28	172.41(19)
O6	C5	C7	C8	-106.3(3)
O6	C5	C7	C14	97.7(3)
O6	C7	C8	C9	-153.3(3)
O21	C22	C23	C24	-152.4(3)
O21	C22	C32	C20	-109.8(3)
C1	S1	S2	C17	-86.46(15)
C1	C2	C3	C4	134.0(3)
C1	C2	C13	C10	165.9(3)
C1	C2	C13	C12	55.2(4)
C2	C3	C4	C5	68.8(3)
C3	C2	C13	C10	39.9(4)
C3	C2	C13	C12	-70.8(4)
C3	C4	C5	O6	-162.8(3)
C3	C4	C5	C7	-88.0(4)
C4	C5	C7	O6	-109.7(4)
C4	C5	C7	C8	144.0(3)
C4	C5	C7	C14	-12.0(5)
C5	O6	C7	C8	107.1(3)
C5	O6	C7	C14	-116.4(3)
C5	C7	C8	C9	-86.2(4)
C7	O6	C5	C4	117.0(3)
C7	C8	C9	C10	50.4(4)
C8	C9	C10	C11	152.8(3)
C8	C9	C10	C13	-98.7(4)
C9	C10	C11	C12	147.1(3)
C9	C10	C11	C15	34.3(4)
C9	C10	C11	C16	-95.2(5)
C9	C10	C13	C2	88.5(4)
C9	C10	C13	C12	-145.9(3)
C10	C11	C12	C13	-21.1(3)
C11	C10	C13	C2	-146.7(3)
C11	C10	C13	C12	-21.0(3)
C11	C12	C13	C2	151.6(3)

C11	C12	C13	C10	20.9(3)
C13	C2	C3	C4	-101.1(3)
C13	C10	C11	C12	20.9(3)
C13	C10	C11	C15	-91.9(3)
C13	C10	C11	C16	138.6(4)
C14	C7	C8	C9	71.6(4)
C15	C11	C12	C13	92.6(4)
C16	C11	C12	C13	-138.9(4)
C17	C18	C19	C20	127.2(3)
C17	C18	C28	C25	173.8(3)
C17	C18	C28	C27	62.9(3)
C18	C19	C20	C32	67.0(3)
C19	C18	C28	C25	43.1(4)
C19	C18	C28	C27	-67.7(4)
C19	C20	C32	O21	-161.7(3)
C19	C20	C32	C22	-86.6(4)
C22	O21	C32	C20	117.4(3)
C22	C23	C24	C25	49.0(4)
C23	C22	C32	O21	-106.3(3)
C23	C22	C32	C20	143.9(3)
C23	C24	C25	C26	153.4(3)
C23	C24	C25	C28	-97.6(4)
C24	C25	C26	C27	146.3(3)
C24	C25	C26	C30	-96.1(4)
C24	C25	C26	C31	31.8(4)
C24	C25	C28	C18	88.2(4)
C24	C25	C28	C27	-145.2(3)
C25	C26	C27	C28	-20.0(2)
C26	C25	C28	C18	-146.6(3)
C26	C25	C28	C27	-19.9(2)
C26	C27	C28	C18	149.5(3)
C26	C27	C28	C25	20.1(2)
C28	C18	C19	C20	-104.5(3)
C28	C25	C26	C27	19.9(2)
C28	C25	C26	C30	137.5(3)
C28	C25	C26	C31	-94.6(3)
C29	C22	C23	C24	72.7(3)
C29	C22	C32	O21	97.4(3)
C29	C22	C32	C20	-12.4(5)
C30	C26	C27	C28	-137.7(3)
C31	C26	C27	C28	94.7(3)
C32	O21	C22	C23	105.9(3)
C32	O21	C22	C29	-117.9(3)
C32	C22	C23	C24	-85.7(3)

Table S12. Hydrogen Atom Coordinates (Å×10^4) and Isotropic Displacement Parameters (Å^2×10^3) for disulfide 1e.

Atom	***X***	***y***	***z***	**U(eq)**
H1A	7096	5123	3262	68
H1B	5918	6007	2682	68
H2	9070(30)	5710(20)	2561(14)	32(6)
H3A	7000	6609	1142	77
H3B	7202	7507	1911	77
H4A	9024	8135	1156	85
H4B	9995	7503	1965	85
H5	9180(30)	6270(30)	360(18)	58(9)
H8A	11764	3837	800	86
H8B	10434	4472	138	86
H9A	9348	2717	588	83
H9B	9985	3057	1526	83
H10	7805	4697	624	69
H12A	5210	4749	1241	92
H12B	5371	3631	1898	92
H13	7980(30)	3820(30)	2303(17)	44(8)
H14A	11744	6060	2415	102
H14B	12890	5087	2146	102
H14C	11318	4642	2381	102
H15A	7389	1916	1768	185
H15B	7297	1423	858	185
H15C	5768	1497	1226	185
H16A	6104	2875	-383	200
H16B	5169	4038	-171	200
H16C	4571	2696	-30	200
H17A	8615	4929	5013	68
H17B	10014	5526	5648	68
H18	7010(30)	6500(20)	5177(14)	33(6)
H19A	8691	7670	6583	63
H19B	9457	7879	5807	63
H20A	7763	9516	5838	66
H20B	7001	8693	5067	66
H23A	2637	6988	6090	73
H23B	3810	7656	6812	73
H24A	4089	5575	7080	72
H24B	4216	5278	6160	72
H25	6570(40)	6710(30)	7080(20)	69(10)
H27A	9380	5555	7254	80
H27B	8953	4174	6921	80
H28	6857	4806	5935	59
H29A	4790	7618	4500	86

H29B	3058	7339	4586	86
H29C	4380	6345	4871	86
H30A	6672	5440	8629	121
H30B	8123	6166	8436	121
H30C	8309	4778	8732	121
H31A	6204	3377	6901	121
H31B	5383	3776	7628	121
H31C	7027	3115	7830	121
H32	6130(30)	8570(30)	6643(19)	53(8)

Experimental

A suitable crystal of **1e** was mounted on a **Xcalibur, Eos** diffractometer. The crystal was kept at 100.0(3) K during data collection. Using Olex2,[1] the structure was solved with the ShelXS[2] structure solution program using Direct Methods and refined with the ShelXL[3] refinement package using Least Squares minimization.

7. Cytotoxic and antiviral data

Viruses and cells. Influenza virus A/Puerto Rico/8/34 (H1N1) was obtained from the collection of viruses of Influenza Research Institute. Prior to experiment, virus was propagated in the allantoic cavity of 10-12 day old chicken embryos for 48 hours at 36 °C. Infectious titer of the virus was determined in MDCK cells (ATCC # CCL-34) in 96-wells plates in alpha-MEM medium with 10% fetal bovine serum.

Toxicity studies. Microtetrazolium test (MTT) was used to study cytotoxicity of the compounds (Mossman, 1983). Briefly, series of two-fold dilutions of each compound (1000–4 μg/ml) in MEM were prepared. MDCK cells were incubated for 48 h at 37°C in 5% CO_2 in the presence of the dissolved substances. The degree of destruction of the cell monolayer was then evaluated in the microtetrazolium test (MTT). The cells were washed twice with saline, and a solution of 3-(4,5-dimethylthiazolyl-2)-2,5-diphenyltetrazolium bromide (ICN Biochemicals Inc., Aurora, Ohio) (0.5 mg/ml) in phosphate-buffered saline was added to the wells. After 1 h incubation, the wells were washed and the formazan residue dissolved in DMSO (0.1 ml per well). The optical density of cells was then measured on a Victor 1440 multifunctional reader (Perkin Elmer, Finland) at 535 nm and plotted against concentration of the compounds. Each concentration was tested in three parallels. The 50% cytotoxic dose (CC_{50}) of each compound (i.e., the compound concentration that causes the death of 50% cells in a culture, or decreasing the optical density twice as compared to the control wells) was calculated from the data obtained.

Determination of the antiviral activity. The compounds in appropriate concentrations were incubated with MDCK cells for 1 h at 36 °C. The cell culture was then infected with viruses at m.o.i 0.01. The plates were incubated for 24 h at 36 °C in the presence of 5% CO_2. 10-fold dilutions were then prepared from the culture medium and used for infecting of MDCK cells in the plates. The plates were incubated for 48 h at 36 °C in the presence of 5% CO_2. The presence of the virus was estimated by hemagglutination reaction with chicken erythrocytes. Each concentration of the compounds was tested in three parallels. The antiviral activity of the compounds was estimated by the decrease in the virus titre compared to the control. The 50% effective dose (IC_{50}) of the compound, i.e., the concentration at which the virus production decreased twice compared to placebo control, and the selectivity index (the ratio of CC_{50} to IC_{50}) were calculated from the data obtained.

8. References

1. O.V. Dolomanov, L.J. Bourhis, R.J. Gildea, J.A.K. Howard and H. Puschmann, *J. Appl. Crystallogr.*, 2009, **42**, 339.
2. G.M. Sheldrick, *Acta Crystallogr.*, 2008, **A64**, 112.
3. G.M. Sheldrick, *Acta Crystallogr.*, 2015, **C71**, 3.