

First synthesis and characterization of isolable thioselenenic acid, triptycene-9-thioselenenic acid†

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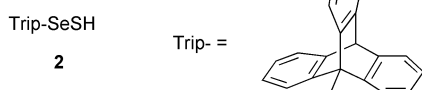
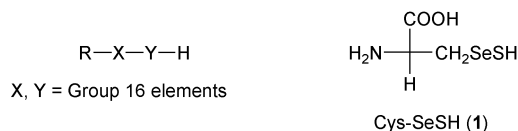
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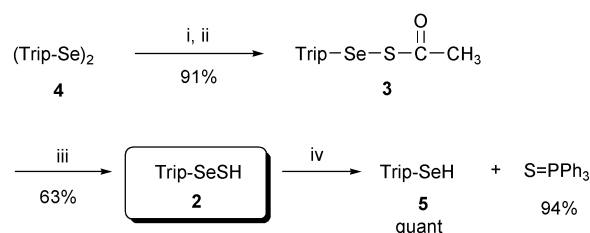
Triptycene-9-thioselenenic acid was synthesized by hydrolysis of acetyl triptycene-9-thioselenenate, the structure of which was determined by spectroscopic data and X-ray diffraction analysis.

Hydrodichalcogenides R–X–Y–H, where X and Y are the same or different Group 16 elements, have drawn considerable interest from various points of view. While hydroperoxides (R–O–O–H) are compounds with a long history, the chemistry of sulfenic acids (R–S–O–H)¹ and selenenic acids (R–Se–O–H)^{2,3} are of current interest. On the other hand, hydrodisulfides (R–S–S–H)^{4,5} and selenosulfenic acids (R–S–Se–H)⁶ have been claimed to be intermediates in enzymatic reactions of cysteine and selenocysteine with their lyases. A hydrodisulfide was found to be a key intermediate in thiol-mediated DNA-damage by leinamycin and its model compounds.⁷ Thioselenenic acids, R–Se–S–H, are a member of this group and have not been isolated yet. To our knowledge, there are only two reports on the observation of Cys–SeSH [1, Cys = (HO₂C)(H₂N)CHCH₂] by UV–vis spectroscopy^{8a} and RSeSLi (R = Bu, Ph) in THF by ⁷⁷Se NMR spectroscopy.^{8b} We report herein the isolation and structure determination of triptycene-9-thioselenenic acid (2).



Acetyl triptycene-9-thioselenenate (3) was prepared using a method analogous to that for the synthesis of acetyl alkyl disulfides (R–S–S–Ac).⁹ Thus, di-9-triptycyl diselenide (4)^{3c} was treated with MCPBA and then with thioacetic acid to give 3¹⁰ in 91% yield; it is not essential to isolate the intermediary formed selenoseleninate (Trip–Se(O)Se–Trip^{3c,11}). The acetyl thioselenenate 3 was hydrolyzed with 60% perchloric acid in refluxing ethanol–dichloromethane to furnish the desired thioselenenic acid 2 in 63% yield. The sulfur atom of 2 was removed readily by treatment with triphenylphosphine to give the selenol 5^{3c} and triphenylphosphine sulfide almost quantitatively (Scheme 1).

The structure of thioselenenic acid 2 was determined by spectroscopic data and X-ray diffraction analysis.¹² An ORTEP drawing is depicted in Fig. 1 with relevant bond lengths and angles data. The Se1–S1 bond length was 2.1796(9) Å, indicating the single bond character, and the C1–Se1–S1 bond angle was 103.85(7)°. The SH proton appeared at δ 2.64 in the



Scheme 1 Reagents and conditions: i, MCPBA, CH₂Cl₂, 0 °C; ii, CH₃C(O)SH, 0 °C, and then rt; iii, HClO₄, EtOH, CH₂Cl₂, refl., 6 h; iv, PPh₃, PhH, rt, 2 h.

¹H NMR spectrum, and an absorption due to the S–H stretching vibration was observed at 2520 cm^{−1} in the IR spectrum.

Thioselenenic acid 2 was stable under acidic conditions, as is evident from the preparation conditions, whereas it decomposed to selenol 5 and a small amount of diselenenyl sulfide 6¹⁵ by treatment with triethylamine followed by neutralization^{4e} [Scheme 2, (a)]; when a solution of 2 was evaporated to dryness in the presence of triethylamine, diselenenyl sulfide 6 and diselenide 4 were formed [Scheme 2, (b)]. Treatment of 2 with triphenyltin chloride in the presence of triethylamine yielded stannyl thioselenenate 7¹⁶ and stannyl selenide 8¹⁶ [Scheme 2, (c)].

Polidoro and coworkers reported that treatment of (Cys–Se)₂ with Na₂S in an aqueous NaOH solution (1 × 10^{−3} M) generated Cys–Se–SH that exhibited an absorption maximum at 375 nm in the UV–vis spectrum.⁸ Fig. 2 shows UV–Vis spectra of thioselenenic acid 2 and diselenenyl sulfide 6 in dichloro-

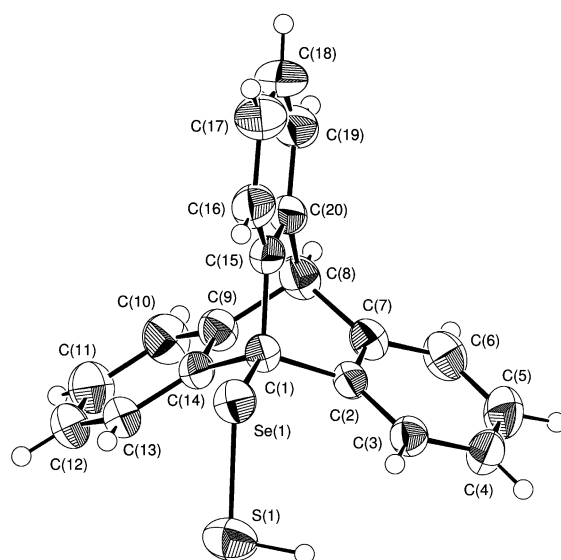
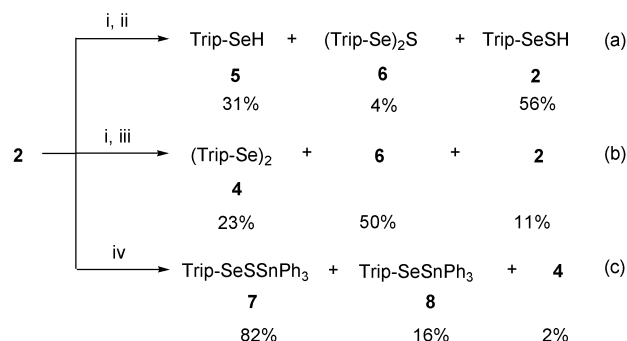


Fig. 1 ORTEP drawing of triptycene-9-thioselenenic acid (2) (50% ellipsoidal probability). Relevant bond lengths (Å) and angles (deg) data: Se1–C1 1.975(2); Se1–S1 2.1796(9); C1–C14 1.536(3); C1–C2 1.537(3); C1–C15 1.538(3); S1–H1 1.24(6); C1–Se1–S1 103.85(7); C14–C1–C2 106.19(17); C14–C1–C15 105.15(17); C2–C1–C15 105.31(17); C14–C1–Se1 115.62(15); C2–C1–Se1 115.27(15); C15–C1–Se1 108.37(15).

† Electronic supplementary information (ESI) available: experimental section. See <http://www.rsc.org/suppdata/cc/b2/b207810d/>



Scheme 2 Reagents and conditions: i, Et_3N , PhH, rt, 5 min; ii, aq. NH_4Cl ; iii, evaporation in the presence of Et_3N ; iv, Ph_3SnCl , Et_3N , PhH, rt, 1 h. Yields are calculated from ^1H NMR integral ratios.

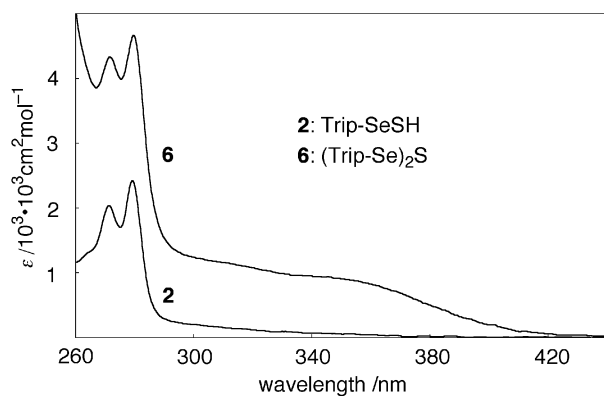


Fig. 2 UV-vis spectra of triptycene-9-thioselenenic acid (**2**) and di(triptycene-9-selenenyl) sulfide (**6**).

methane. The absorption of **2** ceased approximately at 360 nm, while **6** has a broad absorption from 285 to 360 nm with the molecular absorption coefficient ($\epsilon/10^3 \text{ cm}^2 \text{ mol}^{-1}$) ≈ 1000 . Anyway, we did not observe an explicit absorption maximum around 375 nm. This might be attributed to the contrasting character of the substituents: the more sterically demanding, hydrophobic 9-triptycyl group and the much less sterically demanding, hydrophilic 2-amino-3-propionyl (Cys) group. We are therefore now investigating the preparation of thioselenenic acids having groups derived from the Cys group or alkyl substituents structurally simpler than the 9-triptycyl group.

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 - 3**: mp 177–180 °C (CH_2Cl_2 –hexane). ^1H NMR (CDCl_3 , 400 MHz) δ 2.50 (s, 3H), 5.37 (s, 1H), 6.98–7.05 (m, 6H), 7.35–7.40 (m, 3H), 7.47–7.51 (m, 3H); ^{13}C NMR (CDCl_3 , 100.6 MHz) δ 29.8, 54.1, 64.9, 123.5, 123.7, 125.0, 125.9, 144.1, 145.2, 192.1; IR (KBr) 1700 (C=O) cm^{-1} . Anal. Calc. for $\text{C}_{22}\text{H}_{16}\text{OSSe}$: C, 64.86; H, 3.96. Found: C, 64.80; H, 3.92%.
 - In this one-pot reaction, we have prepared (1-Ad) CH_2SeSAc and (1-Ad) $\text{CH}(\text{CH}_3)\text{SeSAc}$ (1-Ad = 1-adamantyl).
 - 2**: pale yellow plates, mp 170–172 °C decomp (CH_2Cl_2 –hexane). ^1H NMR (CDCl_3 , 400 MHz) δ 2.64 (s, 1H, SH), 5.38 (s, 1H), 7.00–7.08 (m, 6H), 7.36–7.42 (m, 3H), 7.49–7.54 (m, 3H); ^{13}C NMR (CDCl_3 , 100.6 MHz) δ 54.0, 61.1, 123.6, 123.8, 125.0, 125.7, 144.1, 145.8; IR (KBr) 2520 cm^{-1} . Anal. Calc. for $\text{C}_{20}\text{H}_{14}\text{SSe}$: C, 65.75; H, 3.86. Found: C, 65.73; H, 3.89%. Crystal data: $\text{C}_{20}\text{H}_{14}\text{SSe}$, M_w 365.36, pale yellow plate, $0.24 \times 0.16 \times 0.08 \text{ mm}^3$, triclinic, space group $P1$, $a = 8.181(2)$, $b = 8.217(1)$, $c = 13.175(3)$ Å, $\alpha = 82.53(1)$, $\beta = 72.58(1)$, $\gamma = 67.82(1)^\circ$, $V = 782.4(2)$ Å 3 , $Z = 2$, $\rho_{\text{calc}} = 1.551 \text{ g cm}^{-3}$, $\mu(\text{CuK}\alpha) = 4.42 \text{ mm}^{-1}$. Mac Science MXC3KHF diffractometer with graphite-monochromated CuK α radiation ($\lambda = 1.54178$ Å), $\theta/2\theta$ scans method in the range $3^\circ < 2\theta < 140^\circ$ ($-9 \leq h \leq 9$, $0 \leq k \leq 10$, $-15 \leq l \leq 16$), 2994 independent reflections. The structure was solved with direct methods (SIR92 13), and refined with full-matrix least-squares (SHELXL-97 14) using all independent reflections for 256 parameters. Absorption correction was done by a psi-scan method. The non-hydrogen atoms were refined anisotropically: $R1 = 0.0303$ ($I > 2\sigma(I)$), 2822 reflections), $wR2 = 0.0860$ (for all), $\text{GOF} = 1.05$; max/min residual density = $0.454/-0.452 \text{ e Å}^{-3}$. CCDC reference number 191691. See <http://www.rsc.org/suppdata/cc/b2/b207810d/> for crystallographic data in CIF or other electronic format.
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 - 6**: pale yellow crystals, mp 345–346 °C decomp (hexane– CH_2Cl_2). ^1H NMR (CDCl_3 , 300 MHz) δ 5.46 (s, 2H), 7.11 (pseudo d of quintet, $J = 1.5, 7.4 \text{ Hz}$, 12H), 7.46 (dd, $J = 1.5, 7 \text{ Hz}$, 6H), 7.76 (dd, $J = 1.5, 8 \text{ Hz}$, 6H); ^{13}C NMR (CDCl_3 , 100.6 MHz) δ 54.2, 65.2, 123.7, 124.4, 125.1, 125.9, 144.7, 145.6. Anal. Calc. for $\text{C}_{40}\text{H}_{22}\text{SSe}_2$: C, 68.96; H, 3.76. Found: C, 68.31; H, 3.68%.
 - The structures of **7** and **8** were determined by X-ray crystallography. CCDC reference numbers 191692 (**7**) and 191693 (**8**): **7**: yellow crystals, mp 176–178 °C decomp (Et_2O –hexane). ^1H NMR (CDCl_3 , 200 MHz) δ 5.29 (s, 1H), 6.74 (dt, $J = 1, 8 \text{ Hz}$, 3H), 6.93 (dt, $J = 1, 7 \text{ Hz}$, 3H), 7.30 (dd, $J = 1, 7 \text{ Hz}$, 3H), 7.43–7.55 (m, 12H), 7.74–7.84 (m, 6H, accompanying satellite signals, $J = 55 \text{ Hz}$, due to ^{117}Sn and ^{119}Sn); ^{13}C NMR (CDCl_3 , 75.5 MHz) δ 54.0, 61.7, 123.1, 124.6, 124.8, 125.4, 129.1, 130.2, 137.0, 137.1, 144.4, 145.4. Anal. Calc. for $\text{C}_{38}\text{H}_{28}\text{SSeSn}$: C, 63.89; H, 3.95. Found: C, 63.71; H, 3.90. **8**: colorless cubes, mp 253–255 °C (hexane– CH_2Cl_2). ^1H NMR (CDCl_3 , 400 MHz) δ 5.28 (s, 1H), 6.64 (dt, $J = 1, 8 \text{ Hz}$, 3H), 6.87 (dt, $J = 1, 8 \text{ Hz}$, 3H), 7.20–7.34 (m, 12H), 7.40 (dd, $J = 1, 8 \text{ Hz}$, 6H, accompanying satellite signals, $J = 55 \text{ Hz}$, due to ^{117}Sn and ^{119}Sn), 7.79 (d, $J = 7.5 \text{ Hz}$, 3H); ^{13}C NMR (CDCl_3 , 100.6 MHz) δ 54.1, 61.7, 122.6, 124.5, 125.36, 125.41, 128.6, 129.4, 136.8, 138.2, 144.8, 146.4. Anal. Calc. for $\text{C}_{38}\text{H}_{28}\text{SeSn}$: C, 66.89; H, 4.14. Found: C, 66.65; H, 4.04%.