Crystal structure of 2-(benzo[d]thiazol-2-yl)-3,3-bis(ethylsulfanyl)acrylonitrile

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In the title compound, C_{14}H_{14}N_{2}S_{3}, the double-bond system of the acrylonitrile moiety is significantly non-planar, with absolute cis torsion angles of 13.9 (2) and 15.1 (2)°. The ring system and the double bond system subtend an interplanar angle of 11.16 (4)°. The wide angle C—C(CN)—C of 129.40 (12)° may be associated with a balance between planarity and avoidance of a very short S···S contact.

1. Chemical context
Research into medicinal chemistry based on benzothiazoles has become a fast developing and progressively more active topic. The high degree of structural diversity has proved to be important in the search for new effective treatments (Ammazzalorso et al., 2020; Elgemeie, 1989). A large number of therapeutic agents based on benzothiazole systems have been synthesized and evaluated in terms of their pharmacological properties (Gill et al., 2015; Fathy et al., 1988). Much information about benzothiazoles has been reported in the scientific literature, describing their anti-inflammatory, antimicrobial, neuroprotective, anticonvulsant and antiproliferative effects (Seenaiah et al., 2014). The molecular mechanisms responsible for this variety of pharmacological activity have not been completely established, and various biological pathways have been indicated as possible targets of this class of molecules (Keri et al., 2015). We are engaged in developing synthetic strategies for benzothiazole systems that show important biological activity as novel antimicrobial and antiviral agents (Azzam et al. 2017a,b, 2020a,b,c, 2021; Elgemeie et al., 2000a,b; 2020).

As an extension of this research (Fathy & Elgemeie, 1988; Elgemeie & Elghandour, 1990), we report here a novel benzothiazole cyanoketene dithioacetal (2). Compound 2 was synthesized by the reaction of 2-cyanomethylbenzothiazole 1 with carbon disulfide in the presence of sodium ethoxide, followed by alkylation with ethyl iodide. The structure of 2 was originally based on its elemental analysis and spectroscopic data (see Experimental). In order to establish the structure of the compound unambiguously, the crystal structure was determined.

2. Structural commentary
The molecule of 2 is shown in Fig. 1. The heterocyclic system is coplanar to within an r.m.s. deviation of only 0.007 Å, and its
dimensions are as expected (a selection of molecular dimensions are presented in Table 1). There is appreciable twisting of ca. 14° about the double bond C8ŚC9 (see torsion angles in Table 1), so that the ‘plane’ of the atoms C2, C8, C9, C10, S2 and S3 displays an r.m.s. deviation of 0.14 Å; the two planes subtend an interplanar angle of 11.16 (4)°. The angle C2ŚC8ŚC9 (formally sp²) is strikingly wide, at 129.40 (12)°; for comparison, the corresponding angles in the five structures mentioned below (with refcodes) range from 122–126°. One might speculate that this large angle and the deviation from planarity about the double bond represent aspects of a compromise between (i) achieving coplanarity of the heterocyclic systems, (ii) avoiding too short a spatial overlap about the double bond C8ŚC14 of the heterocyclic systems face each other; however, there is a considerable offset. The centroids of the five-membered rings lie 3.72 Å apart, and the shortest contact is C7AŚC7A’ (operator 1 – x, 1 – y, 1 – z) 3.741 (2) Å. The sulfur atom S1 lies 3.61 Å from the centroid of the six-membered ring in the facing molecule; such potential S–S interactions have been discussed by e.g. Ringer et al. (2007) and Silva et al. (2018).

3. Supramolecular features

The molecular packing is fairly featureless; a general view is given in Fig. 2 and some borderline possible ‘weak’ hydrogen bonds are listed in Table 2. The main feature is the loose association of pairs of molecules across inversion centres, whereby the heterocyclic systems face each other; however, there is a considerable offset. The centroids of the five-membered rings lie 3.72 Å apart, and the shortest contact is C7AŚC7A’ (operator 1 – x, 1 – y, 1 – z) 3.741 (2) Å. The sulfur atom S1 lies 3.61 Å from the centroid of the six-membered ring in the facing molecule; such potential S–S interactions have been discussed by e.g. Ringer et al. (2007) and Silva et al. (2018).

4. Database survey

Searches of the Cambridge Structural Database (Groom et al., 2016) were performed using ConQuest Version 2021.3.0. A search for the moiety benzo[d]thiazol-2-yl joined to C(CN)ŚC gave 27 hits, but none in which any further atom at the double bond was sulfur. A search for the group CŚC(CN)ŚC(S – C)₂, with the first carbon atom three-coordinate, both sulfur atoms two-coordinate and not involving cyclicity, gave only five hits. The refcodes, references and absolute cis torsion angles NCŚCŚC were as follows: CIYDIY, Kumar et al. (2008), 9.9°; MTBCEY, Abrahamsson et al. (1974), 15.4°; VAPJAA, Azzam et al. (2017c), 7.3°; VELSIP, Peng et al. (2006), 3.6°; ZEDJEX, Osaka et al. (1994), 10.5°.

5. Synthesis and crystallization

A mixture of sodium ethoxide (0.08 mol) and 2-cyanomethylbenzothiazole (0.04 mol) in absolute ethanol (100 ml) was refluxed for 20 min. After cooling, carbon disulfide was added dropwise over 10 min. The mixture was then placed in a Petri dish and allowed to evaporate to give a mirror-like plate. The mother liquor was discarded. A crystalline mass was then obtained by dissolving the remaining material in a small amount of chloroform and allowing the solution to evaporate. The resulting crystals were isolated and washed with diethyl ether. The crystals were then dried under vacuum at 30 °C. The crystal was then subjected to X-ray diffraction analysis.
(0.04 mol) was added gradually and then the solution was warmed for 20 min. Ethyl iodide (0.08 mol) was then added, and the reaction mixture was stirred overnight at room temperature. The solution was poured onto ice–water and the solid product thus formed was filtered off. The product was purified by dissolving it in hot petroleum ether, filtering, and allowing the solution to cool. The solid that formed was recrystallized from DMF to give pale-yellow crystals, m.p. 366–368 K, yield 72%; IR (KBr, cm \(^{-1}\)): \(\nu\) 3056 (ArCH), 2924 (CH\(_3\)), 2213 (CN), 1502 (C=C=N); \(^1\)H NMR (300 MHz, DMSO-\(d_6\)): \(\delta\) 1.27–1.34 (m, \(2\)H), 7.50–7.57 (\(2\)H, benzothiazole H), 8.04–8.15 (\(2\)H, benzothiazole H); analysis, calculated for C\(_{14}\)H\(_{14}\)N\(_2\)S\(_3\) m/m\%: C% 54.87; H% 4.60; N% 9.14; S% 31.39; found: C% 54.85; H% 4.58; N% 9.16; MS \(m/z\) (%): 306 (\(M^+\), 15%), 276 (100%), 273 (57%), 248 (26%), 217 (76%), 204 (26%), 146 (20%).

6. Refinement

Crystal data, data collection and structure refinement details are summarized in Table 3. The methyl groups as idealized rigid groups allowed to rotate but not tip, with C—H = 0.98 \(\text{Å}\) and H—C—H = 109.5°. Other hydrogen atoms were included using a riding model starting from calculated positions (C—H\(_\text{aromatic}\) = 0.95, C—H\(_\text{methylene}\) = 0.99 \(\text{Å}\)). The \(U(H)\) values were fixed at 1.5 or 1.2 times the equivalent \(U_{	ext{iso}}\) value of the parent carbon atoms for methyl and non-methyl hydrogen atoms, respectively.

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Computing details

Data collection: CrysAlis PRO (Agilent, 2014); cell refinement: CrysAlis PRO (Agilent, 2014); data reduction: CrysAlis PRO (Agilent, 2014); program(s) used to solve structure: SHELXS97 (Sheldrick, 2008); program(s) used to refine structure: SHELXL2018/3 (Sheldrick, 2015); molecular graphics: XP (Siemens, 1994); software used to prepare material for publication: SHELXL2018/3 (Sheldrick, 2015).

2-(Benzo[d]thiazol-2-yl)-3,3-bis(ethylsulfanyl)acrylonitrile

Crystal data

C_{14}H_{14}N_{2}S_{3}
Mr = 306.45
Orthorhombic, Pbc\(\alpha\)
\(a = 10.0771\) (3) Å
\(b = 16.0292\) (5) Å
\(c = 17.8768\) (6) Å
\(V = 2887.58\) (16) Å\(^3\)
\(Z = 8\)
\(F(000) = 1280\)

\(D_x = 1.410\) Mg m\(^{-3}\)
Mo \(K\alpha\) radiation, \(\lambda = 0.71073\) Å

Cell parameters from 10579 reflections
\(\theta = 2.6–30.3^\circ\)
\(\mu = 0.50\) mm\(^{-1}\)
\(T = 100\) K
Tablet, pale yellow
0.4 × 0.4 × 0.15 mm

Data collection

Oxford Diffraction Xcalibur, Eos diffractometer
Radiation source: Enhance (Mo) X-ray Source
Graphite monochromator
Detector resolution: 16.1419 pixels mm\(^{-1}\)
\(\omega\)–scan
Absorption correction: multi-scan
– (CrysAlisPro; Agilent, 2014)
\(T_{\text{min}} = 0.954, T_{\text{max}} = 1.000\)
58593 measured reflections
4475 independent reflections
3679 reflections with \(I > 2\sigma(I)\)
\(R_{\text{int}} = 0.053\)
\(\theta_{\text{max}} = 31.2^\circ, \theta_{\text{min}} = 2.3^\circ\)
\(h = -14\rightarrow 14\)
\(k = -23\rightarrow 22\)
\(l = -25\rightarrow 25\)

Refinement

Refinement on \(F^2\)
Least-squares matrix: full
\(R(F^2 > 2\sigma(F^2)) = 0.032\)
\(wR(F^2) = 0.077\)
\(S = 1.05\)
4475 reflections
174 parameters
0 restraints
Primary atom site location: structure-invariant direct methods
Secondary atom site location: difference Fourier map
Hydrogen site location: inferred from neighbouring sites
H-atom parameters constrained
\(w = 1/[\sigma(F_c^2) + (0.0318P)^2 + 1.3474P]\)
where \(P = (F_c^2 + 2F_{\text{e}}^2)/3\)
\((\Delta\sigma)_{\text{max}} = 0.002\)
\(\Delta p_{\text{max}} = 0.40\) e Å\(^{-3}\)
\(\Delta p_{\text{min}} = -0.32\) e Å\(^{-3}\)
Special details

Geometry. All esds (except the esd in the dihedral angle between two l.s. planes) are estimated using the full covariance matrix. The cell esds are taken into account individually in the estimation of esds in distances, angles and torsion angles; correlations between esds in cell parameters are only used when they are defined by crystal symmetry. An approximate (isotropic) treatment of cell esds is used for estimating esds involving l.s. planes.

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å²)

| Atom | x     | y     | z     | Uiso/Ur |     |
|------|-------|-------|-------|---------|-----|
| S1   | 0.48621 (3) | 0.63526 (2) | 0.48864 (2) | 0.01440 (8) |
| C2   | 0.64877 (12) | 0.62079 (7) | 0.52085 (7) | 0.0129 (2) |
| N3   | 0.72242 (10) | 0.57082 (6) | 0.48059 (6) | 0.0141 (2) |
| C3A  | 0.65225 (12) | 0.54010 (7) | 0.42020 (7) | 0.0135 (2) |
| C4   | 0.70382 (14) | 0.48489 (8) | 0.36681 (7) | 0.0169 (2) |
| H4   | 0.793137 | 0.466208 | 0.369750 | 0.020* |
| C5   | 0.62153 (14) | 0.45833 (8) | 0.30983 (7) | 0.0194 (3) |
| H5   | 0.654822 | 0.420983 | 0.273082 | 0.023* |
| C6   | 0.48945 (14) | 0.48568 (8) | 0.30536 (7) | 0.0198 (3) |
| H6   | 0.435044 | 0.466538 | 0.265499 | 0.024* |
| C7   | 0.43675 (14) | 0.53990 (8) | 0.35774 (7) | 0.0179 (3) |
| H7   | 0.347076 | 0.557869 | 0.354695 | 0.022* |
| C7A  | 0.51995 (12) | 0.56737 (7) | 0.41532 (7) | 0.0141 (2) |
| C8   | 0.70646 (12) | 0.65707 (7) | 0.58882 (7) | 0.0135 (2) |
| C9   | 0.66224 (12) | 0.72227 (7) | 0.63140 (7) | 0.0137 (2) |
| C10  | 0.82871 (13) | 0.61618 (8) | 0.60980 (7) | 0.0147 (2) |
| N1   | 0.92273 (12) | 0.58066 (7) | 0.62713 (6) | 0.0200 (2) |
| S2   | 0.77453 (3) | 0.7692 (2) | 0.69408 (2) | 0.01682 (8) |
| C11  | 0.67428 (14) | 0.80013 (8) | 0.77350 (7) | 0.0190 (3) |
| H11A | 0.723828 | 0.842357 | 0.802710 | 0.023* |
| H11B | 0.591943 | 0.826694 | 0.754915 | 0.023* |
| C12  | 0.63786 (15) | 0.72831 (9) | 0.82435 (8) | 0.0224 (3) |
| H12A | 0.584732 | 0.687626 | 0.796466 | 0.034* |
| H12B | 0.586321 | 0.749299 | 0.866859 | 0.034* |
| H12C | 0.718942 | 0.701444 | 0.842693 | 0.034* |
| S3   | 0.50142 (3) | 0.76155 (2) | 0.62083 (2) | 0.01684 (8) |
| C13  | 0.53315 (14) | 0.87150 (8) | 0.60082 (8) | 0.0192 (3) |
| H13A | 0.447342 | 0.900815 | 0.594773 | 0.023* |
| H13B | 0.579883 | 0.896822 | 0.643920 | 0.023* |
| C14  | 0.61552 (15) | 0.88404 (9) | 0.53106 (8) | 0.0242 (3) |
| H14A | 0.701489 | 0.856282 | 0.537151 | 0.036* |
| H14B | 0.629538 | 0.943837 | 0.522807 | 0.036* |
| H14C | 0.568927 | 0.860130 | 0.487976 | 0.036* |

Atomic displacement parameters (Å²)

|   | U₁₁  | U₂₂  | U₃₃  | U₁₂  | U₁₃  | U₂₃  |
|---|------|------|------|------|------|------|
| S1 | 0.01247 (14) | 0.01380 (15) | 0.01694 (15) | 0.00051 (11) | 0.00032 (11) | −0.00103 (11) |
| C2 | 0.0125 (5) | 0.0120 (5) | 0.0143 (5) | −0.0005 (4) | 0.0015 (4) | 0.0019 (4) |
### Geometric parameters (Å, °)

|    |    |    |    |    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|----|----|----|----|----|
| N3 | 0.0150 (5) & 0.0129 (5) & 0.0143 (5) & −0.0007 (4) & 0.0011 (4) & −0.0009 (4) |
| C3A| 0.0158 (6) & 0.0119 (5) & 0.0129 (5) & −0.0019 (4) & 0.0006 (4) & 0.0020 (4) |
| C4 | 0.0197 (6) & 0.0152 (6) & 0.0158 (6) & 0.0014 (5) & 0.0009 (5) & −0.0003 (5) |
| C5 | 0.0268 (7) & 0.0158 (6) & 0.0157 (6) & 0.0009 (5) & −0.0002 (5) & −0.0016 (5) |
| C6 | 0.0261 (7) & 0.0171 (6) & 0.0163 (6) & −0.0023 (5) & −0.0067 (5) & −0.0011 (5) |
| C7 | 0.0184 (6) & 0.0153 (6) & 0.0200 (6) & −0.0014 (5) & −0.0039 (5) & 0.0021 (5) |
| C7A| 0.0173 (6) & 0.0106 (5) & 0.0144 (5) & −0.0013 (4) & 0.0003 (5) & 0.0012 (4) |
| C8 | 0.0131 (6) & 0.0127 (5) & 0.0145 (5) & −0.0018 (4) & 0.0018 (4) & 0.0008 (4) |
| C9 | 0.0134 (6) & 0.0127 (5) & 0.0150 (5) & −0.0017 (4) & 0.0024 (4) & 0.0010 (4) |
| C10| 0.0182 (6) & 0.0137 (6) & 0.0122 (5) & −0.0011 (5) & 0.0010 (4) & −0.0028 (4) |
| N1 | 0.0218 (6) & 0.0205 (5) & 0.0177 (5) & 0.0028 (5) & −0.0026 (4) & −0.0029 (4) |
| S2 | 0.01627 (15) & 0.01690 (16) & 0.01730 (15) & −0.00122 (12) & 0.00140 (11) & −0.00523 (12) |
| C11| 0.0250 (7) & 0.0161 (6) & 0.0159 (6) & 0.0035 (5) & 0.0025 (5) & −0.0049 (5) |
| C12| 0.0231 (7) & 0.0208 (7) & 0.0232 (7) & 0.0015 (5) & 0.0051 (5) & 0.0012 (5) |
| S3 | 0.01226 (15) & 0.01522 (15) & 0.02304 (17) & 0.00007 (11) & 0.00338 (11) & −0.00326 (12) |
| C13| 0.0198 (6) & 0.0139 (6) & 0.0240 (7) & 0.0024 (5) & −0.0015 (5) & −0.0002 (5) |
| C14| 0.0270 (7) & 0.0238 (7) & 0.0218 (7) & −0.0025 (6) & −0.0011 (6) & 0.0031 (5) |

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_Supporting information_
supporting information

| C3A—C4—H4 | 120.8 | C11—C12—H12B | 109.5 |
| C4—C5—C6 | 121.01 (12) | H12A—C12—H12B | 109.5 |
| C4—C5—H5 | 119.5 | C11—C12—H12C | 109.5 |
| C6—C5—H5 | 119.5 | H12A—C12—H12C | 109.5 |
| C7—C6—C5 | 121.44 (12) | H12B—C12—H12C | 109.5 |
| C7—C6—H6 | 119.3 | C9—S3—C13 | 101.91 (6) |
| C5—C6—H6 | 119.3 | C14—C13—S3 | 112.70 (10) |
| C6—C7—C7A | 117.76 (12) | C14—C13—H13A | 109.1 |
| C6—C7—H7 | 121.1 | S3—C13—H13A | 109.1 |
| C7A—C7—H7 | 121.1 | C14—C13—H13B | 109.1 |
| C7—C7A—C3A | 121.08 (12) | S3—C13—H13B | 109.1 |
| C7—C7A—S1 | 129.43 (10) | H13A—C13—H13B | 107.8 |
| C3A—C7A—S1 | 109.49 (9) | C13—C14—H14A | 109.5 |
| C9—C8—C10 | 118.69 (11) | C13—C14—H14B | 109.5 |
| C9—C8—C2 | 129.40 (12) | H14A—C14—H14B | 109.5 |
| C10—C8—C2 | 111.90 (10) | C13—C14—H14C | 109.5 |
| C8—C9—S3 | 121.13 (10) | H14A—C14—H14C | 109.5 |
| C8—C9—S2 | 117.68 (10) | H14B—C14—H14C | 109.5 |

Hydrogen-bond geometry (Å, °)

| D—H···A | D—H | H···A | D···A | D—H···A |
|———|———|———|———|———|
| C7—H7···S2i | 0.95 | 3.02 | 3.6083 (13) | 122 |
| C12—H12A···S1i | 0.98 | 3.03 | 3.9677 (15) | 161 |
| C13—H13A···N3i | 0.99 | 2.68 | 3.5746 (17) | 151 |
| C14—H14A···S1ii | 0.98 | 2.91 | 3.7648 (15) | 146 |
| C14—H14B···N3iv | 0.98 | 2.63 | 3.5277 (18) | 152 |

Symmetry codes: (i) x−1/2, −y+3/2, −z+1; (ii) x, −y+3/2, z+1/2; (iii) x+1/2, −y+3/2, −z+1; (iv) −x+3/2, y+1/2, z.