Supplementary Information for:

Reversible Crystal-to-Crystal Chiral Resolution:

Making/Breaking Non-bonding S…O Interactions

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Experimental

General Considerations. Reactions were performed under $Ar_{(g)}$ using standard Schlenk techniques. Anhydrous CH₃CN, stored in a solvent keg filled off-site by Caledon Labs, was dispensed using a Solvent Purification System (LC Technology Solutions Inc.) equipped with molecular sieves (3 Å). α -Isonitrosopropiophenone and S₂Cl₂ were purchased from Sigma Aldrich; pyridine, formic acid and DMSO were purchased from Fisher Scientific. All commercial reagents were used as received. SCl₂ was prepared from S₂Cl₂ and Cl₂ in the presence of FeCl₃ and freshly distilled before use. IR (KBr pressed pellet) spectra were recorded on a Nicolet 4700 FT-IR spectrometer at 4 cm⁻¹ resolution. NMR spectra were recorded on a Bruker Avance-400 spectrometer at ambient temperature (400 MHz for ¹H; 100 MHz for ¹³C). Elemental analyses were performed by MHW Laboratories (Phoenix, AZ). Electron impact GC/MS was performed by the University of Waterloo Mass Spectrometry Facility.

4-Benzoyl-1,2,3-dithiazol-5-one (1). α-Isonitrosopropiophenone (1.0260 g, 6.2879 mmol) was dissolved in anhydrous CH₃CN and cooled to -10 °C before addition of SCl₂ (0.88 mL, 13.84 mmol). The solution was allowed to stir for 4 h before separating the orange precipitate from the red solution by filtration. The solid was rinsed with cold, anhydrous CH₃CN, then dried under vacuum. DMSO (0.8 mL, 11.3 mmol) was added to a slurry of the collected precipitate in dry CH₃CN and the solids were consumed over the next 1.5 h to yield an orange solution. The solvents were allowed to evaporate overnight. The crude, orange solid product was dissolved in CH₂Cl₂ and passed through a silica plug. The solvent was removed on a rotary evaporator to yield yellow, crystalline solid, identified as 1, with a small amount of elemental sulfur byproduct. Purification of 1 was achieved by sublimation under dynamic vacuum (10^{-2} Torr), using a threestage programmable temperature-gradient tube furnace. Setting all three temperature zones to 60 $^{\circ}$ C removed S₈ byproduct, then cooling the system to ambient temperature followed by a program of 70, 45, 30 °C reproducibly sublimed crystalline 1; yield 0.5870 g (2.630 mmol, 42%). Elemental Analysis. Calc. for C₉H₅NO₂S₂: C, 48.41; H, 2.26; N, 6.27. Found: C, 48.19; H, 2.50; N, 6.19. ¹H NMR: (CDCl₃, 25 °C, ppm) δ 7.95 (2 H, d, CH), δ 7.65 (1 H, t, CH), δ 7.50 (1 H, t, CH). ¹³C NMR: (CDCl₃, 25 °C, ppm) δ 187.8, 185.2 (2 C=O), δ 152.9, 135.3 (2 sp²) quaternary C), δ 134.7, 130.2, 128.8 (5 CH, Ph). Mass Spec: (EI+); parent ion assigned as m/z222.99, $M = (C_9H_5NO_2S_2)^+$, 12.36%; 194.98, $(M - CO)^+$, 33.51%; 105.02, $(C_7H_6O)^+$, 100.00%; 76.99, $(C_6H_5)^+$, 43.86%; 51.00, $(C_4H_3)^+$, 18.98%. Diamond-shaped yellow plates recovered from sublimation were identified as LT-1. IR (KBr) v/cm⁻¹: LT-1 (Figure S1): 3257 (w), 3060 (w), 1991 (w), 1910 (w), 1831 (w), 1665 (s), 1603(s), 1595 (m), 1527 (w), 1475 (s), 1445 (m), 1321 (w), 1309 (m), 1292 (s), 1184 (m), 1159 (w), 1149 (m), 1081 (w), 1024 (w), 999 (w), 954 (m), 943 (m), 934 (w), 854 (w), 833 (m), 799 (m), 754 (m), 730 (s), 689 (s), 646 (s), 529 (w), 508(w), 459 (m), 440 (m), 425 (m). Microcrystalline yellow blocks recovered from sublimation were identified as **HT-1**. **IR (KBr)** v/cm⁻¹: **HT-1** (Figure S1): 3257 (w), 3060 (w), 1991 (w), 1910 (w), 1831 (w), 1677 (s), 1645(s), 1593 (m), 1527 (w), 1498 (s), 1447 (m), 1314 (m), 1309 (m), 1287 (s), 1182 (w), 1148 (m), 1081 (w), 1024 (w), 999 (w), 954 (m), 939 (w), 854 (w), 828 (m), 796 (m), 758 (m), 721 (s), 694 (s), 653 (s), 621 (m), 614 (m), 532 (w), 504(w), 458 (m), 440 (m), 425 (m).



Figure S1. Overlay of the fingerprint region of the FT-IR spectra of LT-1 and HT-1.

Computational Methods. All calculations were performed using the Gaussian09, Revision D.01 package for 64-bit Mac OSX.^[1] Geometry optimization of **1**, performed starting from both the **LT-1** crystal geometry and from the **HT-1** crystal geometry, using B3LYP/6-311⁺G**, converged to the same predicted geometry. Single point energies for the **LT-1** and **HT-1** crystal

geometries were calculated using B3LYP/6-31G^{**} and all non-H atom positions defined as they appear in the CIFs at 150 K. H atom positions were allowed to optimize. To create an energy surface related to the structural conformations, the energies of a sequential series of conformations, related by rotation about torsion angles ϕ_1 and ϕ_2 (Figure S2), were calculated using B3LYLP/6-31G^{**}. To simplify the calculations and definition of torsion angles, the phenyl and DTA rings were confined to planarity. Data points were collected by selecting a fixed value for ϕ_1 , from 0° to 180° in 5° increments, then while holding ϕ_1 constant at each of these 36 positions, ϕ_2 was rotated 360° in 5° increments, and the energy was calculated at each position, allowing relaxation of the unconstrained geometric parameters. These data are plotted as (ϕ_1 , ϕ_2 , energy) to generate the 3D energy surface (Figures 2 and S3).



Figure S2. 1 is positioned such that (top) the torsion angle ϕ_1 lies along the z_1 -axis and (bottom) that torsion angle ϕ_2 lies along the z_2 -axis. In both cases, rotation in a (+)ve direction is defined as clockwise when observed down the respective z-axes, as indicated.



Figure S3. Calculated energy surface (B3LYP/6-31G**) as a function of rotation about torsion angles ϕ_1 and ϕ_2 ; a 3D rendition of the surface is also shown here.

Differential Scanning Calorimetry (DSC). Calorimetric experiments were conducted on a DSC Q2000 analyzer (TA Instruments), using Universal Analysis V4.5A software, calibrated with an indium standard. Samples of varying mass (2-5 mg) were added to aluminum pans and thermograms were recorded with linear cooling and heating rates of 5 °C/min. A variety of temperature intervals was used, all within the extremes of -90 and 150 °C. The reported endotherm onset values and enthalpies of fusion are the average from several experiments (error reported as the standard deviation). Representative thermograms are shown in Figure S4.

Samples of **1** obtained by crystallization at 95 °C from chlorobenzene exhibit a single endotherm indicating melting of **HT-1** at an onset temperature of 100.4(8) °C and an enthalpy of fusion of 23.0(8) kJ/mol (Figure S4). Samples of **1** obtained from recrystallization (in CH₂Cl₂, THF or chlorobenzene) at room temperature exhibit one of two different thermograms. In some cases, a single endotherm is observed indicating melting of **LT-1** with an onset of 92.5(14) °C and enthalpy of fusion of 27(1) kJ/mol. On some occasions, the endotherm indicative of melting of **LT-1** is followed by an exotherm as the melt crystallizes to **HT-1** before undergoing another endothermic process, indicating melting of the newly formed **HT-1** (Figure S4). When measuring a sample through more than one melt-solidification cycle, the melt usually crystallizes as **HT-1**, determined by observing a single endotherm corresponding to melting of **HT-1** on the second heating. Instances where the melt crystallized as **LT-1** and a melting peak at 92 °C was observed were uncommon (~7% chance based on 44 samples) and no correlation was found between the crystallization temperature of the liquid and the form that crystallized.



Figure S4. Representative example of a DSC thermogram of (top) pure **HT-1**, (middle) pure **LT-1** exhibiting a single endotherm, (bottom) pure **LT-1** exhibiting melting of **LT-1** followed by crystallization of the liquid to **HT-1**, and finally melting of **HT-1** (endo-exo-endo)

Ambient Temperature Powder X-Ray Diffraction (PXRD). Diffractograms of LT-1 and HT-

1 were acquired on a PANalytical Empyrean powder X-ray diffractometer equipped with a CuK_{α} radiation source ($\lambda = 1.54184$ Å), Ni K_{β} filter, and PIXcel^{1D} linear detector. Samples were prepared in custom flat brass sample holders and data were collected over $3.99 - 40.01^{\circ}$ range in 0.02° increments.



Figure S5. Ambient temperature powder X-ray diffractograms of (top) **LT-1** and (bottom) **HT-1**; experimental diffractograms are in orange and diffractograms calculated from the single crystal structures at ambient temperature are in blue.

Powder diffractograms of **HT-1** and **LT-1** differ substantially from one another (Figure **S5**). The strong 002 reflection (Bragg angle 7.5°) in the **LT-1** pattern is easily identified and noticeably absent in the diffractogram of **HT-1**. Conversely, there are two strong reflections between 10° and 15° (011 at 11.8°; 101 at 13.2°) in the **HT-1** diffractogram, a region which is void of reflection peaks in the **LT-1** diffractogram, making it easy to distinguish between the two morphologies.

PXRD was used to monitor the transition of **HT-1** to **LT-1** at ambient temperature. Data were collected at the University of Guelph Department of Chemistry X-lab on a SuperNova Agilent single crystal diffractometer equipped with a microfocus Cu K_{α} ($\lambda = 1.54184$ Å) radiation source and Atlas CCD detector. The powder sample was included into a short plastic tube supplied by MiTeGen (~2 mm diameter) and mounted on the SuperNova goniometer head. Two frames were collected from different ω angular positions using 90° ϕ -scan and 90 s exposure time to cover $2\theta = 5 - 60^{\circ}$. Points on the powder diffractogram were generated using CrysAlisPro software^[2] from the original images (0.02° steps in 2θ), with each of the points representing readings from 60 – 500 pixels. A polycrystalline sample of **HT-1** was doped with just enough **LT-1** to make the latter's 002 reflection visible (Figure S6; red). The sample was maintained at ambient temperature and diffractograms were collected after 6 and 14 days. After 6 days, increased intensity of reflections associated with **LT-1** at the expense of **HT-1** reflections was observed, consistent with transformation from **HT-1** to **LT-1** (Figure S6; orange). After 14 days, the 011 and 101 reflections of **HT-1** had nearly disappeared (Figure S6; black).



Figure S6. Diffractograms of **HT-1** seeded with **LT-1**, immediately after grinding (red), after 6 days at room temperature (orange), and after 14 days at room temperature (black). Over time, the 002 reflection of **LT-1** clearly increases in intensity while with 011 and 101 reflections of **HT-1** decrease, indicating the spontaneous transition from **HT-1** to **LT-1** at room temperature.

Variable Temperature-PXRD. A 0.5 mm glass capillary was charged with a sample composed of 99% **HT-1** and 1% **LT-1**, mixed by gentle grinding in a mortar. The sample was mounted on a Linkam LTS420 stage with a small amount of Kapton tape. The apparatus was mounted on a custom instrument in the Department of Physics at the University of Guelph, equipped with an ENRAF NONIUS FR571 rotating anode Cu source ($\lambda = 1.5418$ Å) with Osmic multilayer optics (power settings 45 kV and 25 mA) and a Bicron NaI point detector. Data were acquired using spec X-Ray diffraction software.^[3] Data were collected only from the Bragg angles of 7° to 22° and 3 hours was required to complete one run. Chosen temperatures (35, 45, 55, 60, 65, 70, 75, and then 65 °C) were consecutively set on the Linkam stage. Once the set temperature was attained, the sample was allowed to equilibrate for 0.5 h before beginning data collection. Data from multiple consecutive collections at a given temperature were averaged to yield a diffractogram representing the average state of the sample over a particular time period at that temperature.

At a concentration of 1% **HT-1** in **LT-1**, reflections in the 10-15° regime associated with **HT-1** were not apparent in the PXRD at ambient temperature. No change in the diffraction pattern was observed until 6 h at 70 °C, at which point the 011 and 101 reflections of **HT-1** appeared just above the baseline (Figure S7; blue). Once the onset of the phase transition had been established as ~70 °C, the temperature was then set to 75 °C to hasten the transition. The diffraction pattern was monitored over a period of 54 h, during which time reflections corresponding to **HT-1** grew at the expense of **LT-1** reflections until all **LT-1** reflections had completely disappeared below the baseline. It should be noted that the capillary sample tube was not rotating during the experiment and that texturing effects (resulting from preferred orientation of crystallites and/or annealing) produce noticeable variation in the relative intensity of the 011 and 101 peaks of **HT-1** over the 54 h experimental window.



Figure S7. PXRD patterns of **LT-1** doped with 1% **HT-1**, monitored over time at set temperatures T = 65, 70, 75 °C; each pattern is the sum of multiple 3 h data collections. Time gaps of approximately 0.5 h between set temperatures allowed for temperature equilibration. Time *t* was arbitrarily reset to 0 once equilibration was established at each set temperature. The variability in intensities of **HT-1** reflections over 54 h at 75 °C is due to texturing effects associated with annealing and preferred orientations in the stationary capillary tube.

After complete conversion to **HT-1**, the temperature was reduced to 65 °C to determine whether the reverse transition could be observed in the same sample. After 12 days, no reflections corresponding to **LT-1** had reappeared. The sample was retained and has been sitting at room temperature for several months. The PXRD pattern has been measured periodically over this time, with no evidence of conversion back to **LT-1**. To date, only the seeded samples have converted to **LT-1**.

Single Crystal X-Ray Diffraction.

LT-1. A thick yellow plate $(0.35 \times 0.35 \times 0.18 \text{ mm})$ grown by sublimation at 70 °C under dynamic vacuum (10⁻² torr) was studied at 150 K. Another yellow plate ($0.20 \times 0.10 \times 0.04 \text{ mm}$) was studied at 296 K. At both temperatures, the reflection data and systematic absences were consistent with the orthorhombic space group *Pbca*.

HT-1. A piece of orange-yellow prism $(0.45 \times 0.3 \times 0.1 \text{ mm})$ grown by slow evaporation of chlorobenzene at 95 °C studied at 150 K and at 296 K. At both temperatures, the reflection data and systematic absences were consistent with the orthorhombic space group $P2_12_12_1$.

Data were collected on a SuperNova single-crystal diffractometer equipped with a microfocus CuK_{α} radiation source ($\lambda = 1.54184$ Å), Atlas CCD detector and a CryoJet low temperature device. Diffraction intensity data were collected using ω -scan technique to the maximum resolution of 0.79-0.8 Å. The unit cell parameters were refined using the entire data sets. The data were processed using CrysAlisPro software.^[2] Absorption corrections were applied using the multiscan method. The structures were solved (direct methods) and refined (full-matrix least-squares on F^2) using SIR-92^[4] and SHELXL-2013.^[5] All non-hydrogen atoms were refined with anisotropic thermal parameters. H atoms were initially included in calculated positions with U_{iso} tied to the carrier atom. In the final cycles, their coordinates were freely refined. Data collection and refinement details are listed in Table S1 and select intermolecular contact distances are given in Table S2. Full crystallographic data and experimental details have been deposited with the Cambridge Crystallographic Data Centre in CIF format, with the deposition numbers listed in Table S1.

	LT-1		HT-1		
Temperature (K)	150(1)	296(2)	150(2)	296(2)	
Wavelength	CuK_{α} $\lambda = 1.54184 \text{ Å}$				
Crystal system	orthorhombic	orthorhombic	orthorhombic	orthorhombic	
Space group	Pbca	Pbca	$P2_{1}2_{1}2_{1}$	$P2_{1}2_{1}2_{1}$	
Unit cell lengths (Å) <i>a</i> <i>b</i> <i>c</i>	7.17006(6) 11.34032(10) 22.9044(2)	7.20370(19) 11.4142(3) 23.2130(7)	7.99603(12) 10.01680(13) 11.32452(15)	8.23838(12) 10.03744(12) 11.30577(14)	
Volume (Å ³)	1862.37(3)	1908.68(9)	907.03(2)	934.90(2)	
Ζ	8	8	4	4	
Ζ'	1	1	1	1	
Volume per molecule ($Å^3$)	232.8	238.6	226.8	233.7	
Density - calculated (g cm ⁻³)	1.593	1.554	1.635	1.586	
Absorption coefficient (mm ⁻¹)	4.954	4.834	5.086	4.935	
<i>F</i> (000)	912	912	456	456	
Crystal size (mm)	0.35 × 0.35 × 0.18	0.20 × 0.10 × 0.04	0.45 × 0.30 × 0.10	0.45 × 0.30 × 0.10	
θ range for data collection (°)	3.86 - 76.87	3.81 - 74.44	5.90 - 76.83	5.90 - 76.74	
Index ranges	h, -9/9; k, -14/12; l -28/28	h, -8/9; k, -12/14; l -27 28	h, -10/10; k, -12/12; l -14/14	<i>h</i> , -10/10; <i>k</i> , -12/12; <i>l</i> -14/13	
Reflections collected	45244	15695	17711	17588	
Independent reflections	1956 ($R_{int} = 0.066$)	1937 ($R_{int} = 0.040$)	1911 ($R_{int} = 0.035$)	1974 ($R_{int} = 0.036$)	
Completeness (%)	100.0	99.5	100.0	100.0	
Absorption correction	Semi-empirical	Semi-empirical	Semi-empirical	Semi-empirical	
Refinement method	Full-matrix least squares on F^2				
Data / restraints / parameters	1956 / 0 / 142	1937 / 0 / 142	1911 / 0 / 142	1974 / 0 / 142	
Goodness-of-fit on F^2	1.139	1.055	1.073	1.064	
Final <i>R</i> indices $[I > 2\sigma(I)]$	R1 = 0.035 wR2 = 0.095	R1 = 0.042 wR2 = 0.102	R1 = 0.023 wR2 = 0.063	R1 = 0.030 wR2 = 0.080	
R indices (all data)	R1 = 0.035 wR2 = 0.095	R1 = 0.051 wR2 = 0.107	R1 = 0.023 wR2 = 0.063	R1 = 0.031 wR2 = 0.081	
Absolute structure parameter (Flack)			0.005(6)	-0.003(7)	
Final min/max (e Å ³)	-0.42 / +0.32	-0.28 / +0.27	-0.31 / +0.18	-0.30 / +0.11	
CCDC deposition #	1522821	1522822	1522823	1522824	

Table S1. Single crystal XRD information for both phases of **1**; molecular formula, $C_9H_5O_2S_2$; formula weight, 223.26 g/mol



Intermolecular	Sum of	LT-1 atoms distance		HT-1			
contact	vdWr ^a			distance	atoms		distance
О…Н	2.7	08	H14	2.57(2)	08	H11	2.59(2)
					06	H12	2.63(3)
					08	H14	2.64(3)
S…H	3.0	S2	H13	2.91(2)	S1	H12	2.96(3)
S…O	3.35	S2	06	3.088(1)	S2	06	3.288(2)
		S2	08	3.108(1)			
		S1	08	3.162(1)			
		S1	O6	3.167(1)			
S…C	3.5	S2	C10	3.292(2)	S2	C13	3.470(2)
		S2	C11	3.389(2)	S2	C14	3.484(2)
С…Н	2.9	C10	H12	2.84(2)			
		C11	H12	2.87(3)			
0…C	3.25	06	C7	3.009(2)			
S····S	3.6	S1	S 1	3.5651(6)			

Table S2. Select intermolecular contact distances (Å) at 150 K.

^aValues determined using the recommended crystallographic vdWr of elements^[6]

Crystal Structure Analysis: Visualization and analysis of crystal structures was aided with the use of Mercury 3.8 and CrystalExplorer 3.1.^[7] Hirshfeld surfaces were generated with CrystalExplorer 3.1 using default van der Waals radii (vdWr) values used for d_{norm} calculations.^[8]



Figure S8. Stick representation of the unit cell viewed normal to (010) for (left) **LT-1** and (right) **HT-1**; cyan lines represent contacts within the sum of vdWr at 150 K



Figure S9. Two representations of the crystal packing and close contacts in **HT-1** (150 K structure), based on the close contacts identified by Hirshfeld surface analysis



Figure S10. Illustration of S…O contact geometries in LT-1 (left) and HT-1 (right). Note that the S…O contacts in HT-1 are greater than the sum of vdWr.

Table S3. S…O contact geometries d, θ , and ϕ , as defined by Rosenfield, *et al.*,^[9] from the 150 K structures.

Form	Contact	<i>d</i> (Å)	θ (°)	φ (°)
	S2…O6	3.088	73.6	131.6
	S2…O8	3.108	48.8	136.6
LT-1	S1…O8	3.162	78.8	140.5
	S1…O6	3.167	77.5	122.6
HT-1	S2…O6	3.288	51.6	131.9

Rosenfield *et al.*^[9] have elucidated the geometric preferences of intermolecular sulfur contacts with electronegative and electropositive exo-atoms. The S…O contacts present in **LT-1** are consistent with these preferred geometries whereas the longer S…O contacts (outside the sum of vdWr) in **HT-1** are not. For ease of comparison with the literature, Table S3 presents contact geometry data in a form consistent with the polar graphs presented in Rosenfield *et al.*

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