Supporting Information

Improvements to practical usability of the "crystalline sponge" method for organic structure determination

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Contents:

General Considerations:

All manipulations were performed under aerobic conditions. 2,4,6-tri(4-pyridyl)-1,3,5-triazine (TCI), methanol (Sigma-Aldrich), zinc (II) iodide (Strem), nitrobenzene (Alfa Aesar) and 2,6-diisopropylaniline (Alfa Aesar) were purchased from the indicated sources. All reagents were used without further purification.

Synthesis and crystal growth of **1**:

In a 100 mL Erlenmeyer flask, ZnI_2 (0.482 g, 1.51 mmol) was dissolved in methanol (50 mL) to make a 30.2 mM solution. Separately, in a 500 mL screw top jar of 2,4,6-tri(4-pyridyl)-1,3,5-triazine (0.315 g, 1.01 mmol) was suspended in nitrobenzene (200 mL) and methanol (50 mL) to make a 4.03 mM solution. The nitrobenzene/methanol solution was sonicated for 20 min to completely dissolve the 2,4,6-tri(4-pyridyl)-1,3,5-triazine. Using a 100-1000 μL Wilmad LabGlass Med Plus pipette, 800 μL of the 2,4,6-tri(4-pyridyl)-1,3,5-triazine solution was added to the center and four corner wells of a 9 well glass plate from Hampton Research. With the same pipette, 200 μL of the ZnI_2 solution was slowly added on top of the five ligand solutions to create two layers of solutions, as shown in **Figure S1a**. (Some mixing occurred, which did not harm the crystal growth). Five nitrile o-rings (Outer Diameter: 32 mm, Inner Diameter: 25 mm, Thickness: 3.53 mm) were placed over the five wells that contain solutions, as shown in **Figure S1b**. A 4"x4"x3/16" flat clear glass plate was placed on top of the five o-rings, covering the whole glass plate, as shown in **Figure S1c**. Two 1-inch binder clips were attached to the left and right side of the apparatus to hold the system together as shown in **Figure S1d**. The apparatus was allowed to sit, undisturbed, for at least 10 hours until small, rod-like crystals formed. (Some evaporation of the solvents does occur, and so the crystal growth should be conducted in a fumehood.)

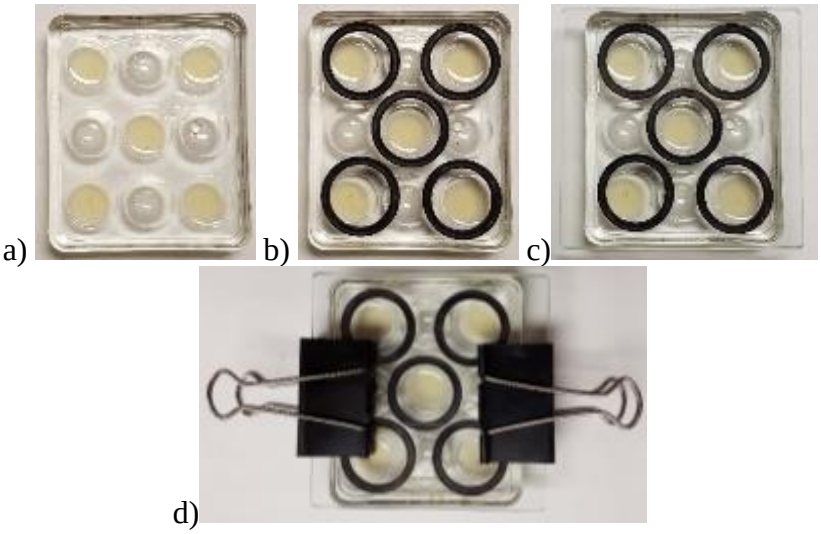


Figure S1: Step by step crystal growth apparatus set up.

DIPA soaking:

After crystals of **1**·$PhNO_2$ formed (see above), the binder clips, glass plate and o-rings were removed, and any remaining solution was removed from the wells using a 100-1000 μL Wilmad LabGlass Med Plus pipette, leaving behind the crystals. 1 mL of the guest (or solution thereof) was added to each of the five wells. A 1/8" thick synthetic blend rubber sheet from

rubber sheetroll was cut (Outer: 3 3/8” x 4”, Inner: 2 7/8” x 3 3/8” Thickness: 1/4") to create a gasket that fits around the outside edge of the glass well plate, as shown in **Figure S2a**. This rubber gasket was placed on the edge of the glass well plate, as shown in **Figure S2b**. The glass plate was placed on top of the rubber gasket, and four 1-inch binder clips were attached to each side of the apparatus, as shown in **Figure S2c**. The solution was allowed to sit, undisturbed, for at least 6 hours. In some cases, a noticeable color change occurs with the crystals. The binder clips, glass plate and rubber gasket were removed, and a majority of the liquid solution was removed leaving behind the now substrate-soaked crystals. (It is important to make sure there is still some of the substrate solution around to prevent the crystals from drying out and cracking.) A large batch of crystals was scooped out of the well using a needle and paratone oil and then placed on a glass microscope slide. Crystals were then chosen by finding crystals that were free of cracks and deformations.

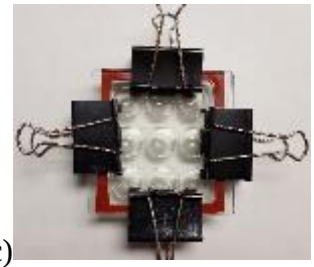
a)  b)  c) 

Figure S2: Step by step guest soaking apparatus set up.

Solvent Exchange:

After crystals of **1**·$PhNO_2$ were formed (see above), the binder clips and o-rings were removed. Most of the remaining solution was removed using a glass pipette without letting the crystals dry out. 1 mL of the new guest solvent (cyclohexane or chloroform) was added to all nine wells. Most of the solution was removed using a glass pipette again. This process was repeated once more, in order to remove as much residual nitrobenzene as possible. 1 mL of the new guest solvent was added to each well, and a thin 4”x4” Teflon sheet (**Figure S3a**) was placed on top of the well plate. A glass plate was placed on top of the Teflon sheet as shown in **Figure S3b**. Four 1” binder clips were attached on each side of the apparatus, as shown in **Figure S3c**. The crystals were allowed to sit at room temperature. The solvent in each well was removed and replenished once every 24 hours. To monitor solvent exchange over time, the solution from one well with crystals was completely removed and the crystals were analyzed by IR spectroscopy. This was repeated until the N-O stretch peak at 1344 cm^{-1} was completely gone. By this analysis method, all $PhNO_2$ was reproducibly gone within 6 days.

a)  b)  c) 

Figure S3: Step by Step Guest Solvent Exchange Set Up

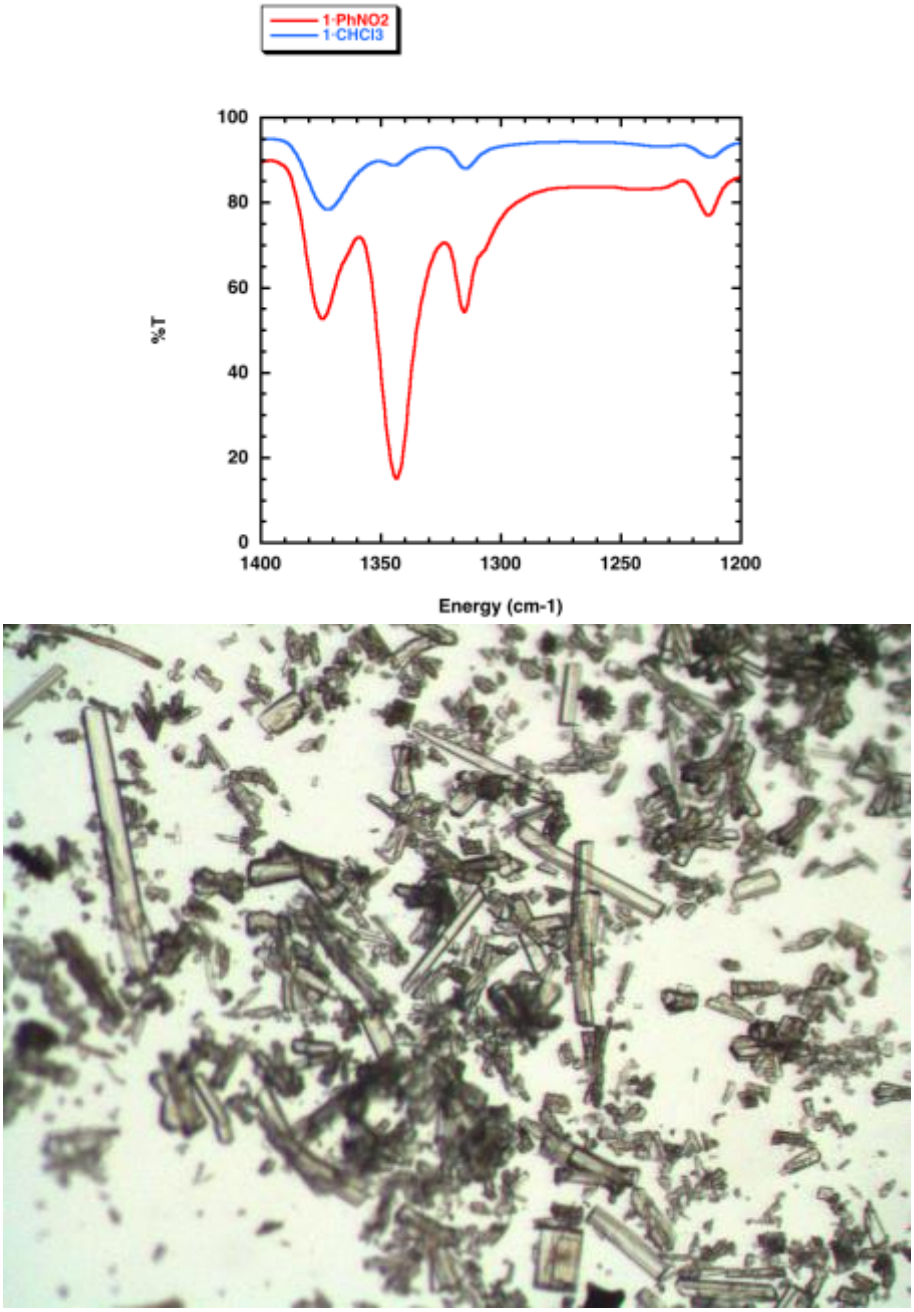


Figure S4. *Top*: FT-IR data for **1**·$PhNO_2$ and **1**·$CHCl_3$. *Bottom*: Photo of **1**·$CHCl_3$ crystals obtained after exchanging $PhNO_2$ for $CHCl_3$ for 6 days.

Crystallographic procedures:

A suitable crystal, measuring roughly 0.10 x 0.05 x 0.05mm, was mounted on a nylon cryoloop with a magnetic base using paratone®-N oil and cooled in a nitrogen gas cryostream to 100K on the spindle axis of the MD2 micro diffractometer at beam line 21-ID-D, Advanced Photon Source, Life Sciences Collaborative Access Team (APS/LS-CAT) at Argonne National Laboratory. Data were collected using 1-10º ϖ-scans, 1-second exposure, at a crystal-to-detector distance of 100mm, for a total rotation of 360º on a MAR 300mm CCD detector. Images were processed with HKL2000.[1] Typical data runs used 72 or 180 images for a single 360° sweep. The unit cell parameters were determined from the full data set using at least 100,000 reflections. Intensity data was indexed, averaged, and scaled in space group C2/m. Direct methods using SHELXS was used to solve, and SHELX-2013 was used to refine the structure on F^2.[2] The zinc and iodide atoms, and triazene molecules, were evident from initial phasing models. Hydrogen atoms were added to the model, and all non-hydrogen atoms were refined with anisotropic Gaussian displacement parameters. The guest molecules were evident from the difference electron density maps, and were added to the model with hydrogen atoms. For each guest, the occupancy was refined. In all cases, hydrogen atoms were refined with the riding model with standard fixed bond lengths and geometry.

Procedures specific to $(ZnI_2)_3$[tris(4-pyridyl)-1,3,5-triazene$)_2$](nitrobenzene$)_{2x}$:

A total of 135676 intensities were used for refinement to a resolution of 0.753A. The ISOR and SIMU commands were used for all non-hydrogen atoms except the Zn and I atoms. This lead to a more reasonable set of anisotropic Gaussian displacement parameters. Since the Zn2, I3, and I4 atoms were split into two sets with partial occupancies constrained to a sum of 1.0, and SIMU and SAME restraints was introduced on them. The SAME restraints were also applied to molecule B (N51-C56), and molecule C (N61-C66) using molecule A (N41-C46) as the model set of 1,3-distances. The molecules soaked into the pores were not at full occupancy, so the occupancy was refined for each molecule, yielding partial occupancies of 0.755(11), 0.800(11), and 0.552(7), respectively. Hydrogen atoms were placed at aromatic calculated positions, C-N = 0.95A. After refinement to convergence, SQUEEZE was run, and a large void was identified in the cell; final refinement using the modified structure factors led to the final R1 = 0.0693 for 11596 intensities greater than 4s, 0.1017 for all 18625 intensities, and GOF = 1.059.

Procedures specific to $(ZnI_2)_3$[tris(4-pyridyl)-1,3,5-triazene$)_2$](2,6-diisopropylaniline$)_{2x}$:

A total of 139789 intensities were used for refinement to a resolution of 0.752A. Refinement was setup as noted above with the ISOR, SUMU, and SAME restraints. In this case, Zn5, I5 and I6 formed two sets with partial occupancies constrained to a sum of 1.0; SIMU restraints were not applied to the Zn or I atoms. Molecule C sits on a site of 2-fold symmetry. The partial occupancies of molecules in the pores were refined to 0.899(12), 0.789(13), and 0.382(12). SQUEEZE was not employed. The final R1 = 0.0916 for 12947 intensities greater than 4s, 0.1281 for all intensities, and GOF = 1.130.

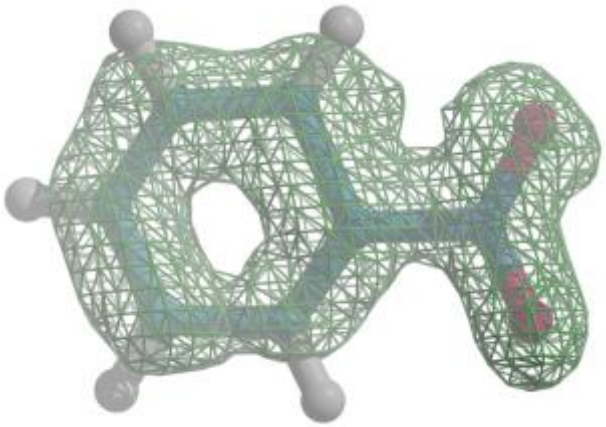


Figure S5. Difference electron density map (3.5σ) for a representative nitrobenzene molecule removed from a **1**·$PhNO_2$ model.

Table S1. Unit cell data for crystals grown from different ZnI_2:L ratios.

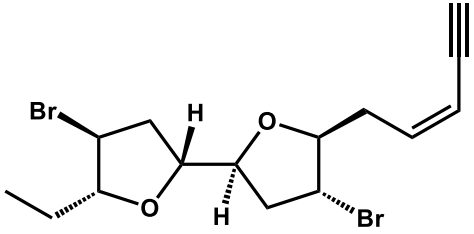
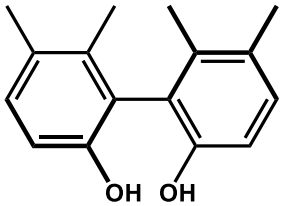
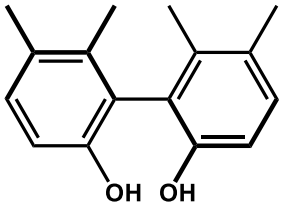
ZnI_2:L Ratio	**a (Å)**	**b (Å)**	**c (Å)**	**beta°**
1:1	33.369(19)	15.123(2)	29.973(6)	99.885(7)
1:2	34.702(19)	14.834(6)	31.030(12)	101.291(80)
1:2	34.683(13)	14.825(3)	31.001(5)	101.282(64)
1:3	34.051(13)	15.041(2)	30.431(3)	100.667(24)
1:4	33.532(14)	15.083(1)	30.139(3)	100.021(8)
1:5	33.522(20)	15.085(2)	30.009(6)	99.853(22)
1:6	35.710(4)	14.952(8)	30.798(2)	102.379(11)
1:7	33.990(5)	15.067(1)	20.427(2)	100.745(7)
1:8	35.589(13)	14.971(4)	30.779(9)	102.246(14)
1:9	34.097(11)	15.046(3)	30.445(5)	100.852(6)
1:10	34.863(19)	14.872(3)	31.203(10)	101.511(9)
1:10	34.232(27)	15.005(2)	30.302(5)	100.558(17)

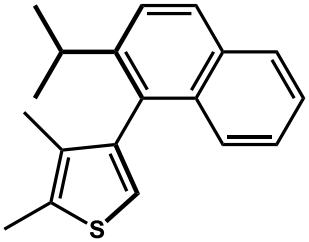
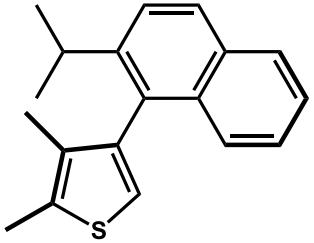
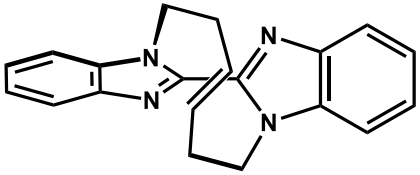
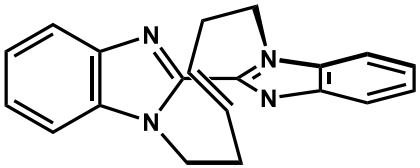
Table S2. Unit cell data for crystals grown by soaking DIPA in from solutions of different concentrations.

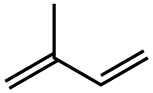
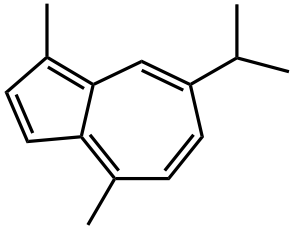
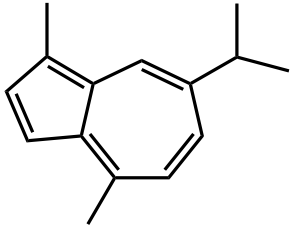
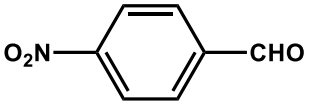
Conc (M)[a]	**a (Å)**	**b (Å)**	**c (Å)**	**β°**
47.7	36.966(7)	14.695(8)	30.906(4)	102.626(4)
23	37.085(3)	14.666(1)	30.858(2)	102.546(5)
12.3	37.024(5)	14.718(2)	30.883(9)	102.706(13)
8	37.018(11)	14.668(2)	30.809(5)	102.471(6)
5.3	37.043(9)	14.668(3)	30.746(6)	102.615(17)
2.3	37.174(19)	14.764(2)	30.537(6)	102.885(21)
1.3	37.096(6)	14.728(1)	30.559(3)	102.700(6)
0.3	36.301(12)	14.776(2)	30.489(6)	101.769(9)
0.3	36.317(19)	14.753(4)	30.512(3)	102.047(13)
0.1	37.266(9)	14.801(1)	30.471(6)	103.229(14)
0.05	36.930(27)	14.741(4)	30.587(11)	102.376(18)
0.05	37.167(11)	14.799(2)	30.481(5)	102.987(17)
Avg	*36.94925*	*14.731667*	*30.6535*	*102.57925*
St Dev	*0.3132014*	*0.0490572*	*0.1731276*	*0.3943224*

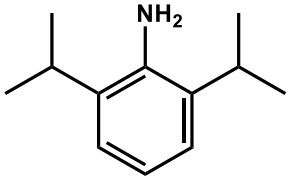
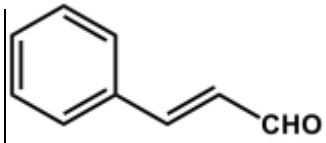
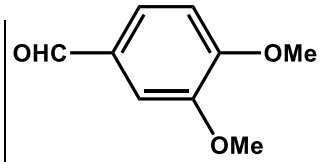
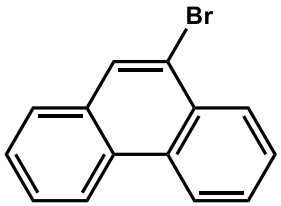
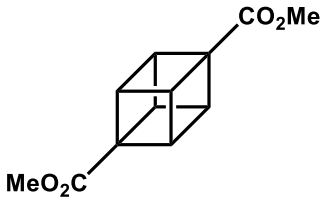
[a] Concentration of 2,6-diisopropylaniline in *n*Bu$_2$O used for guest soaking.

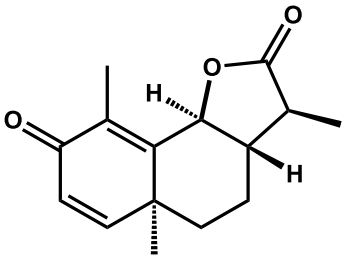
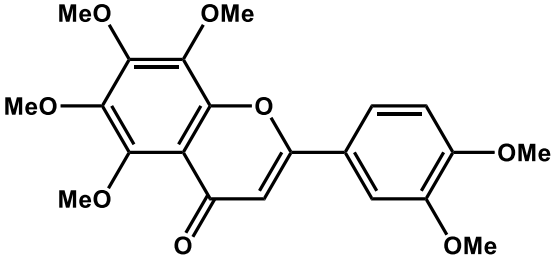
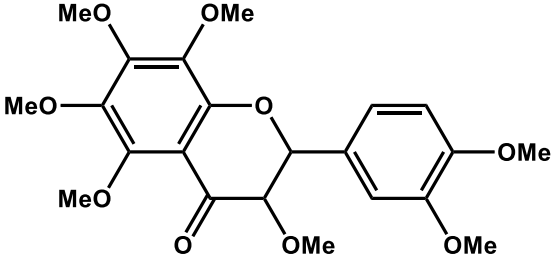
Table S3. Compilation of unit cell data for all known guests in sponge **1**.

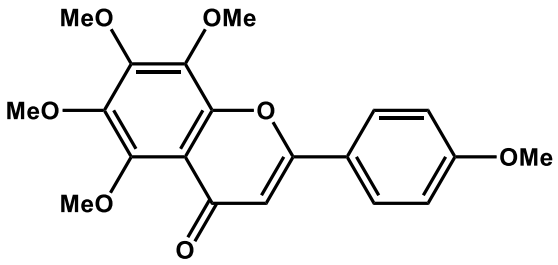
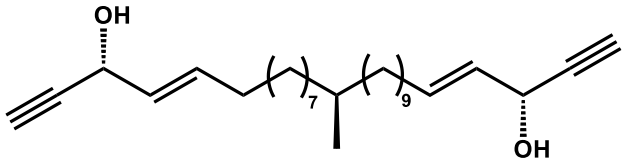
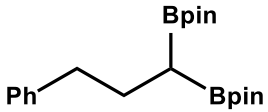
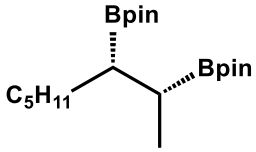
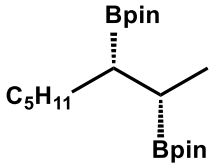
Guest	a (Å)	b (Å)	c (Å)	β (°)	V (Å³)	Space Group	Ref	Note
	34.6788(6)	15.0282(2)	31.1707(9)	101.973(2)	15891.5(6)	C2/c	4	
 $C_{16}H_{18}O_2$	34.627(4)	15.0818(16)	31.194(3)	102.7920(10)	15886(3)	C2/c	5	
 $C_{16}H_{18}O_2$	34.200(3)	15.1265(13)	31.003(3)	102.3850(10)	15665(2)	C2/c	5	

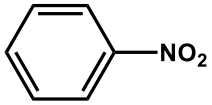
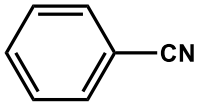
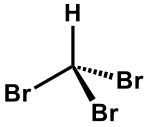
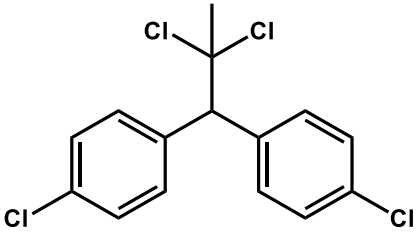
 $C_{19}H_{20}S$	34.4391(11)	15.0959(3)	29.9566(10)	101.454(3)	15263.4(8)	C2/c	5	
 $C_{19}H_{20}S$	34.8299(7)	14.9133(2)	31.5387(6)	102.403(2)	15999.8(5)	C2/c	5	
 $C_{20}H_{18}N_4$	35.2721(9)	14.6427(2)	31.6037(9)	102.029(2)	15964.2(7)	C2/c	5	
 $C_{20}H_{18}N_4$	35.1081(9)	14.6516(2)	31.3279(8)	101.649(2)	15782.8(6)	C2/c	5	

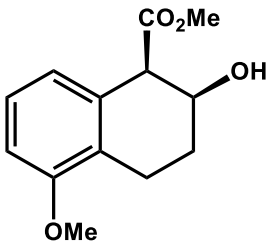
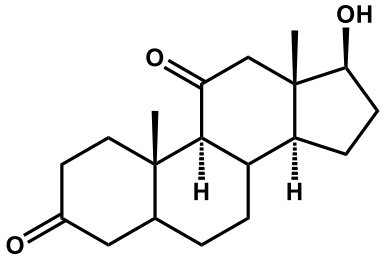
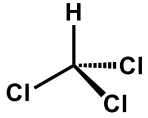
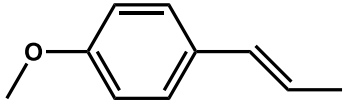
 $C_6H_{10}O$	37.218(6)	37.293(6)	26.388(5)	134.988(2)	25974(8)	C2/m	6	
 C_5H_8	35.060(4)	14.7672(16)	30.527(3)	101.0880(10)	15510(3)	C2/c	6	
 $C_{15}H_{18}$	34.644(6)	14.879(3)	20.836(6)	101.787(2)	15560(5)	C2/c	6	500 ng guest
 $C_{15}H_{18}$	34.576	14.884	30.646	101.17	15473	C2/c	6	80 ng guest
 $C_7H_5NO_3$	35.602(11)	14.879(5)	30.538(10	103.153(4)	15752(9)	C2/c	6	

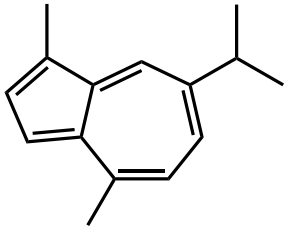
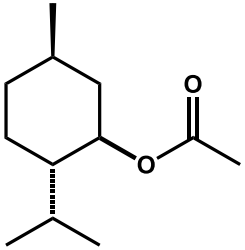
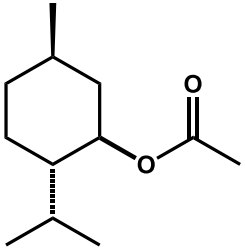
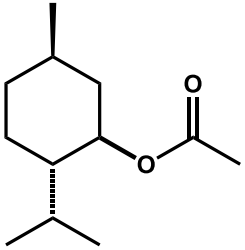
								
$C_{12}H_{19}N$	35.752(9)	14.774(4)	30.5894(7)	101.647(4)	15828(7)	C2/c	6	
								
C9H8O	34.847(4)	14.7560(16)	30.740(4)	102.007(2)	15461(3)	C2/c	6	
								
$C_9H_{10}O_3$	14.907(5)	18.608(6)	32.920(11)	93.089(4)	8323(5)	P-1	6	
								
$C_{14}H_9Br$	35.862(5)	14.902(2)	31.358(5)	102.694(2)	16349(4)	C2/c	6	
								
	14.952(9)	18.584(11)	32.756(19)	102.349(7)	7678(8)	P-1	6	

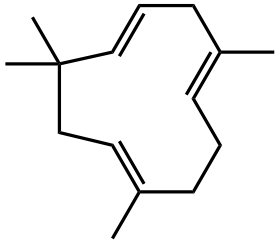
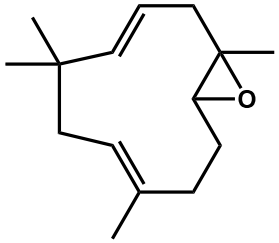
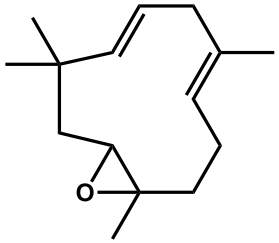
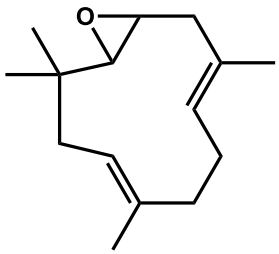
$C_{12}H_{12}O_4$								
 $C_{15}H_{18}O_3$	32.866(5)	14.853(2)	34.850(6)	105.848(2)	16366(5)	$P2_1$	6	
 $C_{21}H_{22}O_8$	34.562(8)	14.950(4)	30.348(7)	100.119(3)	15437(6)	C2/c	6	
 $C_{22}H_{26}O_9$	34.534(6)	15.028(3)	31.197(6)	101.215(3)	15881(5)	Cc	6	

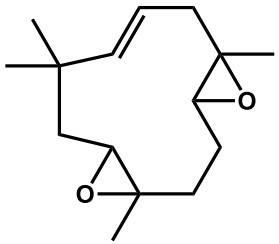
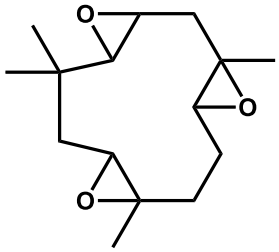
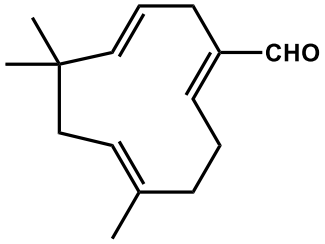
 $C_{20}H_{20}O_7$	34.103(6)	14.767(3)	30.700(6)	99.802(2)	15235(5)	C2/c	6	
 $C_{15}H_{20}O_2$	34.804(3)	14.8607(11)	31.624(2)	102.0830(10)	15994(2)	C2	6	
 C_9H_{10}	35.3355(8)	14.9646(2)	30.5277(5)	102.201(2)	15777.9(5)	C2/c	7	
 C_8H_{16}	34.7466(13)	14.8989(3)	30.5651(9)	100.894(3)	15538.0(8)	C2/c	7	
 C_8H_{16}	35.3841(10)	14.9998(2)	30.4076(7)	101.922(2)	15790.8(6)	C2/c	7	

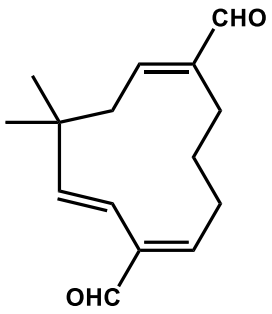
 $C_6H_5NO_2$	36.079(10)	14.978(4)	30.734(9)	102.470(2)	16217(12)	C2/c	8	
 C_7H_5N	35.487(8)	15.080(4)	31.542(7)	102.107(4)	16504(7)	C2/c	8	
 C_6H_6	35.316(3)	14.7247(14)	31.766(3)	101.9062(2)	16163(7)	C2/c	8	
 $CHBr_3$	35.252(5)	39.509(5)	8.553(1)	90.000	11355(3)	Fdd2	8	
Empty (No Guest)	14.573(19)	17.268(23)	28.044(38)	76.956(14)			8	
 $C_{15}H_{12}Cl_4$	35.7365(13)	15.0610(5)	30.9345(11)	104.141(7)	16145.2(11)	C2/c	9	

								
$C_{13}H_{16}O_4$	36.3783(8)	14.6755(2)	31.2278(6)	103.184(2)	16232.2(5)	C2/c	9	
								
$C_{19}H_{28}O_3$	34.7707(6)	14.8406(3)	31.2152(5)	102.601(2)	15719.6(5)	C2/c	9	
								
$CHCl_3$	34.655(3)	14.7307(14)	31.081(3)	101.031(2)	15574(3)	C2/c	10	
								
$C_{10}H_{12}O$	34.346(2)	15.1140(9)	32.5502(19)	103.4150(13)	16436.1(17)	C2/c	10	

 $C_{15}H_{18}$	34.936(3)	14.9785(13)	30.825(3)	102.8570(17)	15726(2)	C2/c	10	
 $C_{12}H_{22}O_2$	34.966(3)	14.8683(14)	66.990(6)	104.1919(1)	33764(5)	$P2_1$	10	ZnI_2
 $C_{12}H_{22}O_2$	33.964(3)	14.5897(14)	33.787(3)	104.9361(14)	16176(3)	C2	11	$ZnBr_2$
 $C_{12}H_{22}O_2$	33.391(2)	14.3975(10)	33.897(2)	105.2725(12)	15720.2(19)	C2	11	$ZnCl_2$

 C15H24	34.7408(7)	14.9018(2)	31.0584(7)	101.437(2)	15759.7(5)	C2/c	11	
 C15H24O	34.5900(4)	14.92734(18)	30.1552(5)	100.9231(13)	15288.1(4)	C2/c	11	
 C15H24O	34.9245(6)	14.9263(2)	29.7839(5)	101.228(2)	15229.0(4)	C2/c	12	
 $C_{15}H_{24}O$	34.9032(8)	14.8011(2)	31.0811(7)	101.564(2)	15730.7(6)	C2/c	12	

 $C_{15}H_{24}O_2$	34.8531(7)	14.7838(3)	31.0339(8)	101.296(2)	15680.8(6)	C2/c	12	
 $C_{15}H_{24}O_3$	34.651(4)	14.9888(15)	30.113(3)	100.7353(19)	15366(3)	C2/c	12	
 $C_{15}H_{22}O$	34.7076(8)	15.0136(4)	29.9475(8)	100.783(2)	15329.7(7)	C2/c	12	

								
$C_{15}H_{20}O_2$	34.307(7)	14.392(3)	34.931(7)	106.22(3)	16560(6)	C2/c	12	

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1. Z. Otwinowski and W. Minor, "Processing of X-ray Diffraction Data Collected in Oscillation Mode," *Methods in Enzymology*, Volume 276: Macromolecular Crystallography, part A, pp. 307-326, 1997, C. W. Carter, Jr. and R. M. Sweet, Eds., Academic Press, New York.
2. G. M. Sheldrick, "A Short History of SHELX," *Acta Crystallogr*., **A64**, 112-122, 2008