Complementary Crystallography and X-ray Powder Diffraction Methods

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Preformulations

Lilly

Answers That Matter.

This document was presented at PPXRD - Pharmaceutical Powder X-ray Diffraction Symposium

Sponsored by The International Centre for Diffraction Data

PPXRD Website – www.icdd.com/ppxrd

ICDD Website - www.icdd.com

Solid-State Pharmaceutics

Identify a phase that is suitable for a product

"Safe and Efficacious"

Bioavailable – sufficiently soluble to achieve efficacy

Physically and Chemically Stable no-phase transitions and less than 2% decomposition when stored for 2 years with 5 to 10 other excipients and exposed to 20-75%RH

Crystalline, Soluble, Non-solvated, filters well, non-hygroscopic, is flowable…..is that all?……um…with just 2g of material in less than 30 days?

Non-discrete phases (continuous)

In that quest – we find many phases that are not discrete

Iso-structural Solvates: drug packs in the same arrangement in the crystal lattice with many different solvents

(or Iso-structural desolvates or “variable hydrates”)

Less commonly Iso-structural Salts

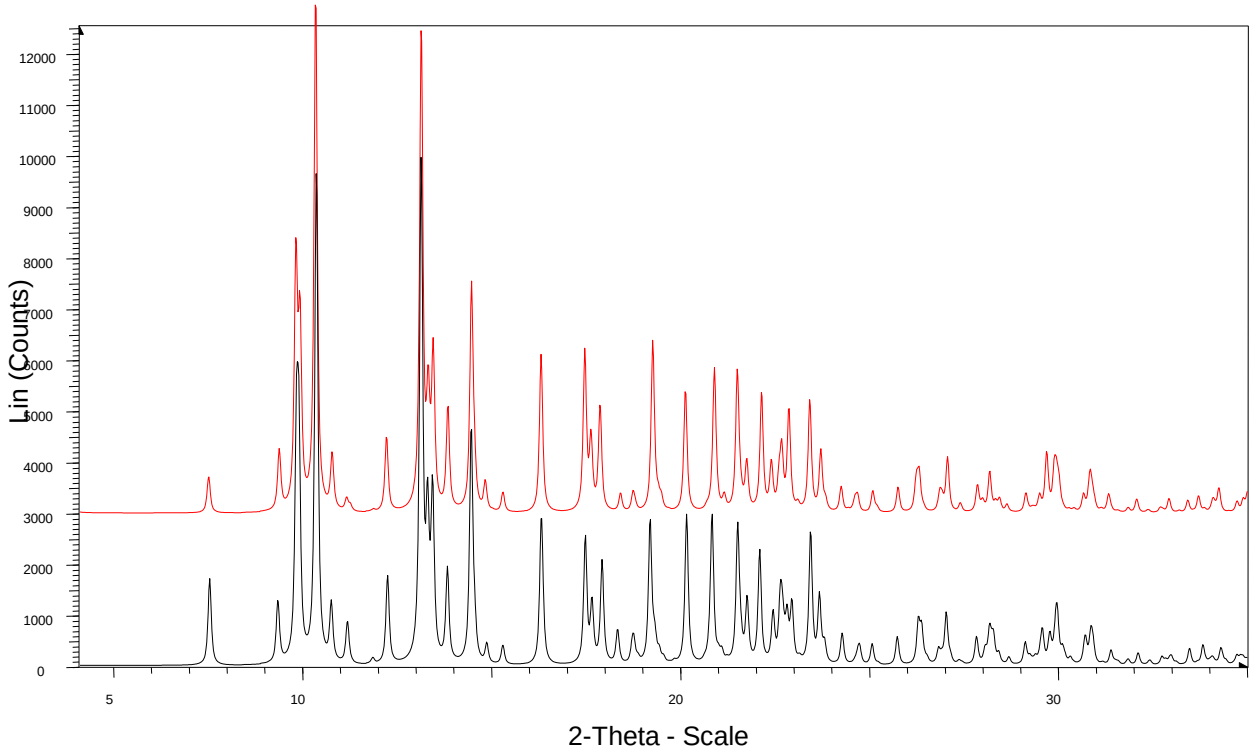
and Solid-Solutions

Also talk about:

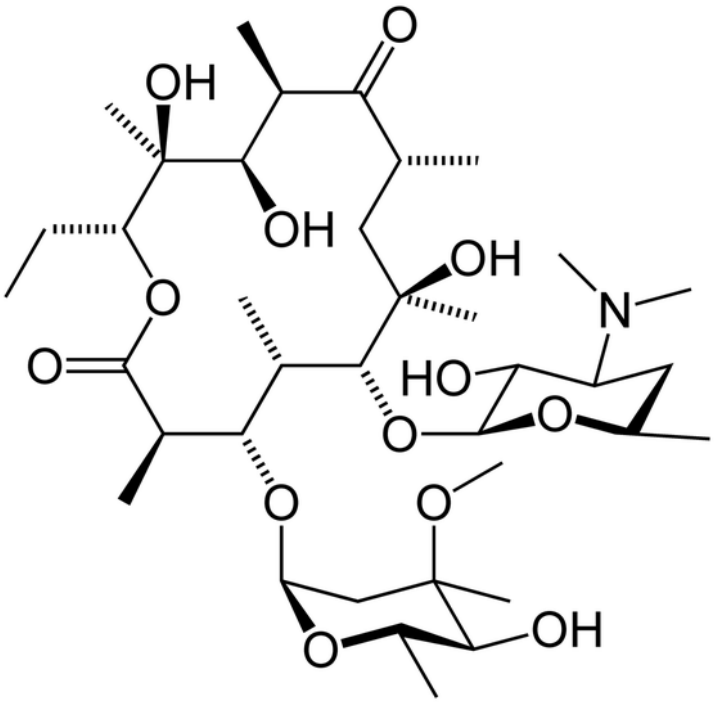
Discuss a couple of Discrete Phases, one quite interesting

End with a Structure solution from Powder Diffraction

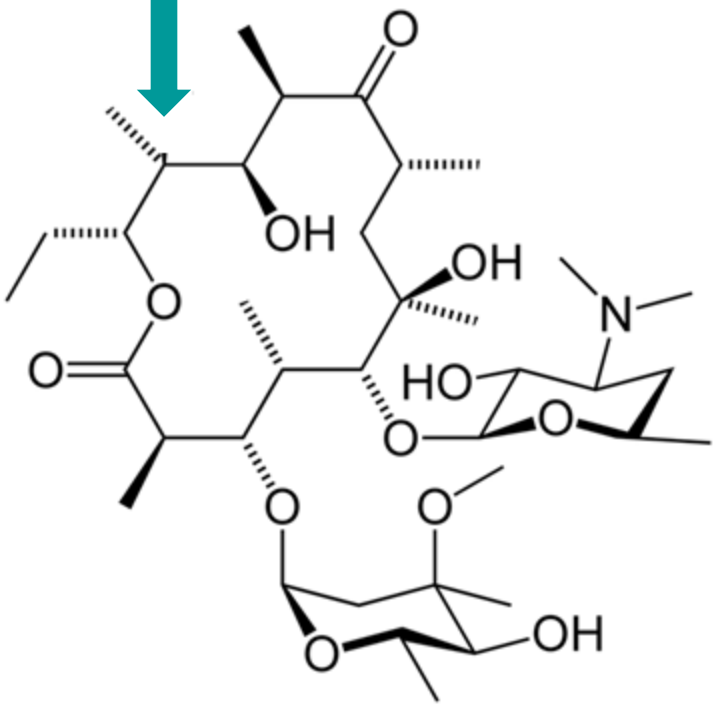
Erythromycin Dihydrate: Same or Different Form Based on X-ray Powder Diffraction?



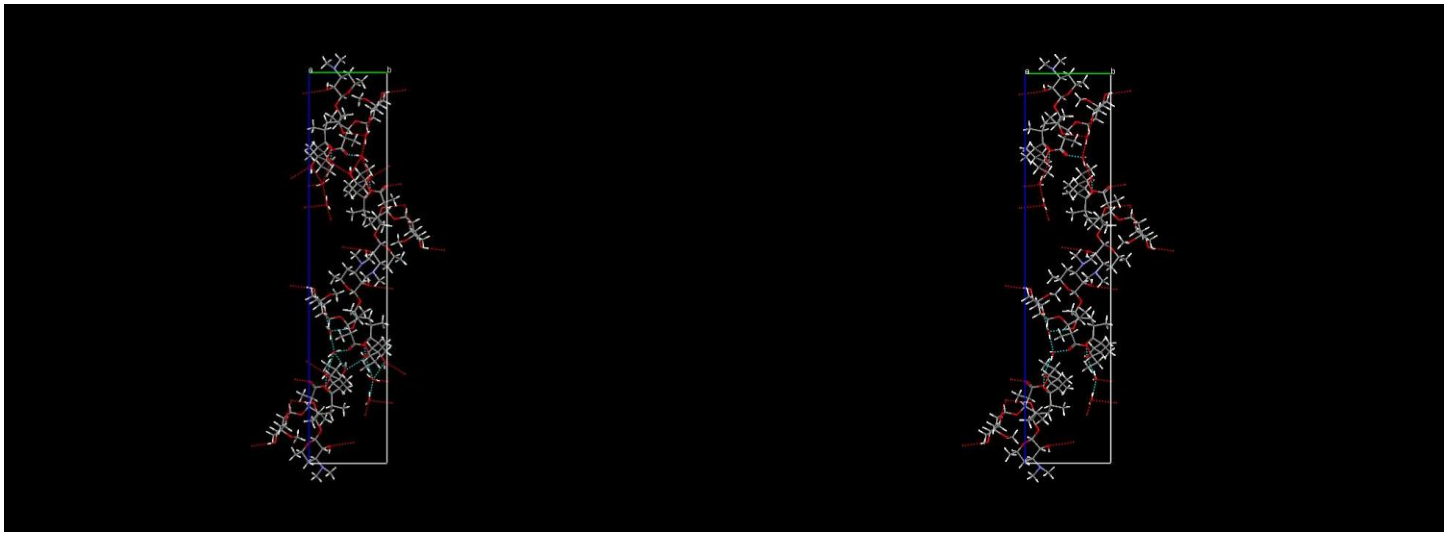
Molecular Structures of Erythromycin A and Erythromycin B



Erythromycin B lacks hydroxyl group



Erythromycin A and Erythromycin B Dihydrate Crystal Forms



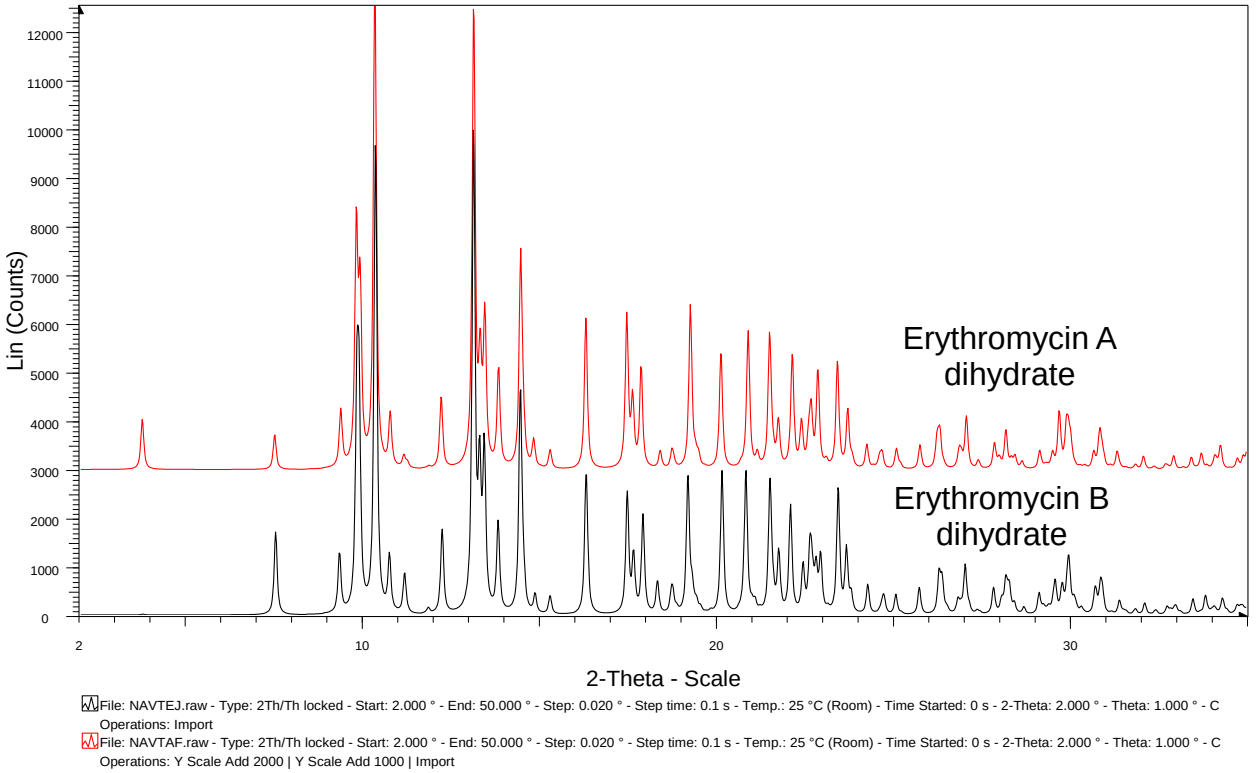
Isostructural Dihydrates

Erythromycin A dihydrate
Orthorhombic, S.G. $P 2_1 2_1 2_1$
a = 9.1829(8) Å
b = 9.6316(7) Å
c = 47.151(13) Å

Erythromycin B dihydrate
Orthorhombic, S.G. $P 2_1 2_1 2_1$
a = 9.170(1) Å
b = 9.672(1) Å
c = 46.985(1) Å

G.A.Stephenson, J.G.Stowell, P.H.Toma, R.R.Pfeiffer, S.R.Byrn
J.Pharm.Sci. (1997), 86, 1239. CCDC Ref Code NAVTAF and NAVTEJ

Erythromycin A dihydrate versus Erythromycin B dihydrate



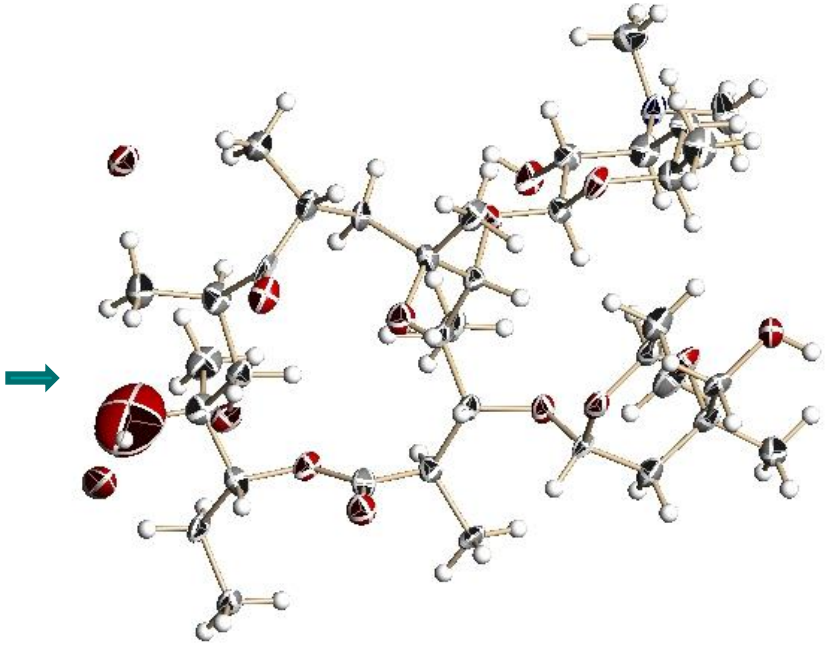
Different

Unit cell metrics nearly identical

Unit cell contents nearly identical

Molecular Packing nearly identical

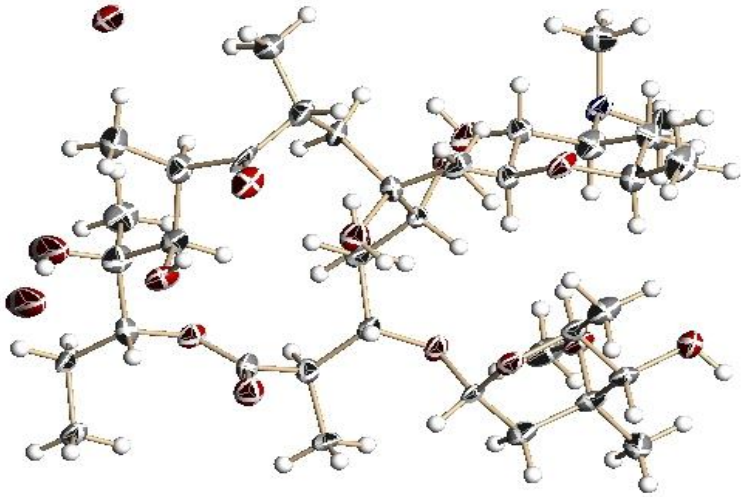
Much information in a Thermal Ellipsoid diagram



Something Wrong with Hydroxyl group during refinement

Refine Hydroxyl Group Site Occupancy

This is actually a solid solution formed upon crystallization of the two molecule's



38% Erythromycin A, 62% Erythromycin B
Well Behaved Structure
(Thermal ellipsoid plot)

All atoms have similar thermal parameters other than where expected

Solid-Solution Formation, Reasonably Common with Related Substances or Natural Products

Solid-Solutions are reasonably common, however are often overlooked

Commonly found in crystallization processes

- That related substance that you just can't seem to reject

Need to find conditions that result in phase separation

- Screen for a solvent that results in different crystal forms for the two different substances, those conditions should afford separation

Coefficient of Isomorphism[1]

Kitaigorodskii defines a coefficient of isosterism - compares molecular volumes common to two molecules that are arranged in such a fashion as to maximize the superposition of constituent groups

$$\epsilon = 1 - (V_{no\text{-}overlap}/V_{overlap})$$

No Solid solution is likely to form when < 0.8, but is likely when > 0.9[2]

Hence larger molecules and related substances

1.Jacques, Collet , Wilen in Enantiomers, Racemates, and Resolutions, Kreigers Publishing, 1991, p128

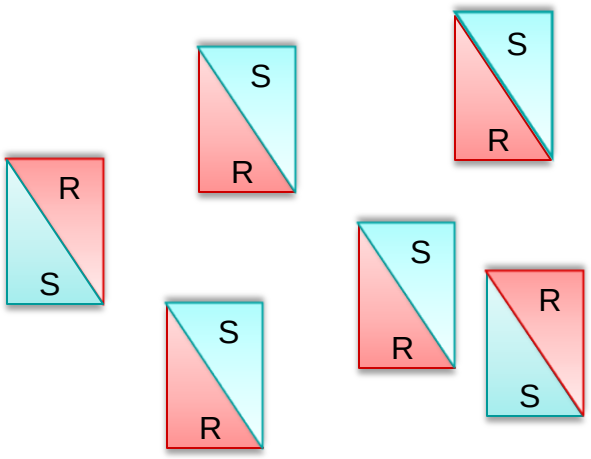
2. A.I. Kitaigorodskii, Organic Chemical Crystallography, Consultants Bureau, New York, 1968, p 453.

Crystallization of Racemic Compounds

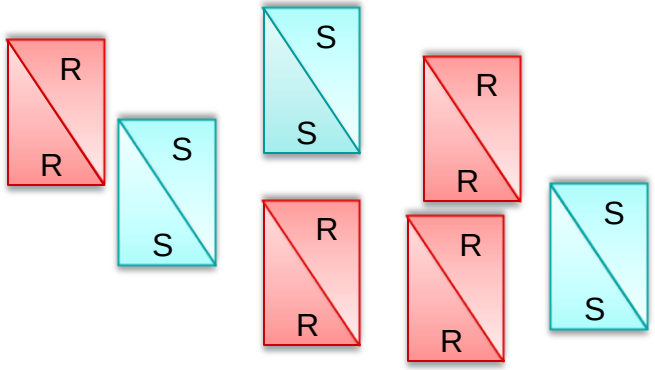
Solution of Two Enantiomers

~90% of the time

~10% of the Time



Racemic Crystals



Mixture of Chiral Crystals of Opposite "Handedness"
Conglomerate Mixture

Wallach's Rule[1]
states that racemic crystals tend to be denser than their chiral counterparts

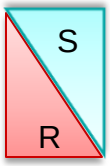
Wallach, O. Liebigs Ann. Chem. 1895, 286, 90-143.

Analytical Differentiation of Racemic Crystals versus a Conglomerate

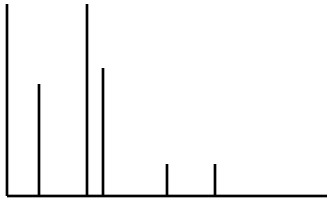
Racemic Crystals

Single Crystals Method

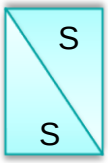
Powder Diffraction
(ssNMR, IR, Raman, mp)



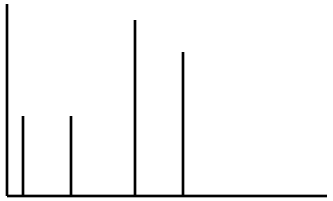
Structure (molecular arrangement) differs from Chiral Forms

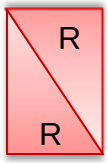


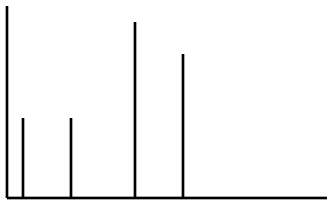
Chiral Crystals



Same Crystal Packing, however Mirror Image Structures

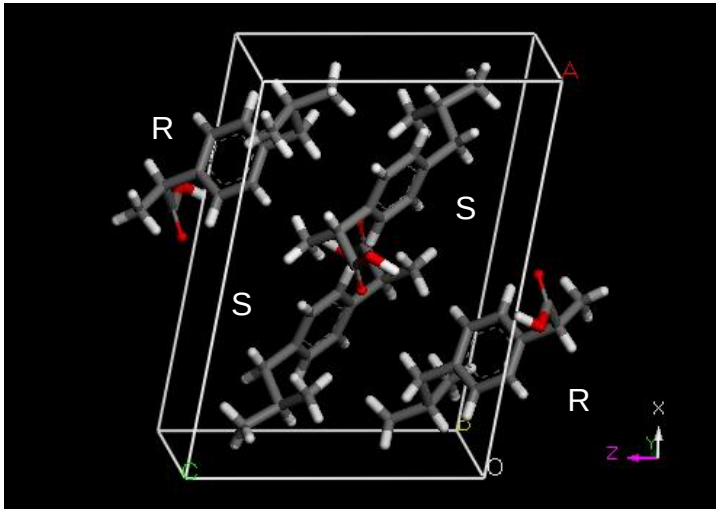






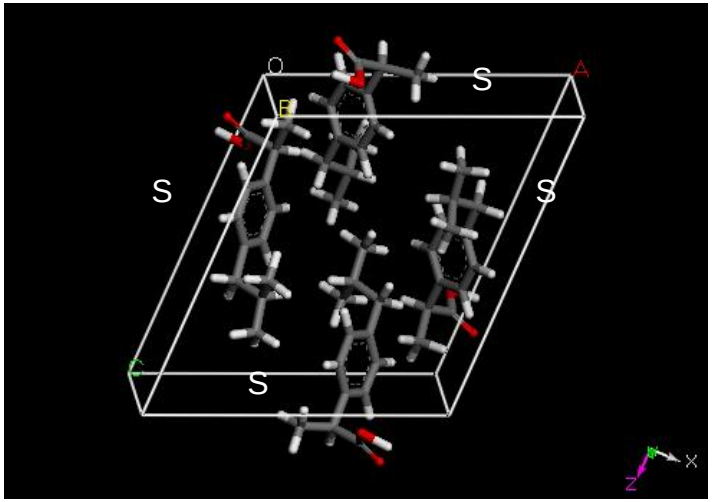
Racemic Ibuprofen and its S Enantiomer

Monoclinic Space Group $P2_1/c$
a = 14.67 Å b = 7.89 Å c = 10.73 Å
Beta = 99.43°



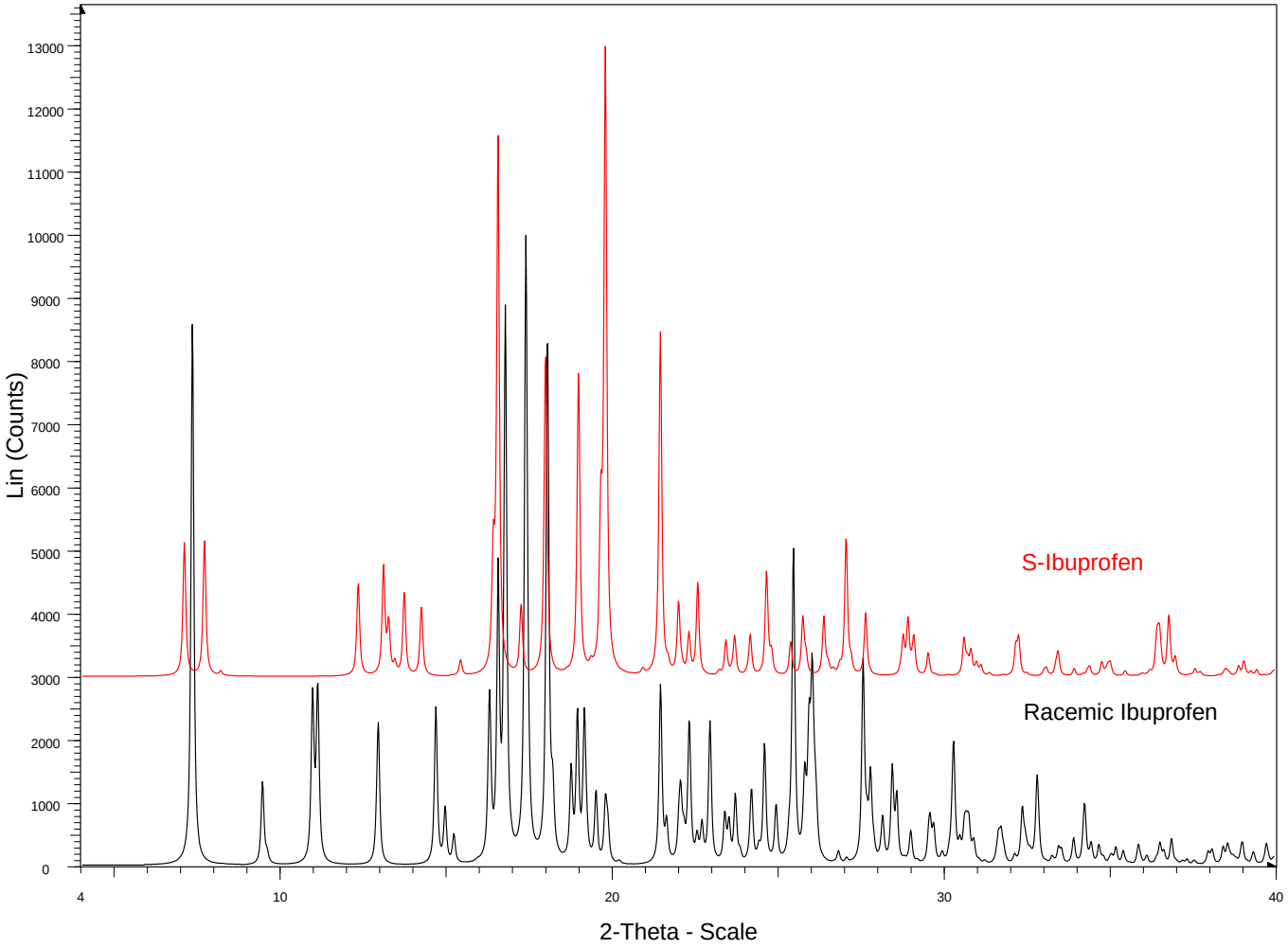
CCDC Structure COTYOA01K.H.Stone, S.Lapidus, P.W.Stephens J.Appl.Crystallogr. (2009), 42, 385

Monoclinic Space Group $P2_1$
a = 12.46 Å b = 8.08 Å c = 13.54 Å
Beta = 112.89°



CCDC Structure JEKNOC10
A.A.Freer, J.M.Bunyan, N.Shankland, D.B.Sheen Acta Crystallogr.,Sect.C:Cryst.Struct.Commun. (1993), 49, 1378

Racemic Crystal Versus Enantiomer



Phase Diagram of Solid Solution

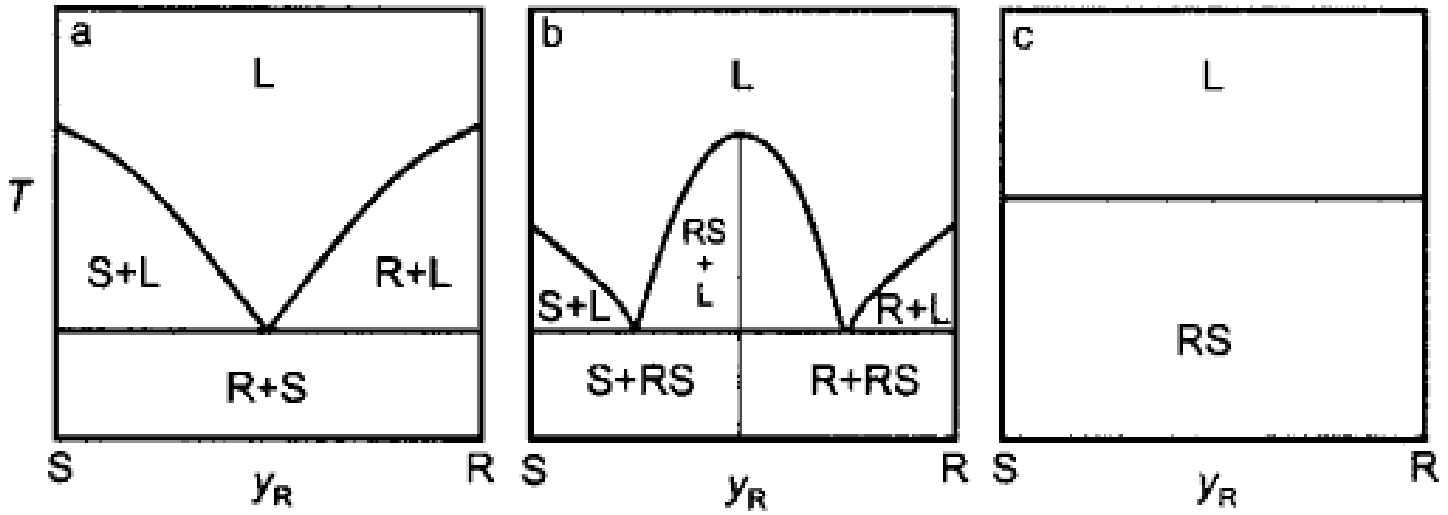
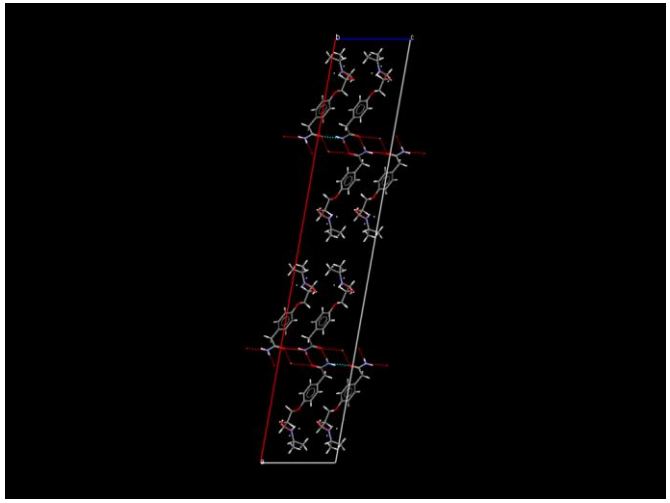
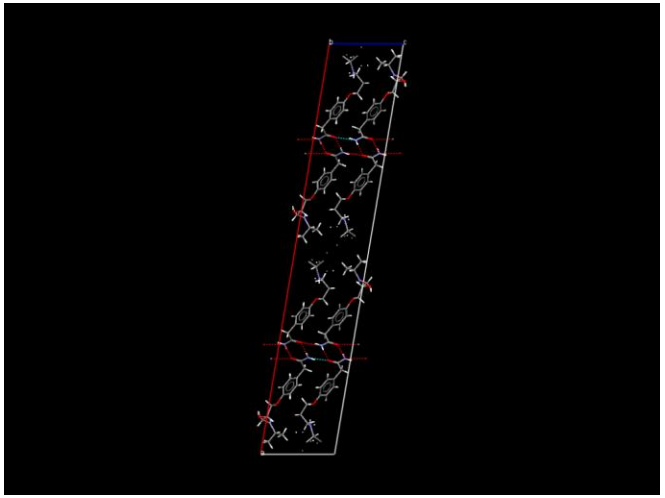


Figure 1. Binary phase diagram of enantiomer mixtures forming (a) a conglomerate, (b) a racemic compound, and (c) a solid solution.[2] *R*, *S*, *RS*, and L represent respectively solid *R*-enantiomer phase, solid *S*-enantiomer phase, racemic compound *RS*, or solid solution *RS* and liquid phase.

2. Jacques, Collet , Wilen in Enantiomers, Racemates, and Resolutions, Kreigers Publishing, 1991

Atenolol
Racemate versus Enantiomer



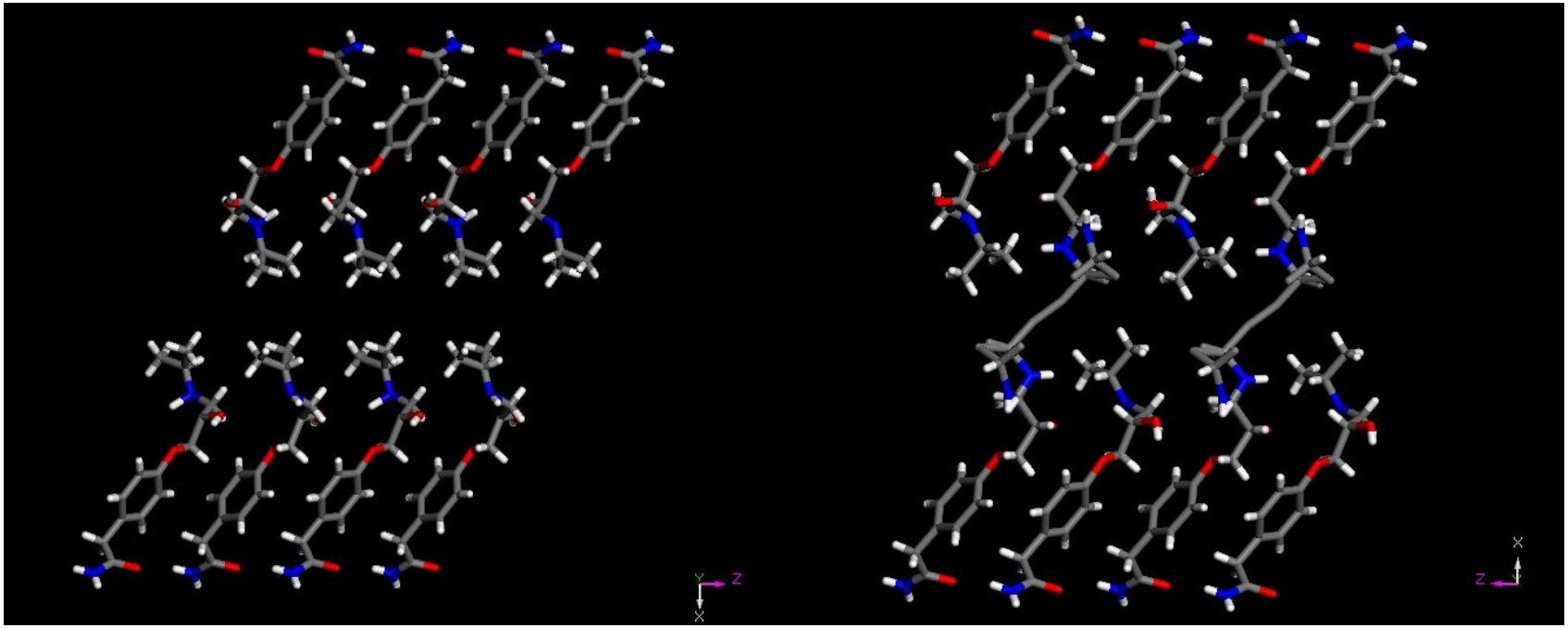


R.A.E.de Castro, J.Canotilho, R.M.Barbosa, M.R.Silva, A.M.Beja, J.A.Paixao, J.S.Redinha Cryst.Growth Des. (2007), 7, 496

(RS)-Atenolol
C 2/c
a = 55.83(3)Å b = 5.559(3)Å c = 9.734(2)Å
α = 90° β = 100.042(6)° γ = 90°
Volume = 2974.75 Å/cm^3
Z: 8 Z': 1

(S)-Atenolol
C 2
a = 54.43(3)Å b = 5.712(3)Å c = 9.676(2)Å
α = 90° β = 99.510(6)° γ = 90°
Volume = 2966.96 Å/cm^3
Z: 8 Z': 2

Chiral Structure Disordered “Pseudo-Symmetry”



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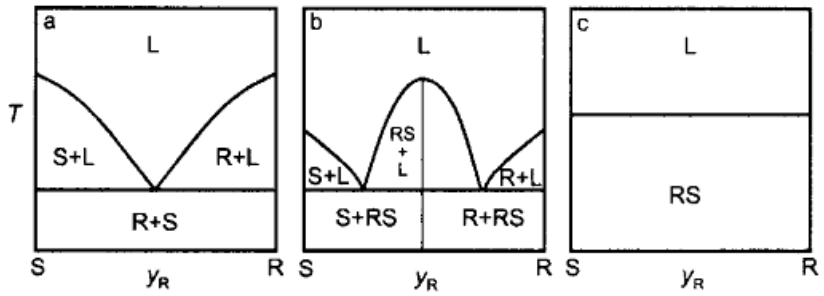

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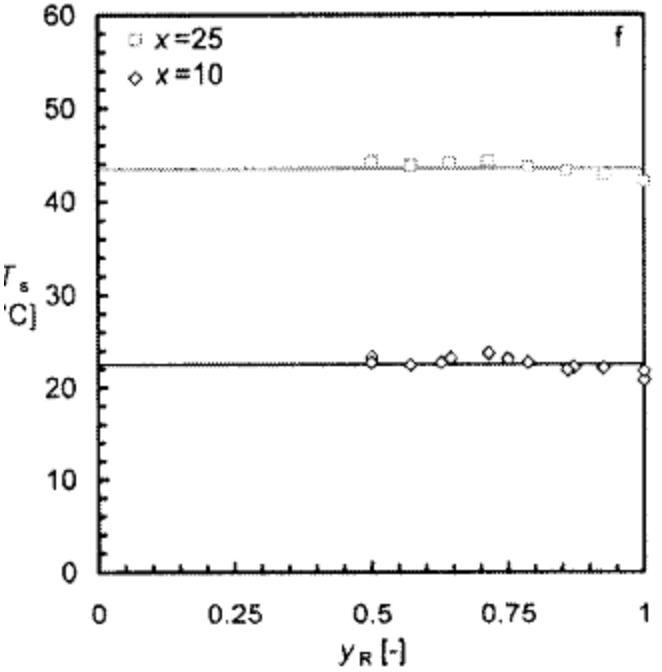
2.Jacques, Collet , Wilen in Enantiomers, Racemates, and Resolutions, Kreigers Publishing, 1991, p128

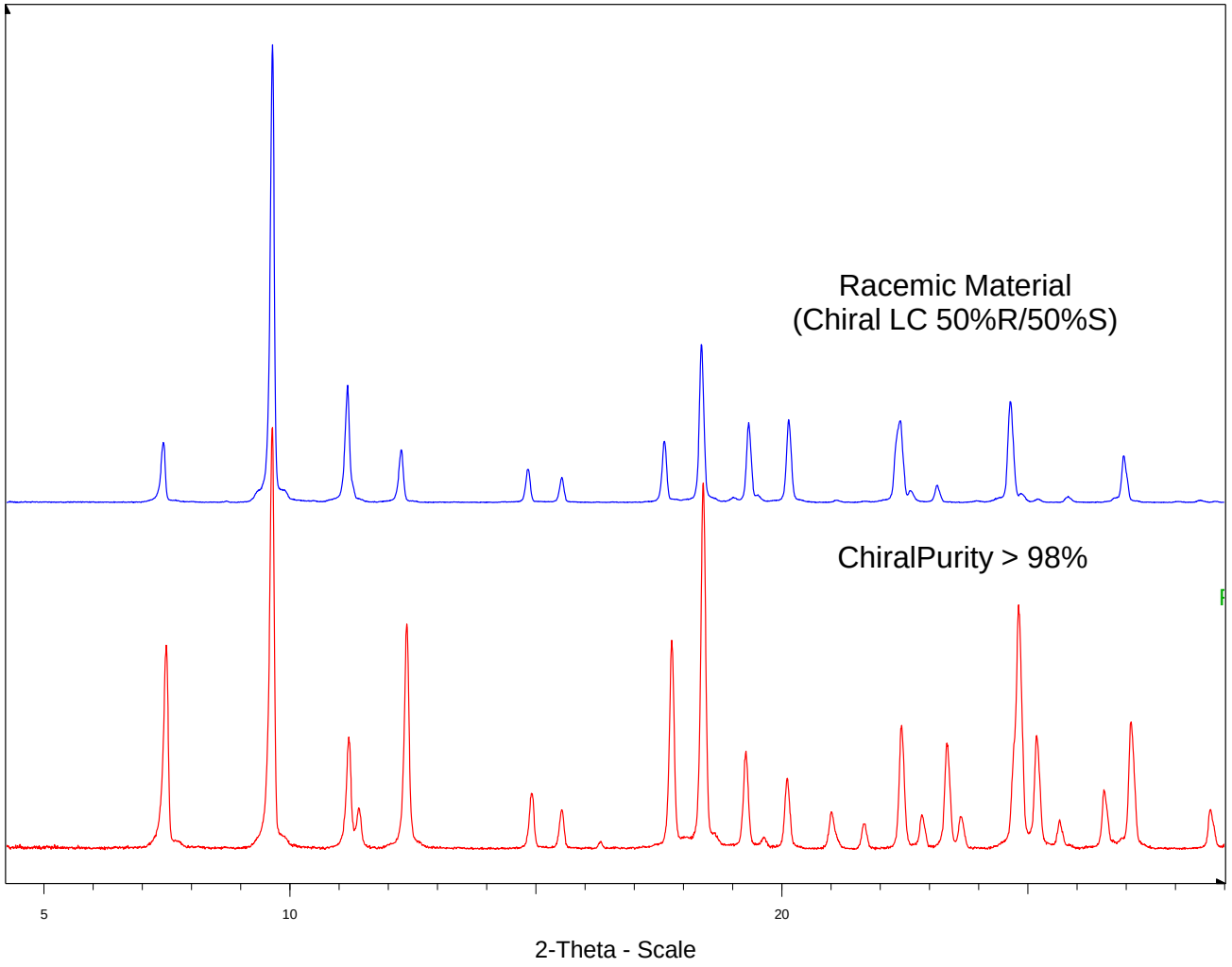


Atenolol Solid-Solution

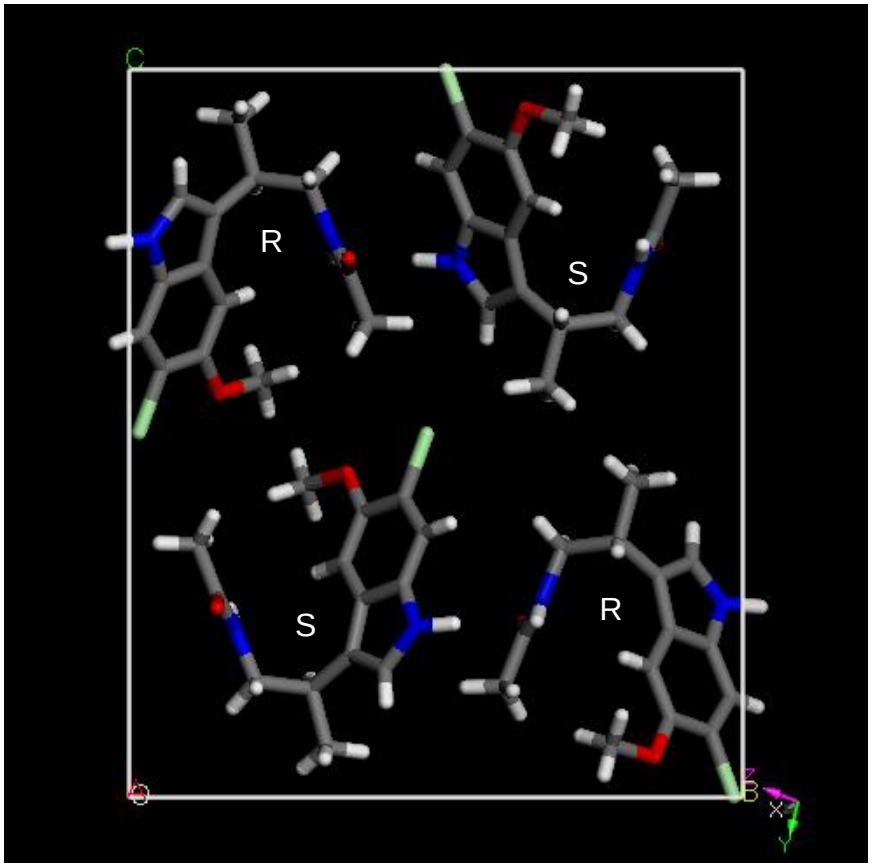
CRYSTAL GROWTH & DESIGN Article
2010, Vol. 10
1808–1812

Sukanya Srisanga and Joop H. ter Horst*

Racemic or Conglomerate?

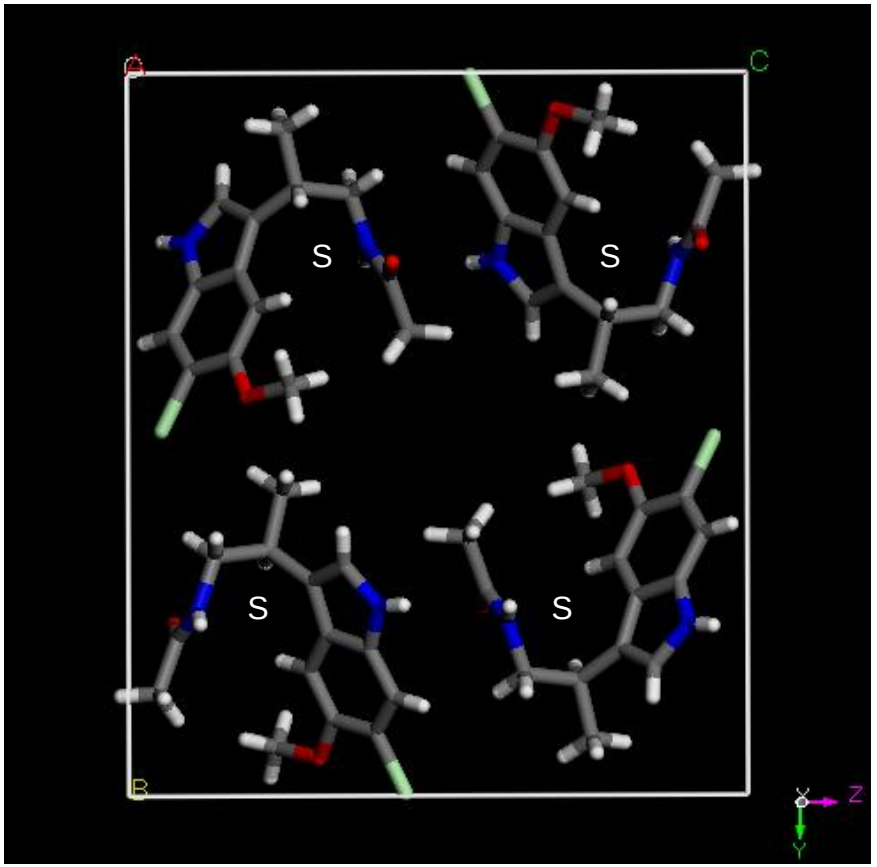


Chiral vs Racemic Crystals: Unit Cells



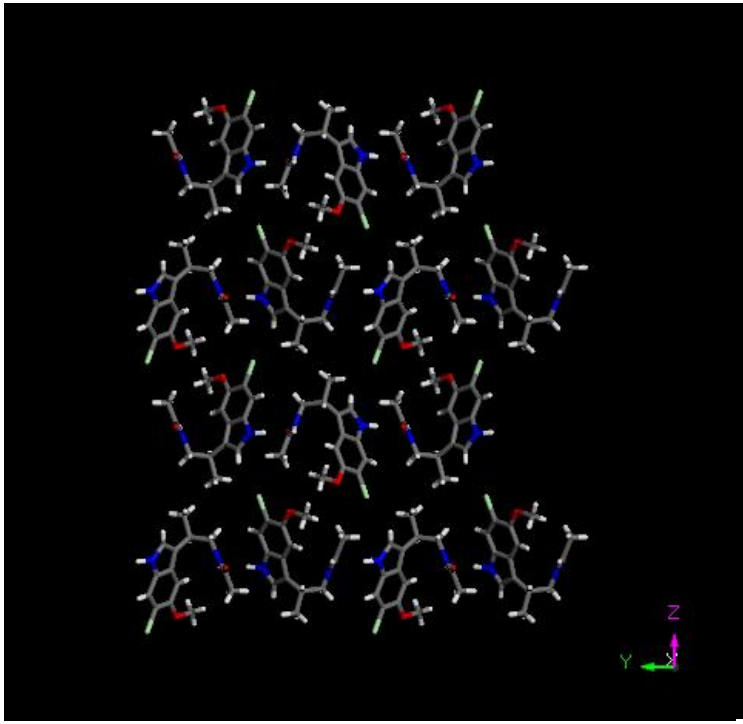
Enantiomer: Orthorhombic $P2_12_12_1$
a = 4.97 Å, b = 15.50 Å, c = 17.96 Å

Volume = 1383.64 Å ^{3}, Z=4, Z' =1, density = 1.348 g/cc
Enthalpy of Fusion 99.43 J/g, Tm 127.16°C

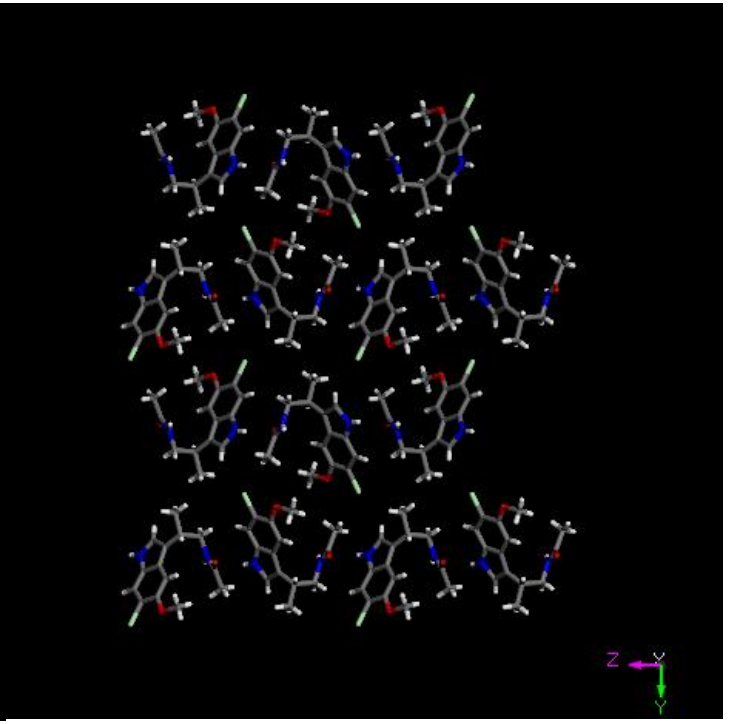


Racemate: Monoclinic $P2_1/c$
a = 4.94 Å, b = 18.14 Å, c = 15.61 Å
β = 92.951°
Volume = 1395.90 Å ^{3}, Z = 4, Z'= 1, density = 1.336 g/cc
Enthalpy of Fusion 102.19 J/g, Tm 136.09°C

Looking at Super Structure

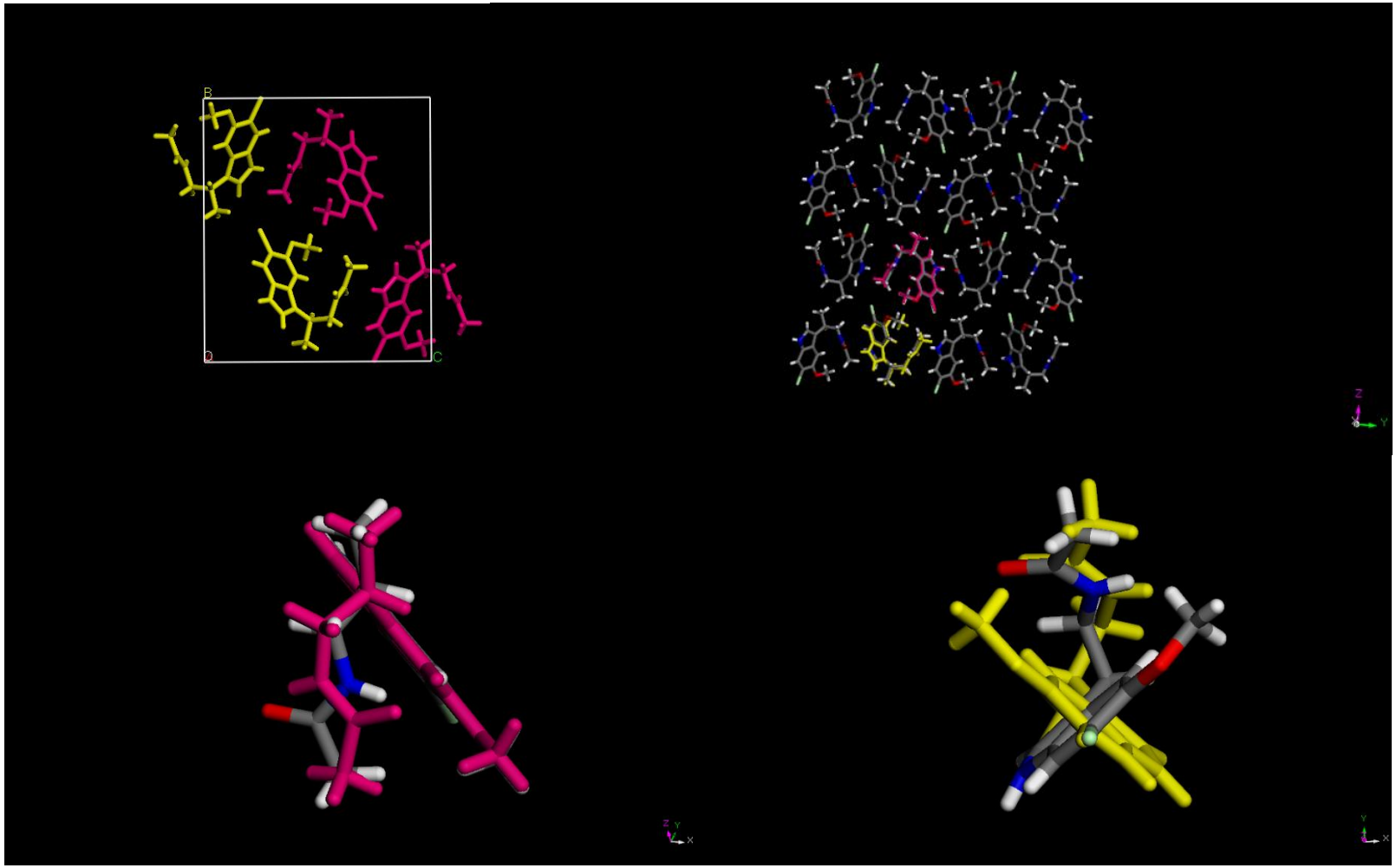


Chiral, Enantiopure
$P2_12_12_1$

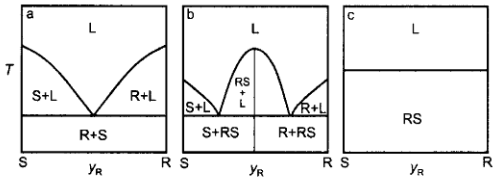


Racemic, both enantiomers present in unit cell
$P2_1/c$

A Closer Look



Truly Racemic Crystal Not a Solid Solution Confirmed by Thermal Analysis



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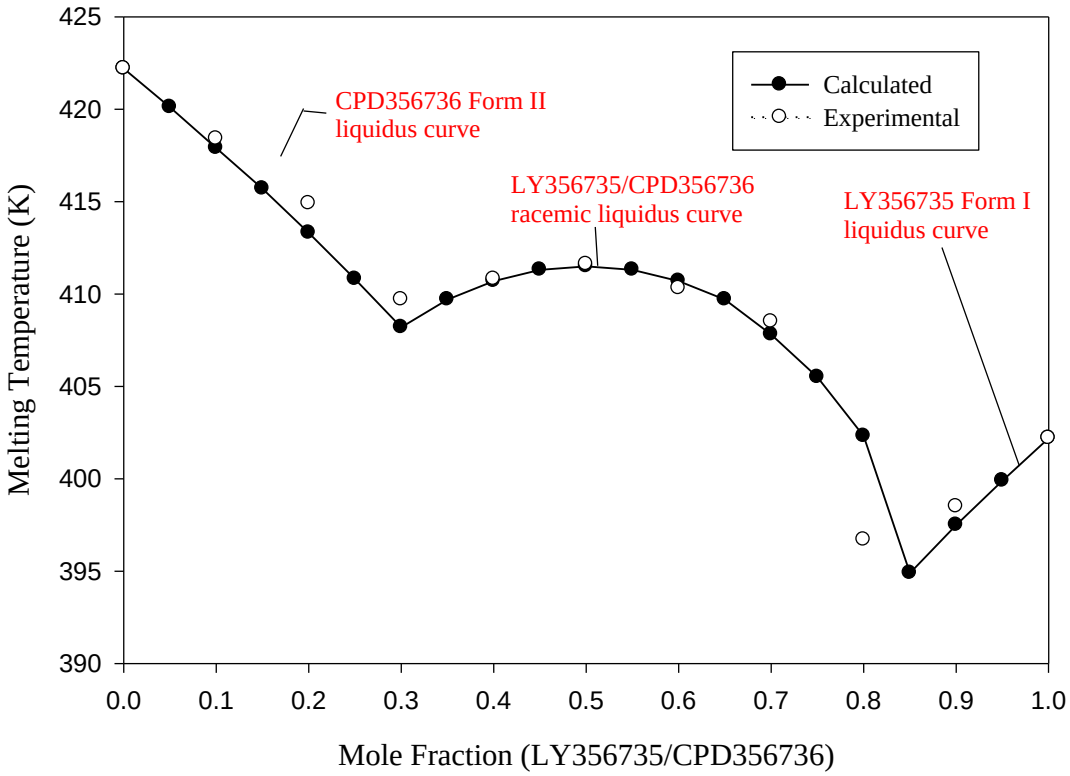
Phase Diagram for LY356735 and LY356736



Phase Diagram of Enantiomeric Mixtures

The phase diagram for a mixture of two enantiomers can be calculated using the Schroder Van-Laar equation to determine the liquidus curve for the portion of the phase diagram which is at the extremes of chiral purity as expressed below:

Equation. 1 $\ln x = \Delta H^f_A / R \ (1/T^f_A - 1/T^f)$

where R = 1.9869 cal mol^{-1} K^{-1}, where x is the mole fraction of the more abundant enantiomer ($0.5 <= x <= 1$) of a mixture whose melting terminates at T^f (degrees K). ΔH^f_A, and T^f_A .are the enthalpy of fusion and the melting point of the pure enantiomer. Usually these curves are symmetrical at the two extremes. In the case of LY356735 versus LY356736, the enantiomerically pure regions are not the same, since the stable form of LY356736 is the more stable crystalline form, whereas the form used for LY356735 is the metastable polymorphic form. The two polymorphs have different melting points and enthalpies of fusion, hence the curves are not symmetrical.
The Prigogine and Defay equation can be used for calculating the liquidus curve for the racemic portion of the curve (from x=0.5 to where the mole fraction defines the two eutectic points) as define below:

Eqn. 2 $\ln 4x\,(1-x) = 2\,\Delta H^f_R / R \ (1/T^f_R - 1/T^f)$

The same variables are used, however the enthalpy of fusion, ΔH^f_R, of the racemate and the temperature of melting of the racemic crystal, T^f_R, is used throughout this region of the phase diagram.

Experimental data was collected at 10 percent intervals and was used to validate the calculations.