Bond lengths, crystal structure determinations, and research in the undergraduate classroom

Drs. Guy Crundwell*, Neil M. Glagovich, and Barry L Westcott… and many students!

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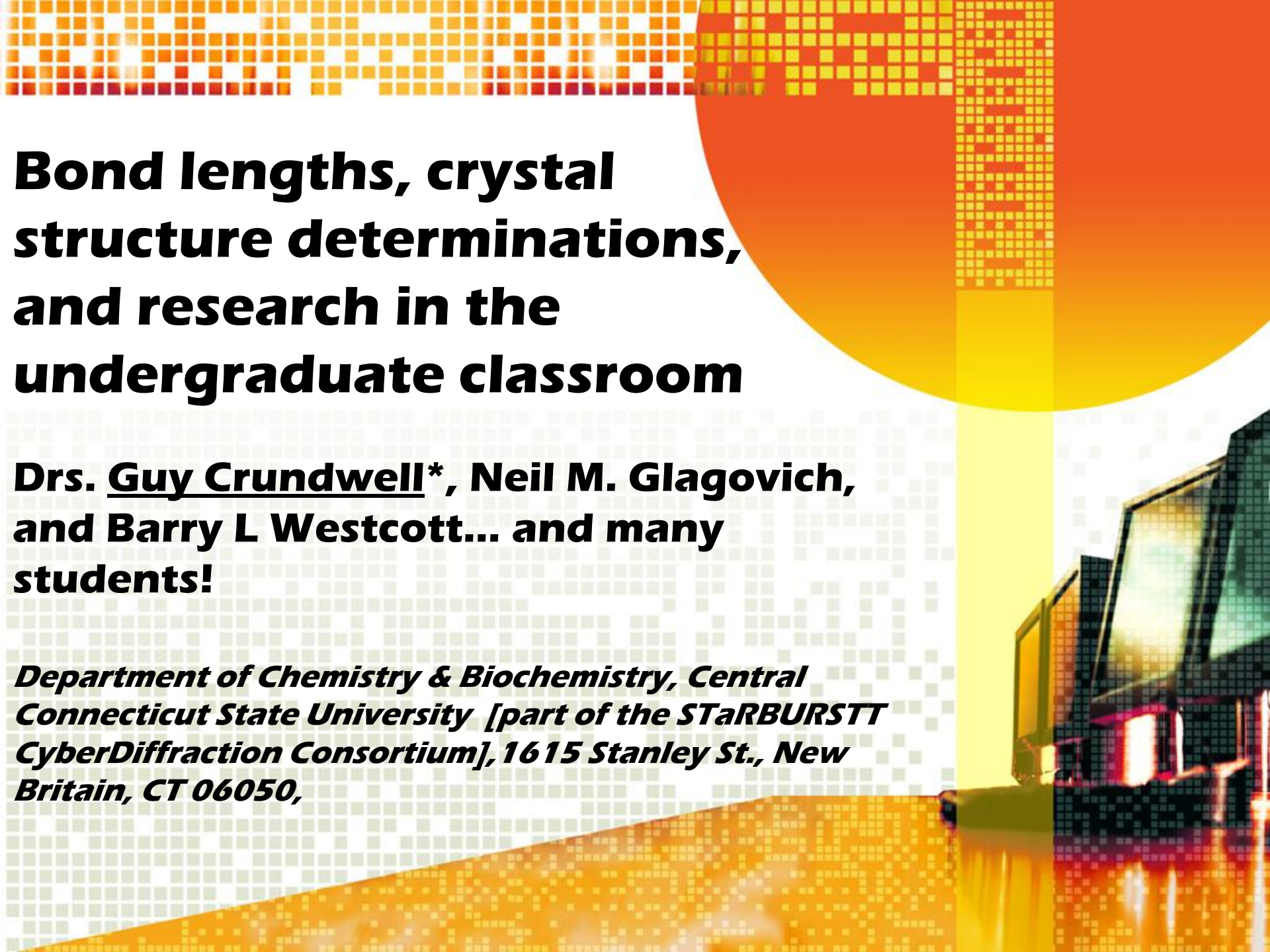


CCSU

- 9 Full-time Faculty
- Undergrad / No Grad
- ~5 Graduating seniors per year
- Undergrad research encouraged
- ACS Accredited
- Two recent NSF-MRI grants ... (X-ray/NMR)
- CSD subscriber for 5+ years

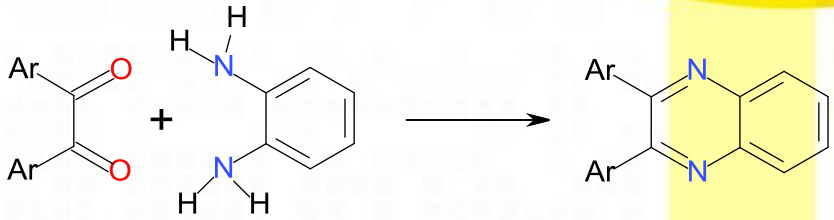
We needed a project:

- Got a new X-ray diffractometer and wanted to incorporate its use into classes
- Looking for a concept to bridge upper-level classes and undergrad research
- Assessment goal of incorporating “technology” into the classroom/lab
- An overarching project combining synthesis, characterization, and modeling/data mining
- Hopefully, for assessment purposes, the project would challenge one or more theoretical beliefs from core coursework

<u>Courses “linked” by project</u>
CHEM 313- Chemical Preparations
CHEM 462- Inorganic Chemistry Lab
CHEM 490- Special Topics (X-ray Crystallography)
CHEM X99- Undergraduate Research

So we decided to start making quinoxalines…

- We had diarylethanediones from a previous research arc.
- Students made benzoin & benzil in orgo lab.
- Diamines were cheap
- Reaction is simple and yields product readily



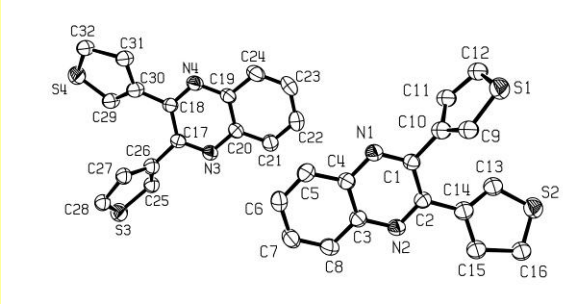
Students…

•Synthesized, purified, characterized, and crystallized, over 15 new quinoxalines

•Worked up crystallographic *cif* files for publication

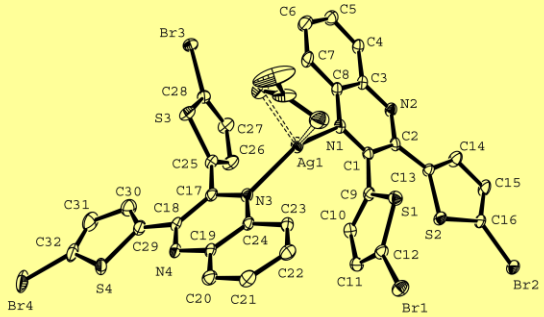
•Analyzed the structures for interesting bond lengths and crystal packings (using Mercury, of course!).

What do these structures have in common?



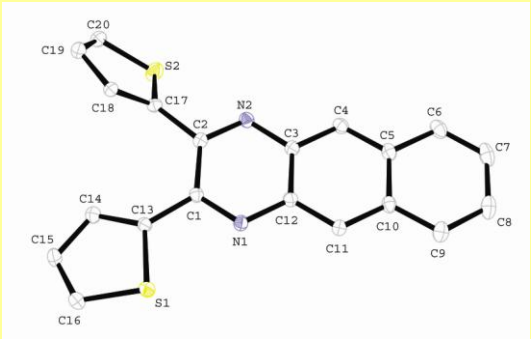
N1 C1 1.317(6) N1 C4 1.369(6)
N2 C2 1.318(6) N2 C3 1.367(7)

N3 C17 1.322(6) N3 C20 1.372(6)
N4 C18 1.325(6) N4 C19 1.365(7)

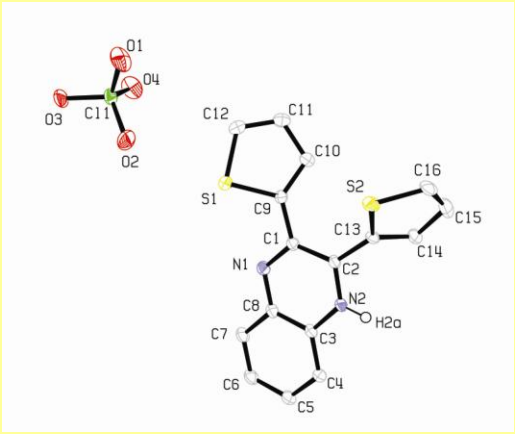


N1 C1 1.326(4) N1 C8 1.364(4)
N2 C2 1.328(4) N2 C3 1.362(4)

N3 C17 1.328(4) N3 C24 1.371(4)
N4 C18 1.326(4) N4 C19 1.357(4)



N1 C1 1.3191(16) N2 C2 1.3181(16)
N1 C12 1.3780(16) N2 C3 1.3736(16)



N1 C1 1.321(3) N2 C2 1.328(3)
N2 C3 1.371(3) N1 C8 1.358(3)

Interesting preliminary result

It seems as if the quinoxaline and benzo[g]quinoxalines have unequal N-C bonds.

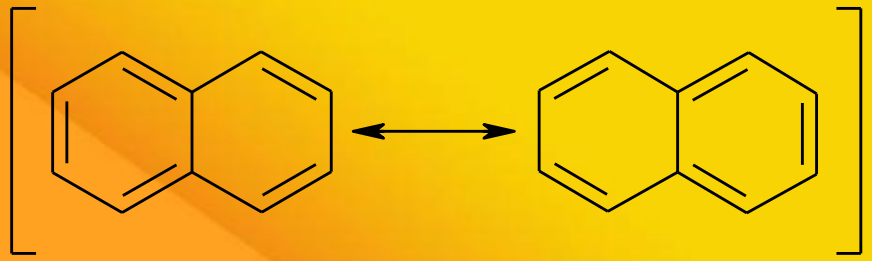
From bond length data, the C-N bond on the ethanedione side is consistently shorter… the diamine C-N bond is longer.

Do other quinoxalines in the CSD show evidence that the C-N bond lengths in the heterocycle are asymmetric and inequivalent?

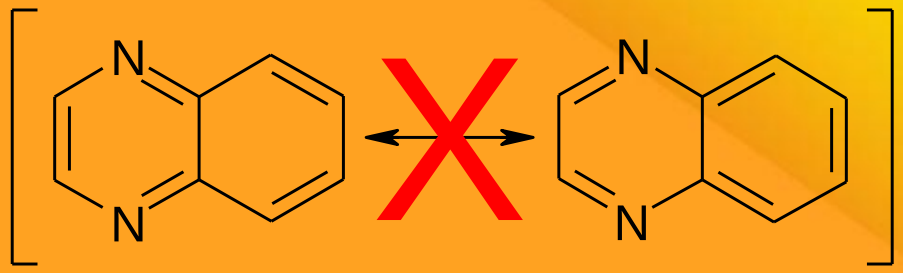
If so, this could test the students' ideas of resonance… since Intro organic chem often treats heterocycles in the same manner as their all-carbon analogs...

Resonance:

Students have all accepted that…



but what if…



these heterocycles are made via a mechanism that "locks" the local environment around the nitrogen and "fixes" the quinoxaline into a specific resonance form?

Does the data support unequal bond legths?

Enter the CSD!
Search Criteria

We cared that…

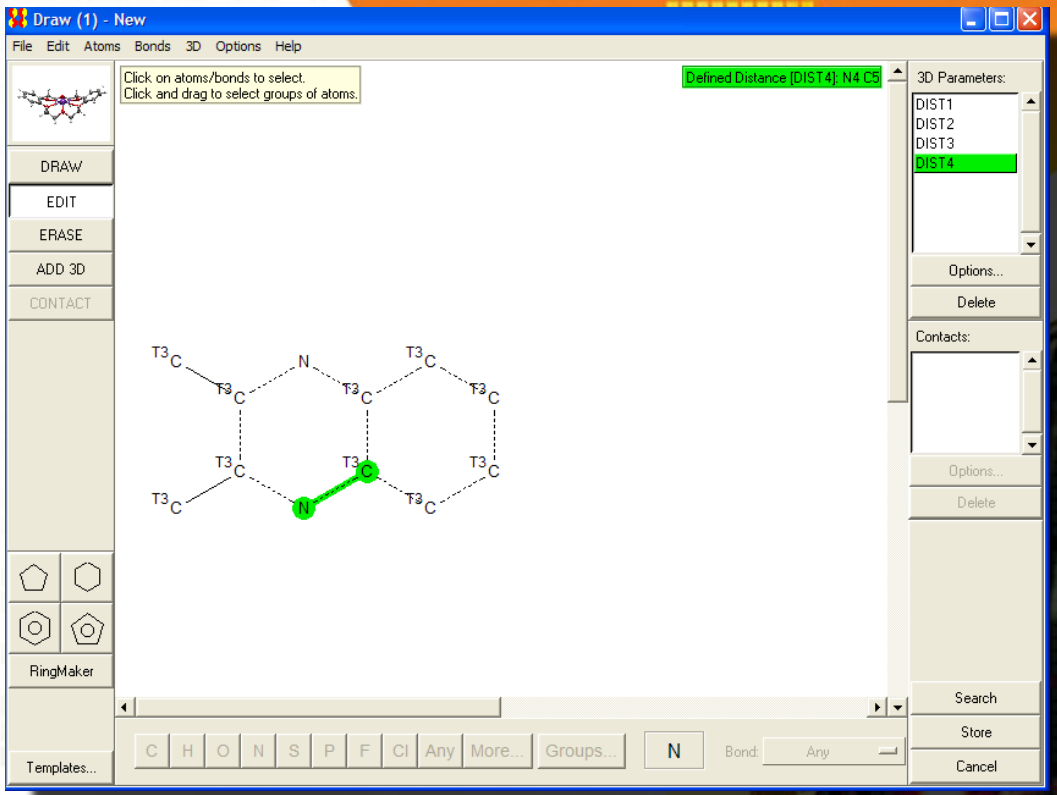
- The quinoxaline had to be asymmetric (to eliminate packing/flip disorder)
- The quinoxaline was not part of a larger fused system

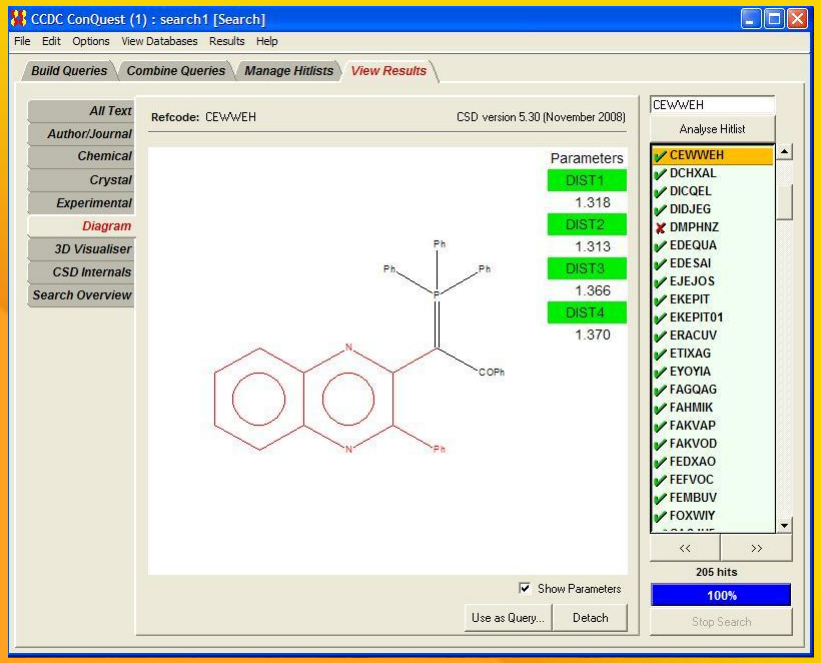
We did not care that…

- The crystal structures were at different temperatures (we've assumed they would average out)
- Many structures had more than one quinoxaline per asymmetric unit so we used all unique quinoxalines
- Many were not 2,3-disubstituted… but many were!

Steps…

- **Entered simplified quinoxaline molecular structure (see right)**
- **Eliminated symmetric molecules and extended fused systems**
- **Exported DIST and REFCODE data into Excel**
- **Built histograms and applied preliminary stats**

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Search Overview
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CSD version 5.30 (November 2008)
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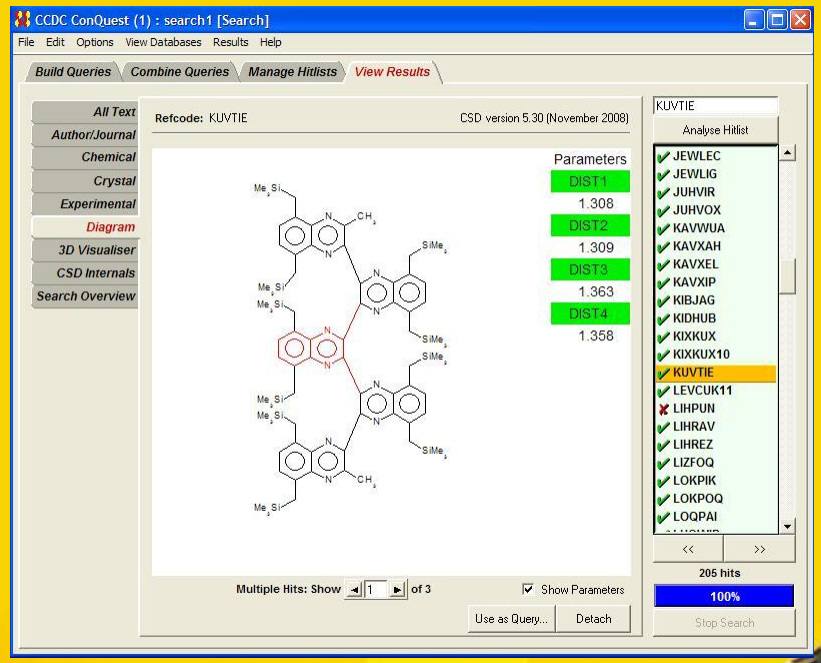
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KIXKUX10
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LEVCUK11
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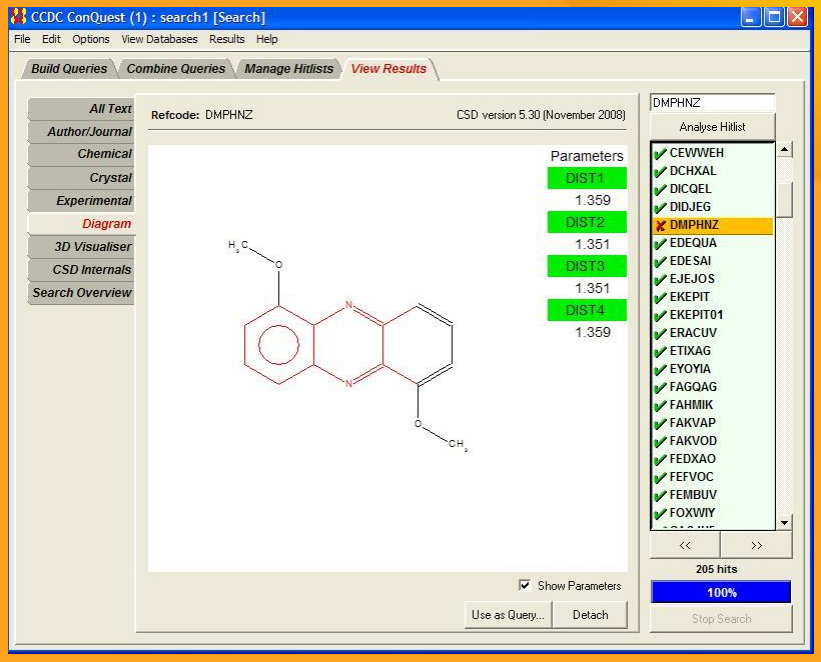
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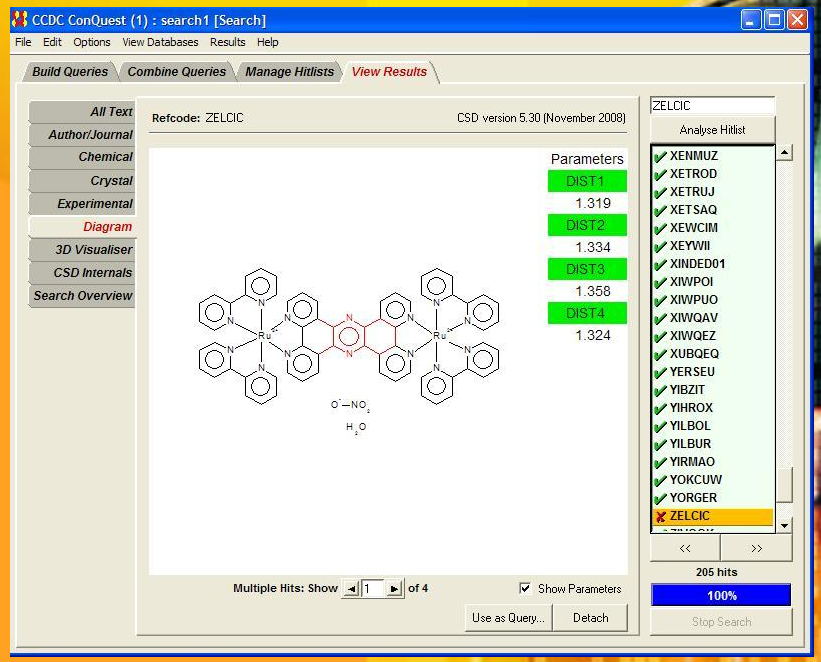
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Build Queries Combine Queries Manage Hitlists View Results
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Search Overview
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XUBQEQ
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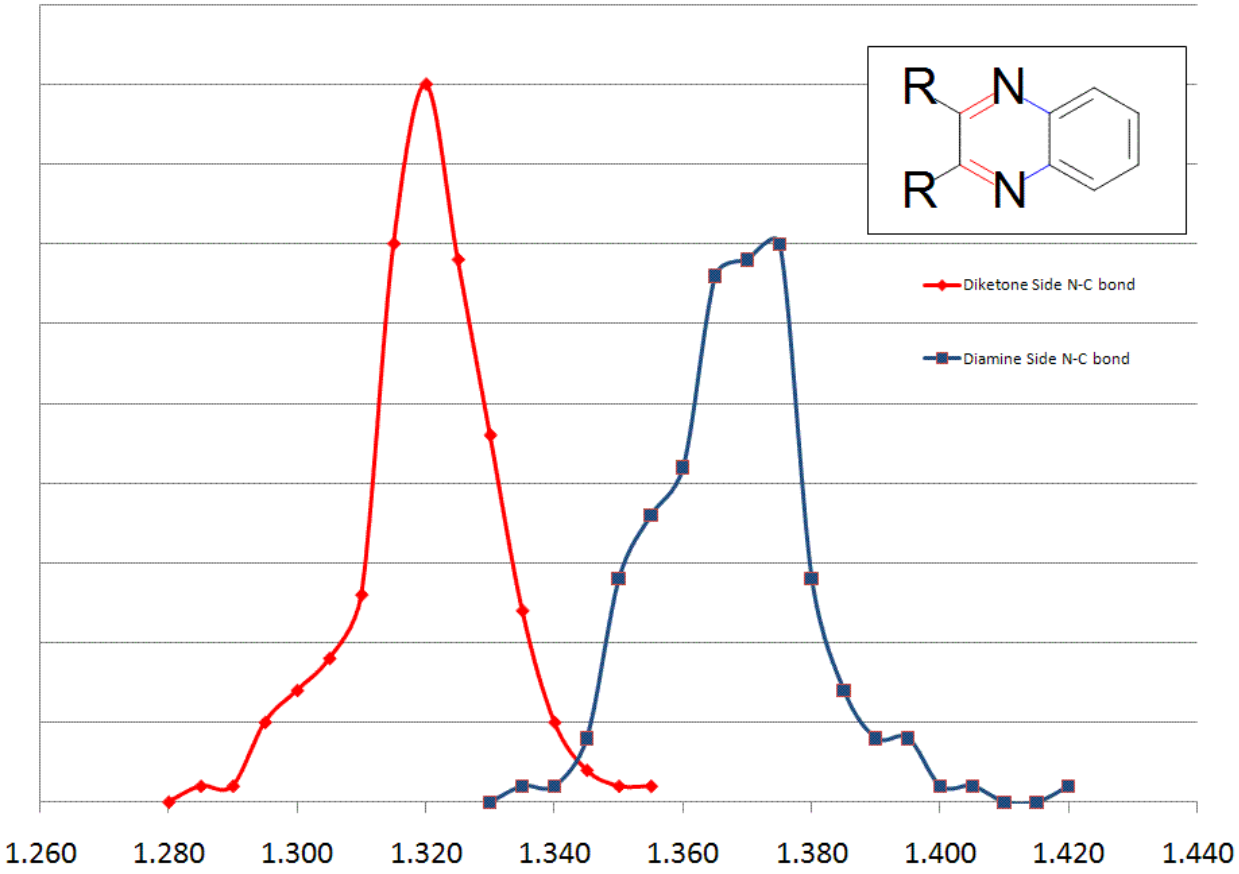
N-C Bond Lengths Mined from the CSD Show Significant Difference



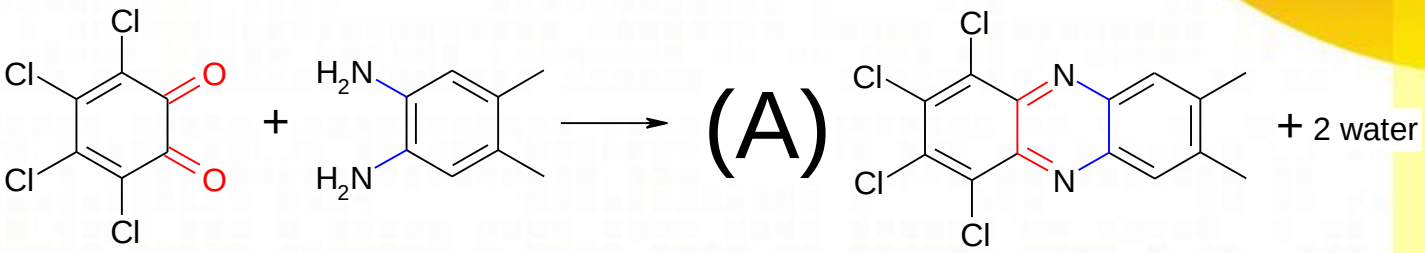
N=194 measurements from 97 structures

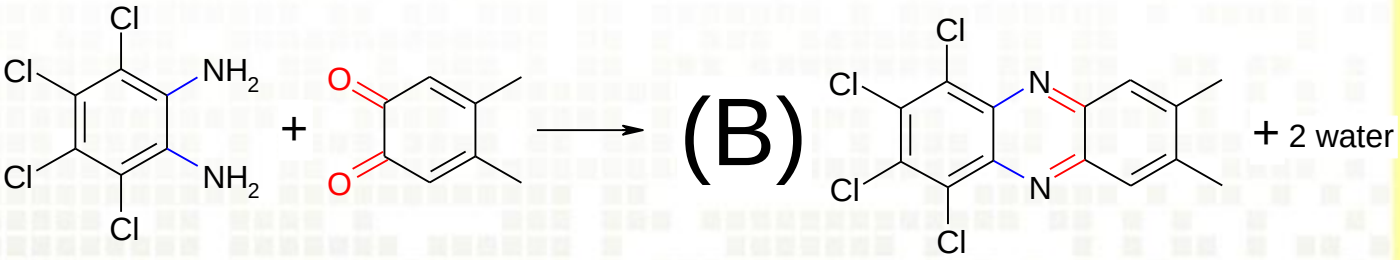
Ethanedione side C-N (red)	**range 1.282 to 1.353**	**average 1.317**	**st dev 0.011**
Diamine side C-N (blue)	**range 1.331 to 1.423**	**average 1.366**	**st dev 0.013**

Can we make the same molecule from two different condensation reactions such that they have the same exact structure but differ only in the location of their short and long C-N bonds?

(…and dare we call them “bond length isomers”?)

Current Work (synthetic):





Future Work

- Statistical test on C-N bond lengths and other in heterocycles
- Purify (A) and synthesize (B)
- Grow crystals of pure (A), of pure (B), and of a 50/50 mixture of (A/B) and send them unlabelled to fellow crystallographers… can the bond length results from X-ray studies allow my pals to identify which molecule came from which starting materials?

Acknowledgements:

- Dr. Gary Battle, CSD
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Students:

All the students in the courses… particularly:

- Paul Foss
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- Vanessa Stacy (Pfizer)
- Krystal Brown (Ph.D. program Utah)
- Aaron Pierpont (Ph.D. program N.Texas)