

Introduction to the special issue on crystal structure prediction

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Synopsis One or two sentences suitable for the Journal contents listing (style: IUCr synopsis).

Abstract Single paragraph providing a clear and brief summary of the most important aspects and results of the study. The abstract should be capable of being understood on its own without access to the text or figures (style: IUCr abstract).

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This special issue was organised to showcase recent work in the area of crystal structure prediction (CSP). The prediction of crystal structures of organic molecules continues to attract considerable interest; the problem is fundamentally attractive for theoreticians and computational scientists, and the methods developed in this area have an important role to play in the development of molecular materials. *Acta Crystallographica Section B* has had a key role in publishing influential works in this area, in part through publication of the series of blind tests of crystal structure prediction (Lommerse, Motherwell et al. 2000, Motherwell, Ammon et al. 2002, Day, Motherwell et al. 2005, Day, Cooper et al. 2009, Bardwell, Adjiman et al. 2011). These blind tests have been held regularly every 2-3 years since the first “collaborative workshop held at the Cambridge Crystallographic Data Centre (CCDC) in May 1999” (Lommerse, Motherwell et al. 2000). The role of these exercises, and their accompanying publications, is to provide snapshots of the state of this research field, and this special issue was organised around the publication reporting the results of the sixth blind test (Reilly *et al* 2016)

The field has clearly evolved over the years, not least in the number of contributing research groups: the author list of 92 contributors to the 6th blind test paper now spills over a page, compared to the original blind test, which involved 14 of the CSP pioneers. This expansion of the author list reflects an increased range of computational methods that are being applied to the challenge of CSP as well as its varied applications, and it is now, more than ever, impossible to capture the development of this

research field in a single report of the blind test results. Anyone with a serious interest in following the research area should read the report on the 6th blind test, but cannot rely on this paper alone as a summary of such an active area. We expect that the set of contributions to the current special issue will help provide a broad view of current CSP research for those who have followed the field, and a valuable entry point to the literature for readers who are new to the area.

The main approach to CSP has remained largely unchanged since the earliest published attempts at *ab initio structure* prediction (Dzyabchenko 1984, Gavezzotti 1991, Gdanitz 1992, Holden, Du et al. 1993, van Eijck, Mooij et al. 1995, Williams 1996): trial crystal structures are created and assessed based on their calculated energies. The perfect theoretical approach to lattice energy calculations still does not exist and we should not expect the field to converge to a single method; users of CSP methods benefit greatly from having a range of available, validated options for their calculations, to make choices depending on the type of molecule being studied and available computational resources. Therefore, the development and careful assessment of approaches for calculating accurate lattice energies continues to feature heavily in CSP-related publications. A number of contributions to this special issue describe research in this area, including the development of atom-atom force fields aimed at pharmaceutical applications (Broo & Nilsson Lill, 2016) and advanced, atomic multipole-based models (Pyzer-Knapp *et al* 2016; Elking *et al* 2016). The methods used in the current blind test show a clear trend towards an increased use of solid state electronic structure methods for evaluating lattice energies. Brandenburg & Grimme (2016) present an evaluation of various quantum chemical methods on the target molecules in the 6th blind test, using both density functional theory (DFT) and semi-empirical methods, and suggest a set of these structures as a benchmark for testing such methods. Another developing trend in CSP is towards the evaluation of free energies in place of lattice energies, to allow thermal and pressure effects on the structural landscape to be evaluated; Heit & Beran's contribution (2016) addresses the question of whether including thermal expansion in the models is important for the energetic evaluation of structures.

Another important ingredient in CSP is the method used to generate trial structures and explore the space of crystal structures available to a given molecule. Cole *et al* (2016) investigate the use of known crystal structures from the Cambridge Structural Database as templates for predicting crystal structures of similarly-shaped molecules. Schneider *et al* (2016) describe an enhanced molecular dynamics approach for exploring the free energy surface for crystalline benzene and naphthalene, demonstrating that the method is promising for predicting structures, as well as packing defects.

Finally, two contributions describe application of CSP. Mohamed *et al* (2016) applied CSP to two pharmaceutical salts, as an evaluation of the predictive ability of current methods, and to examine whether the resulting landscape of structures helps explain their hydration behaviour. Curtis *et al* (2016), as well as evaluating the performance of various DFT methods on one of the blind test targets,

examine how the electronic properties, such as band gap, vary between predicted structures, demonstrating how the results of CSP could be used to screen organic molecular semiconductors.

The special issue demonstrates the breadth of research in the area of CSP and we hope that the issue will stimulate interest and new research in this area, as well as publication of future research in *Acta Cryst Section B*. We thank all of the authors who have contributed to this varied and high quality issue.

References

- Bardwell, D. A., C. S. Adjiman, Y. A. Arnautova, E. Bartashevich, S. X. M. Boerrigter, D. E. Braun, A. J. Cruz-Cabeza, G. M. Day, R. G. Della Valle, G. R. Desiraju, B. P. van Eijck, J. C. Facelli, M. B. Ferraro, D. Grillo, M. Habgood, D. W. M. Hofmann, F. Hofmann, K. V. J. Jose, P. G. Karamertzanis, A. V. Kazantsev, J. Kendrick, L. N. Kuleshova, F. J. J. Leusen, A. V. Maleev, A. J. Misquitta, S. Mohamed, R. J. Needs, M. A. Neumann, D. Nikylov, A. M. Orendt, R. Pal, C. C. Pantelides, C. J. Pickard, L. S. Price, S. L. Price, H. A. Scheraga, J. van de Streek, T. S. Thakur, S. Tiwari, E. Venuti and I. K. Zhitkov (2011). "Towards crystal structure prediction of complex organic compounds - a report on the fifth blind test." *Acta Crystallographica Section B* **67**(6): 535-551.
- Day, G. M., T. G. Cooper, A. J. Cruz-Cabeza, K. E. Hejczyk, H. L. Ammon, S. X. M. Boerrigter, J. S. Tan, R. G. Della Valle, E. Venuti, J. Jose, S. R. Gadre, G. R. Desiraju, T. S. Thakur, B. P. van Eijck, J. C. Facelli, V. E. Bazterra, M. B. Ferraro, D. W. M. Hofmann, M. A. Neumann, F. J. J. Leusen, J. Kendrick, S. L. Price, A. J. Misquitta, P. G. Karamertzanis, G. W. A. Welch, H. A. Scheraga, Y. A. Arnautova, M. U. Schmidt, J. van de Streek, A. K. Wolf and B. Schweizer (2009). "Significant progress in predicting the crystal structures of small organic molecules - a report on the fourth blind test." *Acta Crystallographica Section B* **65**(2): 107-125.
- Day, G. M., W. D. S. Motherwell, H. L. Ammon, S. X. M. Boerrigter, R. G. Della Valle, E. Venuti, A. Dzyabchenko, J. D. Dunitz, B. Schweizer, B. P. van Eijck, P. Erk, J. C. Facelli, V. E. Bazterra, M. B. Ferraro, D. W. M. Hofmann, F. J. J. Leusen, C. Liang, C. C. Pantelides, P. G. Karamertzanis, S. L. Price, T. C. Lewis, H. Nowell, A. Torrisi, H. A. Scheraga, Y. A. Arnautova, M. U. Schmidt and P. Verwer (2005). "A third blind test of crystal structure prediction." *Acta Crystallographica Section B* **61**(5): 511-527.
- Dzyabchenko, A. V. (1984). "Theoretical structures of crystalline benzene: the search for a global minimum of the lattice energy in four space groups." *J. Struct. Chem.* **25**: 416-420.
- Gavezzotti, A. (1991). *Journal of the American Chemical Society* **113**: 4622-4629.
- Gdanitz, R. J. (1992). *Chem. Phys. Letters* **190**: 391.
- Holden, J. R., Z. Y. Du and H. L. Ammon (1993). *J. Comput. Chem* **14**: 422-437.
- Lommerse, J. P. M., W. D. S. Motherwell, H. L. Ammon, J. D. Dunitz, A. Gavezzotti, D. W. M. Hofmann, F. J. J. Leusen, W. T. M. Mooij, S. L. Price, B. Schweizer, M. U. Schmidt, B. P. van Eijck, P. Verwer and D. E. Williams (2000). "A test of crystal structure prediction of small organic molecules." *Acta Cryst.* **B56**: 697 - 714.
- Motherwell, W. D. S., H. L. Ammon, J. D. Dunitz, A. Dzyabchenko, P. Erk, A. Gavezzotti, D. W. M. Hofmann, F. J. J. Leusen, J. P. M. Lommerse, W. T. M. Mooij, S. L. Price, H. Scheraga, B. Schweizer, M. U. Schmidt, B. P. van Eijck, P. Verwer and D. E. Williams (2002). "Crystal structure prediction of small organic molecules: a second blind test." *Acta Cryst.* **B58**: 647-661.
- van Eijck, B. P., W. T. M. Mooij and J. Kroon (1995). "Attempting Prediction of the Crystal Structures of Six Monosaccharides." *Acta Crystallographica* **B51**: 99.
- Williams, D. E. (1996). "Ab Initio Molecular Packing Analysis." *Acta Crystallographica* **A52**: 326.