# Exploring Non-Covalent Interactions in Simple Binary Adducts by a Combination of DSC and Variable Temperature Powder and Single-Crystal X-ray Diffraction

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Weak non-covalent (and non-ionic) intermolecular interactions encompass a wide range of intermolecular forces from van der Waals to hydrogen-bonding, and the recently IUPAC-defined halogen bond. Other weakly-directing forces include: molecular and bond dipoles and higher order electrostatic terms. However, despite the discovery over 60 years ago of one of the simplest organic co-crystals containing molecules without "classical" hydrogen bonding or even halogen bonding, namely the 1:1 adduct of benzene ($C_6H_6$) and hexafluorobenzene ($C_6F_6$),[1] the study of non-covalent interactions has only recently sparked mainstream interest, particularly with the recognition of the halogen bond, as shown by the recent series of international conferences themed around non-covalent interactions (Lisbon, 2019; Strasbourg, 2022; and Belgrade, 2024).

Of particular interest for crystal structure prediction are the stacking interactions between aromatic rings. These are exacting to predict but are crucial in understanding the structures of molecular solids lacking stronger molecular interactions. Often dubbed "π-π stacking", it has been suggested that it is maybe more helpful to think of these interactions in *adducts* (1:1 co-crystals) such as $C_6H_6$:$C_6F_6$ (and its derivatives) as determined by positive and negative molecular quadrupole interactions[2] despite the fact that this interaction is only a minor component of the energy of formation in these adducts.

Many years ago, we explored the crystal structure of the prototypical system $C_6H_6$:$C_6F_6$ as a function of temperature using what was a novel combination of powder neutron and synchrotron X-ray diffraction.[3] However, with the massive improvement in modern laboratory instrumentation during the decade and using new methodologies to study samples that are frequently liquid at ambient temperature,[4] we have been able to study the structures of a large number of derivatives of the prototypical system as a function of temperature in order to understand the non-covalent interactions between these simple molecules.[5-9] One of the key questions that we have been attempting to answer is: how does changing substituents on the benzene or hexafluorobenzene rings affect the non-covalent interaction between molecules and, ultimately, the structures formed as a function of temperature? Using variable temperature powder and single-crystal X-ray diffraction (and backed up by differential scanning calorimetry), it is possible to investigate the strength of the non-covalent interactions both within columns of molecules and between columns of molecules. For example, the variation in strength of the bond-dipole interactions in adjacent molecules due to changes in temperature can change the configuration of the molecules from being staggered to eclipsed within a column. The phase transitions observed in these systems is thus related to the dynamics of the molecules as a function of temperature.

This talk will discuss our more recent findings including some soon to be published work on the effect of substituting Cl for F in $C_6F_6$ on the formation of adducts / co-crystals with *p*-xylene.

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