“Seeing” frustration in two-dimensional molecular lattices

General Scope: Implementing complexity in lattices of objects is a fascinating goal in physics, holding promises for the discovery of new states of matter with unique properties. One strategy is the search for lattices with complex tilings, such as those predicted centuries ago by Archimedes and Kepler. Strikingly, it is only today that these predictions find practical realizations at the nanometer scale. Another strategy is to use unit objects having more than a single state on the lattice sites, and whose mutual interactions prevent them minimizing simultaneously all their pairwise interaction energies. We then say that the system is frustrated. This frustration is linked to the lattice topology, and can be found in various systems, such as H$_2$O ice or in certain charge and spin lattice models.

Recently, direct visualisation of frustrated spin lattices has proven to be particularly insightful, revealing intriguing and exotic phenomena. For example, in micrometer-scaled lattices of magnetic dipoles, we observed magnetic phases being at the same time liquid and solid [1], and other phases apparently violating the third law of thermodynamics [2]. Based on these results, we now want to launch a new research track, and address frustration effects at a much smaller (nanometer) scale and in nonmagnetic systems. More precisely, we would like to investigate the properties of certain two-dimensional molecular lattices through their real space imaging (using scanning tunneling microscopy). Molecular systems present the advantage of being tunable with “turning knobs” that are not accessible in larger-scale systems: in particular, temperature allows to make them fluctuate, and local electrostatic potentials applied under the metal tip of the microscope allow us to create point lattice defects at will or to excite the system locally.

Research topic and facilities available: The student will fabricate lattices of C$_{60}$ buckyballs onto a metal surface. We expect the formation of triangular lattices (with 1 nm lattice constant) where each C$_{60}$ buckyball can have two possible heights (see figure) due to repulsive interactions between neighboring molecules. There is a direct analogy between this C$_{60}$ lattice and a triangular lattice made of Ising spins coupled antiferromagnetically (i.e., “up” and “down” spins preferring to align in opposite directions).

The goal of this project is to image C$_{60}$ lattices using scanning tunneling microscopy, and to characterize their “magnetic” configuration (red / blue arrangement in the figure) based on frustrated spin models. In a second step, defects will be intentionally introduced in the lattices to investigate the impact of structural disorder.

Possible collaboration and networking: The work relies on a collaboration between several researchers at the Néel Institute, experts in the physics of frustrated systems and in the preparation of atomic and molecular lattices on surfaces. The student will be thus involved in a team work and will benefit from strong technical support.

Possible extension as a PhD: Yes.

Required skills: Condensed matter physics and / or nanosciences.

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