PhD Project Description

Title: Exotic electronic phases in two-dimensional crystals
Supervisor: Marcin Mucha-Kruczynski

Two-dimensional crystals are a new class of materials, with the first and most well-known representative being graphene, a single layer of carbon atoms arranged in hexagons [1]. They can be obtained by exfoliation of the "parent" layered bulk material like graphite (which is built of many graphene layers stacked on top of each other) or molybdenum disulphide. Because of the reduced dimensionality, properties of two-dimensional crystals often differ from those of their bulk counterparts. For example, it is now well established that in several semiconducting transition metal dichalcogenides a transition occurs from an indirect electronic band gap in the bulk to a direct one in the monolayer [2]. Similarly, many of the material properties are sensitive to the environment, e.g. presence and type of the substrate, and can be modified via chemical functionalization.

During this project, realised within the group led by Dr Marcin Mucha-Kruczynski, the student will conduct theoretical investigations of the electronic and transport properties of various two-dimensional materials, searching for new physical phenomena related to more exotic of the electronic phases present in those materials, like superconductivity or charge-density waves. For example, what happens to these electronic phases when a bulk piece of material is thinned down to several (and finally to one) atomic layers? In the thinnest flakes, how are these phases influenced by grain boundaries or atoms deposited on the surface?

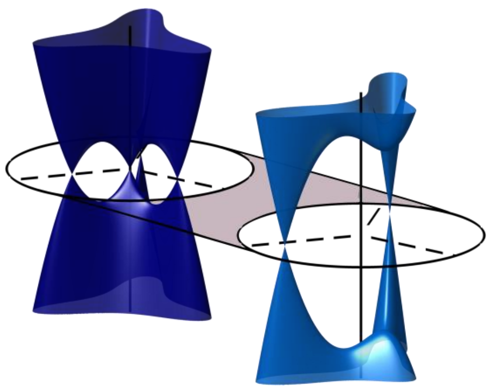

Figure 1 Due to electron-electron interaction, bilayer graphene electronic spectrum with symmetry C_{6v} (upper left) is transformed into spectrum with symmetry C_{2v} (lower right) [3].

The exact theoretical problems will be motivated by and closely related to experimental developments, and often pursued in partnership with other groups in the UK and abroad (recent collaborations include theorists at Lancaster University and Nordita and experimentalists at ETH Zurich and University of Manchester). An example of a recent collaborative project contributed to by the group members is the observation of the electronic spectrum reconstruction due to the formation of a nematic phase of the electron liquid in bilayer graphene [3]. Because of the problem-oriented approach within the group, the student will, over the course of their project, learn to apply a mixture of analytical and numerical methods to physical problems.

For more detailed information on the research, please visit http://people.bath.ac.uk/mlmk20/

The successful candidate should hold, or expect to receive, a first class or good 2.1 Master's degree (or equivalent) in Physics (Theoretical Physics preferred) or Theoretical/Quantum Chemistry (or other closely related field). A keen interest in theoretical condensed matter physics and a strong work ethic are essential. Also required is basic programming experience as well as some knowledge of Matlab/Mathematica.

Potential sources of funding include an EPSRC Centre for Doctoral Training (UK/EU citizens) or individual EPSRC/University of Bath scholarships. Candidates are encouraged to contact Dr Marcin Mucha-Kruczynski (m.mucha-kruczynski@bath.ac.uk) with informal enquiries.

References:

[1] A. K. Geim, *Graphene: Status and Prospects*, Science **324**, 1530 (2009).
[2] Q. H. Wang, K. Kalantar-Zadeh, A. Kis, J. N. Coleman, and M. S. Strano, *Electronics and optoelectronics of two-dimensional transition metal dichalcogenides*, Nature Nanotechnology **7**, 699 (2012).

[3] A. S. Mayorov, D. C. Elias, M. Mucha-Kruczynski, R. V. Gorbachev, T. Tudorovskiy, A. Zhukov, S. V. Morozov, M. I. Katsnelson, V. I. Fal'ko, A. K. Geim, and K. S. Novoselov, *Interaction-Driven Spectrum Reconstruction in Bilayer Graphene*, Science **333**, 860 (2011).