Graphene: the good, the bad, the nano and the pseudo

Cristiane Morais Smith

Institute for Theoret. Physics, Utrecht University, , Utrecht, The Netherlands

C.demoraissmith@gmail.com

Graphene is probably the most fascinating material ever discovered, but it has some drawbacks: it is not superconducting, it does not exhibit the quantum spin Hall effect, and its magnetic properties are still controversial. The interesting electronic properties of graphene, such as the presence of charge carriers that behave as if they would have no mass, are rooted on the honeycomb lattice of the carbon atoms. This insight provides a unique opportunity: by creating honeycomb lattices of materials other than carbon, the effects conferred by the atoms can be combined with those conferred by the honeycomb lattice and novel materials, with unexpected properties, may emerge. A key question in this regard is: if we build a honeycomb lattice out of semiconducting nanocrystals, is it going to behave like graphene or like the semiconducting building blocks?

In the first part of the talk, I will show that these systems, which have been experimentally synthesized in 2014 [1], combine the best of the two material. Honeycomb lattices of semiconducting nanocrystals exhibit a gap at zero energy, as well as Dirac cones at finite energies. In addition, a honeycomb lattice made of CdSe nanocrystals displays topological properties in the valence band [2], whereas for HgTe very large topological gaps are predicted to occur in the conduction p-bands [3]. These artificial materials thus open the possibility to engineer higher-orbital physics with Dirac electrons and to realize quantum (spin) Hall phases at room temperature [3].
In the second part of the talk, I will discuss how to describe the full dynamical electromagnetic interaction in 2D systems like graphene or transition-metal dichalcogenides, where the electrons are constrained to move in the 2D plane, whereas the photons move in 3D see Fig.1). By using the so-called pseudo-QED approach, I will show how quantized edge states emerge in this system and give rise to the quantum Valley Hall Effect in graphene [4], or even to the quantum Hall effect in transition-metal dichalcogenides [5]. The effect is produced through the dynamical breakdown of time-reversal symmetry generated by quantum fluctuations, and occurs in the absence of any perturbation that breaks this symmetry a priori.

References

1. M. P. Boneschanscher et al, Science 344, (2014) 1377.
2. E. Kalesaki, C. Delerue, C. Morais Smith, W. Beugeling, A. Allan, D. Vanmaekelbergh, Phys. Rev. X 4, (2014) 011010.
3. W. Beugeling, E. Kalesaki, C. Delerue, Y.-M. Niquet, D. Vanmaekelbergh, and C. Morais Smith, Nature Communications 6, (2015) 6316.
4. E. Marino, L. O. Nascimento, V. S. Alves, and C. Morais Smith, Phys. Rev. X 5, (2015) 011040.
5. L. O Nascimento, E. Marino, V. S. Alves, and C. Morais Smith, arXiv:1702.01573.

Figures

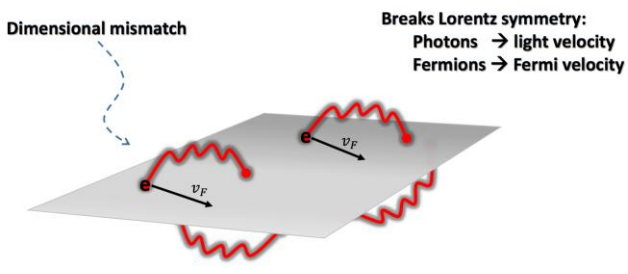

Figure 1: Dimensional mismatch between photons moving in 3D, which mediate the interaction between electrons moving in 2D.