Continuous Mott transition between a Fermi-liquid and a gapless spin-liquid

Wednesday, 9th January 2013. 12:00-13:00

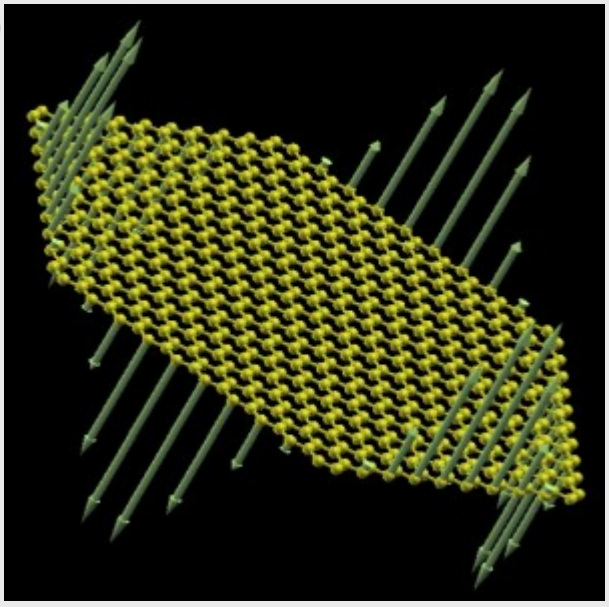
Iván González
(*Centro de Supercomputación de Galicia, Santiago de Compostela*)
ABSTRACT:

Strongly correlated electron systems can have insulating phases caused by correlation effects associated to the interactions between electrons (Mott insulators), in addition to the insulating phases caused by the interactions between the electrons and the lattice (band insulators.) The transition between metallic and Mott insulating phases is called the Mott transition. Despite decades of work, Mott transitions in two- and three-dimensional systems are poorly understood. In the last 30 years, its interest become even more apparent with the discovery of many of technological relevant compounds, such as high-temperature superconducting cuprates or colossal magnetoresistance manganites, obtained by doping Mott insulators.
The Mott transition depends on the nature of the insulating states obtained right after the transition. A common case is a transition to a Mott insulator with a long-range ordered phase, such as an antiferromagnet. An exciting scenario is a transition to a Mott insulator without any type of long-range order, i.e. a quantum spin liquid phase. Research following this possibility has been fueled by recent experiments that found such spin liquid phases to exist [1], precisely with a Mott transition to the spin liquid phase [2], as in the two-dimensional organic salt κ-(ET)2Cu2(CN)3.
An important question in characterizing phase transitions is the order of the transition. In most materials Mott transitions are first order. However if there are strong fluctuations impeding the electron localization, one could have a second order, i.e. continuous, Mott transition. Theoretical work showed that this is indeed possible, and that the continuous phase transition implies the existence of a “critical Fermi surface” at the quantum critical point [3]. The existence of this critical Fermi surface has dramatic consequences for thermodynamics and transport, causing the apperance of

non-Fermi liquid behaviour at finite temperatures above the critical point.
In the first part of my talk I will briefly review the theory of a continuous Mott transition, making a connnection with the experiments on organic salts and showing how non-Fermi liquid behavior arises at finite temperature. In the second part of my talk I will introduce a microscopic model for the electronic system of the organic material κ-(ET)2Cu2(CN)3, and then calculate its phase diagram at zero temperature using numerical techniques. Our results show the existence of a second order phase transition for a relevant range of parameters, confirming previous theoretical work. Specifically, the model shows a second order Mott transition between a Fermi liquid and gapless spin liquid with a spinon Fermi surface [4].
[1] Y. Shimizu *et al.*, Phys. Rev. Lett. 91, 107001 (2003).
[2] Y. Kurosaki *et al*., Phys. Rev. Lett. 95, 177001 (2005).
[3] T. Senthil, Phys. Rev. B 78, 045109 (2008).
[4] O. Motrunich, Phys. Rev. B 72, 045105 (2005).

Periodically nanostructured graphene

Wednesday, 12th Dicember 2012. 12:00-13:00

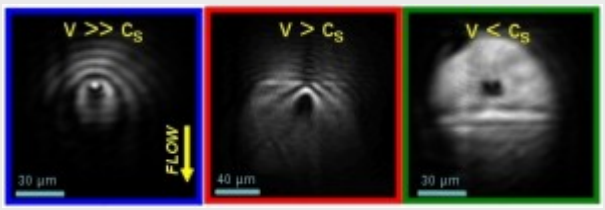


Amadeo L. Vázquez de Parga
(*Departamento de Física de la Materia Condensada, UAM and IMDEA-Nanociencia*)
ABSTRACT:
Ultra perfect graphene monolayers, islands and ribbons can be epitaxially grown on different single crystal metal surfaces under Ultra High Vacuum conditions. These graphene layers are spontaneously nanostructured in a periodic array of ripples by the moiré patterns caused by the difference in lattice parameter with the different substrates.
We characterize its perfection at the atomic scale by means of Scanning Tunnelling

Microscopy (STM) and determine its electronic structure in the real space by local tunnelling spectroscopy (STS). In-situ STM imaging of graphene monolayers on Ru(0001) reveals periodic corrugations with 12×12 periodicity. The apparent corrugation depends strongly on the bias voltage and can even be inverted above +2.6 V, revealing that, in addition to the geometric corrugation, a much stronger electronic corrugation exists. Moiré patterns have been observed with STM on different systems and their interpretation, in some cases, is not straightforward. The main reason is that in STM images the geometric corrugation and the electronic structure are entangled [1, 2]. Graphene grown on Ru(0001) presents periodic variations in the electronic structure induced by the chemical interaction between the carbon atoms and the ruthenium ones. By means of STS we observe inhomogeneities in the charge distribution along the moiré unit cell [3]: The surface potential landscape can be explored with nanometer resolution measuring the Field Emission Resonances (FERs). For graphene on Ru(0001) we have found differences in the value of the surface potential depending on the position on the moiré pattern. The energy position of the first FER presents strong spatial variations due to the hybridization with a Ru(0001) surface resonance [4].
We have been using this periodically nanostructure graphene to growth electron acceptor molecules like 7,7',8,8'-tetracyano-*p*-quinodimethane (TCNQ). The graphene overlayer electronically decouples TCNQ molecules from the Ru(0001). The energy position and spatial distribution of the molecular frontier orbitals for a single molecule are measured by STS maps at 4.6K in ultra high vacuum. The character of the orbitals is determined comparing the experimental data with DFT calculations. When the molecular coverage is increased the molecules begin to form chains that finally cover completely the graphene surface. The STS measurements and DFT calculations show that the interaction between the TCNQ molecules is via a saturated C≡N…H-C bonds. STM images show the formation of a spatially extended intermolecular band connecting the TCNQ molecules [5].
[1] B. Borca, S. Barja et al., *New J. Phys*. 12, 093018 (2010).
[2] D. Stradi, S. Barja et al., *Phys. Rev. Lett.* 106, 186102 (2011).
[3] A.L. Vázquez de Parga, F. Calleja at al., *Phys. Rev. Lett.* 100, 106802 (2008).
[4] B. Borca, S. Barja et al, *Phys. Rev. Lett*. 105, 036804 (2010).
[5] M. Garnica, D. stradi et al, *submitted* (2012).

Theory and experiments with quantum fluids of light

Wednesday, 5th Dicember 2012. 12:00-13:00



Iacopo Carusotto
(INO-CNR BEC Center and Dipartimento di Fisica, Universitá di Trento)
ABSTRACT:
A few years after the first observation of Bose-Einstein condensation, quantum gases of dressed photons in semiconductor microcavities (the so-called exciton-polaritons) are a powerful workbench for the study of phase transitions and many-body effects in a novel non-equilibrium context. In this talk, I will first briefly review remarkable experiments investigating superfluid hydrodynamics effects in photon fluids hitting localized defects: depending on the flow speed, a wide range of behaviors have been observed, from superfluid flow, to the super-sonic Mach cone, to the nucleation of topological excitations such as solitons and vortices. I will then illustrate recent theoretical studies in the direction of generating strongly correlated photon gases, from Tonks-Girardeau gases of impenetrable photons in one-dimension, to quantum Hall liquids in the presence of artificial magnetic fields. Advantages and disadvantages of the different material platforms in view of generating and detecting strongly correlated gases will be reviewed, in particular laterally patterned microcavity and micropillar devices in the optical range, and circuit-QED devices in the microwave domain.

The Nobel prize in Physics 2012

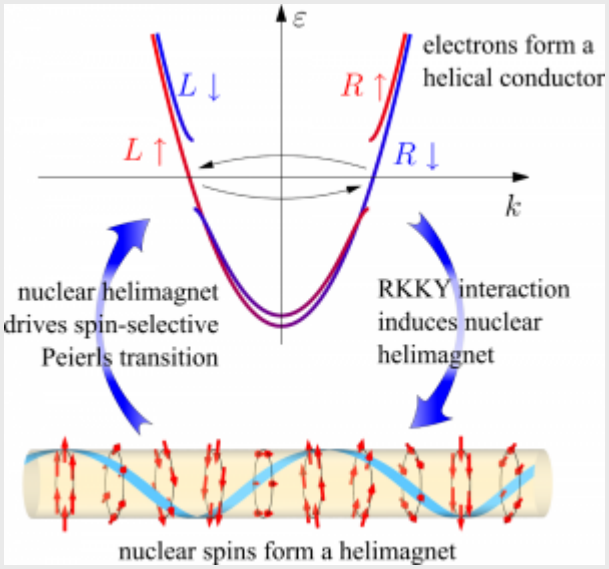
Wednesday, 28th November 2012. 12:00-13:00

Fabrice P. Laussy
(Depto. Física Teórica de la Materia Condensada, UAM)

ABSTRACT:
This year's Nobel prize honored, through the work of Haroche and Wineland, the physics of light-matter interaction at the ultimate quantum limit of one or a few quanta of excitation. This talk will present an overview of this field (quantum optics and, more precisely, cavity QED). While an emphasis will be given to some of the spectacular achievements of the 2012 laureates, particularly those of Serge Haroche, we will also discuss–beyond the EPR paradox, Schrödinger's cats, decoherence, sculpting of quantum states and the quantum Zeno effect–some of our own results that, in a different platform, belong to the same thematics: strong-coupling with quantum dots in microcavities, Mollow triplets in a fully quantized optical fields and frequency-resolved photon correlations.

Spin-orbit interaction in carbon nanotubes and its utility for proving entanglement of electrons

Wednesday, 21st November 2012. 12:00-13:00

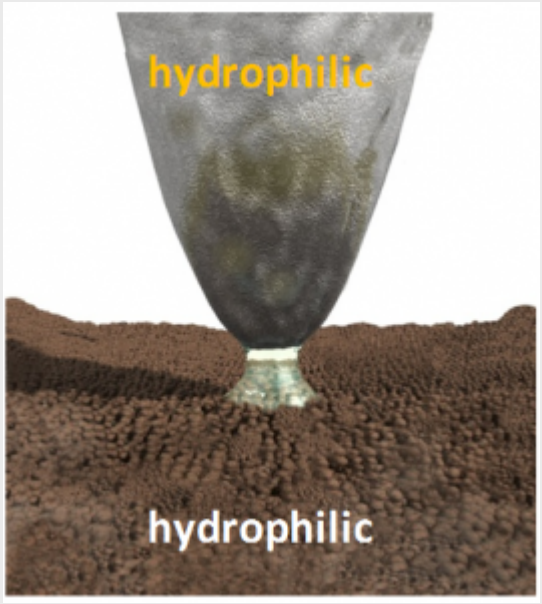


Bernd Braunecker
Departamento de Física Teórica de la Materia Condensada, UAM
ABSTRACT:
Spin-orbit interaction in condensed matter systems has attracted much attention very recently. It underlies the general goal of controlling and detecting spins by electric fields, and is an essential ingredient for the currently very popular topological insulators and Majorana bound states.
In this talk I will show that the spin-orbit interaction in carbon nanotubes has distinct features that allow to obtain information on the entanglement of injected pairs of electrons. I will give an introduction to the spin-orbit interaction in single-wall nanotubes and then discuss the cases of a nanotube cross-junction and a double-dot Cooper pair splitter setup. For the cross-junction I will show that spin-orbit interaction causes an

entanglement-depending noise spectrum with a richer spin structure than in previously discussed setups. For the double-dot system I will demonstrate that tunable spin-orbit induced spin-filtering allows to implement entanglement detectors, such as violations of a Bell inequality or quantum state tomography, by conductance measurements alone.

Structural flexibility mapping by bimodal atomic force microscopy in liquids

Wednesday, 7th November 2012. 12:00-13:00



Elena Tomás Herruzo
(Instituto de Ciencia de Materiales de Madrid, CSIC)
ABSTRACT:
Bimodal atomic force microscopy is based on the simultaneous excitation of two eigenmodes of the cantilever. Bimodal AFM enables the simultaneous recording of several material properties and, at the same time, it also increases the sensitivity of the microscope.
Here, the excitation of two cantilever eigenmodes in dynamic force microscopy enables the separation between topography and flexibility mapping. We have measured variations of the elastic modulus in a single antibody pentamer of 10 MPa when the probe is moved from the end of the protein arm to the central protrusion. Bimodal dynamic force microscopy enables us to perform the measurements under very small repulsive loads (30–50 pN).
We also develop a model based on fractional calculus to express the frequency shift of the second eigenmode in terms of the fractional derivative of the interaction force. We show that this approximation is valid for situations in which the amplitude of the first mode is larger than the length of scale of the force, corresponding to the most common experimental case. The model allows the measurement of the effective elastic modulus and the contact radius on heterogeneous samples.

[1] R. Garcia, E. T. Herruzo. *The emergence of multifrequency force microscopy*, Nat. Nanotechnol. 7, 217-226 (2012).
[2] E. T. Herruzo and R. Garcia. *Theoretical Study of the Frequency Shift in bimodal FM-AFM by fractional calculus*. Beilstein J. Nanotechnol. 3, 198–206 (2012).
[3] D. Martinez-Martin, E. T. Herruzo, C. Dietz, J. Gomez-Herrero and R. Garcia, *Noninvasive Protein Structural Flexibility Mapping by Bimodal Dynamic Force Microscopy*. Phys. Rev. Lett. 106, 198101 (2011).
[4] J. E. Sader and S. P. Jarvis, *Interpretation of frequency modulation atomic force microscopy using fractional calculus*. Phys. Rev. B 70, 01230 (2004).

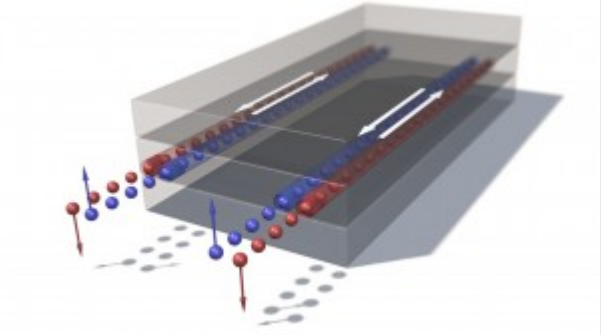
A new tool for particle hydrodynamics at different scales

Monday, 22nd October 2012. 15:00-16:00

Pawel Hawrylak
Emerging Technologies Division, National Research Council of Canada, Ottawa, Canada
ABSTRACT:
We briefly review electronic and optical properties of graphite and graphene, atomically thin layer of carbon atoms, and discuss its strength and shortcomings. We next discuss how one can engineer electronic, optical and magnetic properties of graphene by control of lateral size, character of the edge and number of layers. We describe gate controlled triangular graphene quantum dots with zigzag edges which exhibit a shell of degenerate states at the Fermi level, a prerequisite for strongly correlated electron system. We describe transport, optics and magnetism controlled by the gate and by the number of layers. Potential applications of graphene in spintronics, photovoltaics and quantum information are discussed.

Transport spectroscopy of NS nanowire junctions with Majorana fermions

Wednesday, 17th October 2012. 12:00-13:00

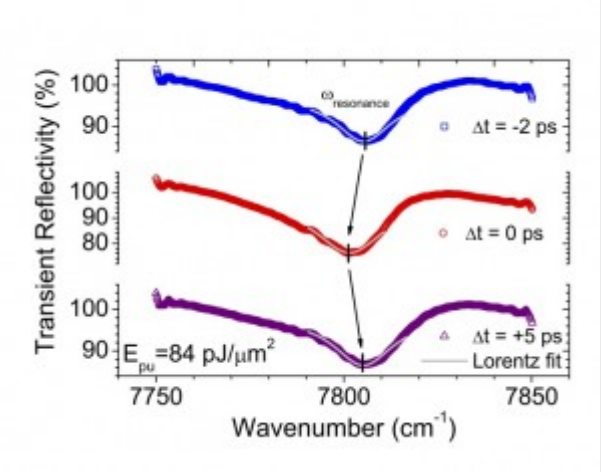


Elsa Prada
(Instituto de Ciencia de Materiales de Madrid, CSIC)

ABSTRACT:
We investigate transport though normal-superconductor nanowire junctions in the presence of spin-orbit coupling and magnetic field. As the Zeeman field crosses the critical bulk value Bc of the topological transition, a Majorana bound state (MBS) is formed, giving rise to a sharp zero-bias anomaly (ZBA) in the tunneling differential conductance. We identify novel features beyond this picture in wires with inhomogeneous depletion, like the appearance of two MBSs inside a long depleted region for B<Bc. The resulting ZBA is in most cases weakly split and may coexist with Andreev bound states near zero energy. The ZBA may appear without evidence of a topological gap closing. This latter aspect is more evident in the multiband case and stems from a smooth pinch-off barrier. Most of these features are in qualitative agreement with recent experiments Mourik *et al.*, Science 336, 1003 (2012). We also discuss the rich phenomenology of the problem in other regimes that remain experimentally unexplored.

Ultrafast switching of semiconductor microcavities

Wednesday, 10th October 2012. 12:00-13:00

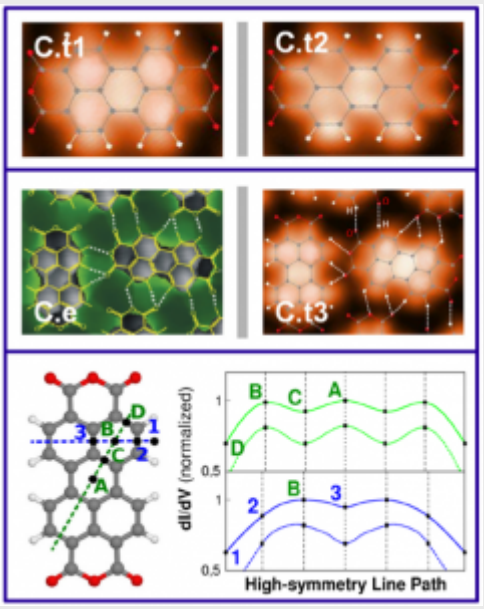


Georgios Ctistis
Complex Photonic Systems, MESA+ Institute & Dept. of Science and Technology, University of Twente, The Netherlands

ABSTRACT:
The interest in all-optical switching of photonic nanostructures is rapidly increasing due to the inherent speed of the process. Achieving ultrafast all-optical switching promises both new developments in information technology and a novel control of fundamental cavity quantum electrodynamics (QED). Switching photonic nanostructures is achieved by changing the refractive index of the constituent materials. To date, the switching speed has been limited by material properties but not by optical considerations. We explore the ultimate fast switching of the cavity resonance in GaAs/AlAs in the telecom range. We exploit the instantaneously fast electronic Kerr effect by the judicious tuning of the pump and probe frequencies relative to the semiconductor bandgap, resulting in a shift of the cavity resonance by nearly one linewidth. The speed of the switching – both on and off – is only limited by the dynamics of the light in our cavity [1].
We explore the not-adiabatic regime of tuning of light in a single-resonance cavity. We observe that the frequency of probe light is changed to a value different from the cavity resonance. The light accumulates a phase shift while it is trapped in the cavity due to a fast change in the refractive index, induced by an earlier pump pulse. Consequently, all light trapped in the cavity obtains a frequency different from the cavity resonance. To our knowledge, such photonic not-adiabatic tuning has not been observed before [2].
[1] G. Ctistis, E. Yüce, A. Hartsuiker, J. Claudon, M. Bazin, J.-M.Gérard, and W. L. Vos, , Appl. Phys. Lett. 98, 161114 (2011).
[2] P.J. Harding, H.J. Bakker, A. Hartsuiker, J. Claudon, A.P. Mosk, J.-M. Gérard, and W.L. Vos, J. Opt. Soc. Am. B 29, A1 (2012).

Improvement of STM Resolution with H-sensitized Tips

Wednesday, 3th October 2012. 12:00-13:00



José Ignacio Martínez
Departamento de Física Teórica de la Materia Condensada, UAM

ABSTRACT:
The general motivation for this contribution is the remarkable attention that the improvement of spatial resolution in STM is attaining in diverse fields such as Surface Science, Nanoelectronics and Catalysis [1]. In particular, recent Scanning Tunneling Hydrogen Microscopy (STHM) experiments on PTCDA/Au(111) have shown unprecedented intramolecular and intermolecular spatial resolution [1, 2]. The origin of this surprising behavior is not understood yet; in particular, the way in which H2 molecules in the STM chamber may affect the STM image is not clear. In our work, we analyze the effect on the STM images of both atomic and molecular hydrogen interacting with tip or sample, using an accurate STHM theoretical simulation technique that includes a detailed description of the electronic structure of both tip and sample [3]. To the best of our knowledge, this is the first theoretical simulation of STHM, which is a very challenging task. Notice that in the widely used Tersoff-Hamman approach to simulate STM images, the STM current is simply proportional to the density of states of the sample at the tip position. Thus, within a Tersoff-Hamman approach it is not possible to take into account the influence on the STM image of an H2 atmosphere in the STM chamber.
We find that the STHM resolution enhancement is due to atomic H adsorbed on the tip [4]. At first sight, this is a surprising result, since it is considered that H2 does not dissociate on Au surfaces. However, the situation is different for Au clusters and nanostructures, that are known to be good catalysts. In our work, the dissociation of H2 molecules on the Au STM tip is further corroborated by state-of-the-art total-energy calculations using a plane- wave DFT code and the PBE0 exchange-correlation functional. Finally, we analyze the physical origin of the improvement of STM resolution; we find that the adsorbed H-atoms induce important changes in the Density of States (DOS) at the Fermi level (EF) of the tip, increasing its total value, and making it more directional. Also, due to the interaction with the H-decorated tip, EF is shifted to the

middle of the PTCDA LUMO peak, increasing dramatically the DOS of the sample at EF. The combination of these effects gives rise to the enhanced STHM intramolecular resolution, as well as the increased visibility of the intermolecular bonds, explaining the experimental observations [4]. Besides, the theoretical formalism permits, by construction, a detailed analysis of the different orbital-component contributions, providing an accurate idea about the formation of the STM images [4].

[1] L. Gross, *Nat. Chem.* 3, 273 (2011).
[2] C. Weiss, C. Wagner, C. Kleimann, *et al.*, *Phys. Rev. Lett.* 105, 086103 (2010).
[3] J. I. Martínez, *et al.*, *Phys. Stat. Sol. B* 248, 2044 (2011); *Org. Electron.* 13, 399 (2012).
[4] J. I. Martínez, E. Abad, C. González, F. Flores, J. Ortega, *Phys. Rev. Lett.* 108, 246102 (2012).