Droplets of Quantum Physics or Why Helium is The Superelement

INC COLLOQUIUM – OFFICIAL ANNOUNCEMENT

Title: Droplets of Quantum Physics or Why Helium is The Superelement.
When: 25 April, 2017, 12h00
Where: Sala de Conferencias, Módulo 00, Facultad de Ciencias.
Speaker: J. Peter Toennies, Max-Planck Institute for Dynamics and Self-Organization, Am Fassberg 10, 37077 Göttingen, Germany.
ABSTRACT:

Helium is an element of many superlatives. It is, on the one hand, the smallest and most inert of all atoms and, on the other, the second most abundant element (after hydrogen) in the universe. The bosonic nature, small mass and weak intermolecular forces explain why it is the only substance that remains liquid down to zero Kelvin and the only naturally occurring superfluid.

Superfluidity and frictionless flow of 4He were long thought, after its controversial discovery in 1938, to exist only in the bulk. Then starting about 1990 molecular beams of clusters and droplets revealed the following unexpected microscopic new super properties [1], each of which is the largest in nature: (1) The He-He scattering cross section at $T \to 0$ is 2,590 nm2. (2) The dimer bond distance is <R> = 5.2 nm. (3) The trimer is even larger and extends out to 30 nm!

The properties of larger helium aggregates have been explored via the spectroscopy of interior-embedded weakly-interacting chromophores, e.g. OCS or SF6. Surprisingly In droplets with more than 60 atoms molecules can rotate freely as if in vacuum. This made it possible to determine their temperature which is only 0.37 K (~ 0.1 K in 3He). Several subsequent experiments confirm that the droplets show many of the hallmarks of bulk superfluidity. These experiments have established that 4He droplets are superfluid making them the coldest and gentlest of all matrices for spectroscopic studies.

The many high resolution spectroscopic studies of small molecules have provided many new unexpected manifestations of microscopic superfluidty. He droplets have also opened up the spectroscopy of large biomolecules and countless taylor-made heterogeneous clusters. Other novel applications [2] are: (1) Assembly of pure and alloy

metal nanowires on quantum vortices in the interior of very large droplets. (2) Facile laser- and field-alignment of the very cold molecules. (3) Catalysis and enhancement of the rates of chemical reactions, (4) Structural studies of large biomolecules using electron diffraction and (5) X-ray diffraction studies of exotic vortex-induced microscopic Abrikosov lattices, to name only a few.

Thus I hope that you will understand why I have been fascinated with helium and why I think it certainly deserves the honor of being named the “Superelement of the universe”.

References

- J. P. Toennies, Mol. Phys. 111, 1879 (2013).
- J. P. Toennies and A. F. Vilesov, Angew. Chem. Int. Edit. 43, 2622 (2004).

Physics Undergraduate Student Research Awards - 2017

Aim

The Instituto Universitario de Ciencia de Materiales Nicolás Cabrera (INC) and the Department of Condensed Matter Physics, Department of Theoretical Condensed Matter Physics, Department of Physics of Materials and Department of Applied Physics, provide 5 awards for research works performed by undergraduate students of Physics. Students will present their work during the Young Researchers Meeting of the INC, to be held in December 2017.

Eligible students

- Physics students with excellent marks, preferably third and fourth year undergraduate students.
- Students must have chosen the Department and the subject of their work.
- The performed work should be different than previous work by the student (for example, work made for the Physics undergraduate studies), but it can be a continuation of previous work, and the student may chose the same responsible scientist.

Students will present

A poster during the Young Researchers Meeting of the INC. The language of the meeting is English.

Applications

The candidates should send their application to inc@uam.es before 1 May 2017. In their email, they should provide their name and surnames, the Department and subject of their choice and a copy of their marks (expediente académico).

Awards

- 5 awards amounting to 1600 € (including taxes) each and 5 diplomas.

More Information

Materials, Energy and Life: Entertaining Aspects of High Magnetic Field Research

INC COLLOQUIUM – OFFICIAL ANNOUNCEMENT

Title: Materials, Energy and Life: Entertaining Aspects of High Magnetic Field Research.

When: 27 March, 2017, 15h00

Where: Sala de Conferencias, Módulo 00, Facultad de Ciencias.

Speaker: Greg Boebinger, Professor of Physics, Florida State University and University of Florida. Director, National High Magnetic Field Laboratory.

ABSTRACT:

The MagLab exists to provide its international user community with unique magnets and expertise spanning condensed matter physics, materials research, chemistry, biochemistry, biology, and biomedicine. We invent new materials in order to generate magnetic fields exceeding two million times the Earth's magnetic field.

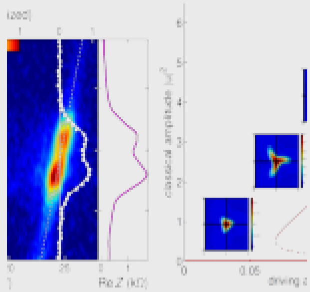
This talk seeks to answer the question, "How and why would anyone want to do such a thing?" Illustrative examples from the portfolio of user research at the MagLab will include:

- MATERIALS: tweaking macroscopic quantum phenomena in two-dimensional square lattices of copper and oxygen to achieve high-temperature superconductivity or magnetic Bose-Einstein condensation.
- ENERGY: analyzing nature's most complex fluids, including petroleum, to improve utilization and mitigate pollution.

LIFE: tracking sodium and gadolinium quantum dots to revolutionize magnetic resonance imaging. During the talk, we anticipate that jokes will be told.

The portion of the talk that surveys my own work on high-temperature superconductivity uses magnetic fields to suppress the superconductivity with a goal of revealing the Wizard who pulls the strings behind the curtain. This work is a collaboration with Camilla Moir, Scott Riggs, Arkady Shehkter, Oskar Vafek and Jon Kemper of the MagLab branch at Florida State University; Jon Betts, Albert Migliori and Fedor Balakirev of the MagLab branch at Los Alamos National Laboratory; and W. N. Hardy, Ruixing Liang and Doug Bonn of the University of British Columbia.

Josephson Photonics: Quantum Optics Meets Quantum Electronics



Title: Josephson Photonics: Quantum Optics Meets Quantum Electronics.

When: Thursday, March 16, (2017), 12:00.

Place: Departamento de Física Teórica de la Materia Condensada, Facultad Ciencias, Module 5, Seminar Room (5th Floor).

Speaker: Joachim Ankerhold, Ulm University, Institute for Complex Quantum Systems, Germany.

Real quantum systems never live in isolation but are embedded in surrounding media. An impressive example is cavity quantum electrodynamics and its more recent realization circuit-QED, where `artificial atoms' in microwave cavities are implemented with superconducting circuits. Quantum electrodynamics, however, implies the interaction of bosonic with fermionic matter in general. For the latter, fascinating progress has been achieved in the field of quantum electronics to control charge transfer down to the level of individual charge carriers.

Activities to combine these two previously almost distinct fields, quantum optics and quantum electronics, have appeared only very recently with the advent of Josephson photonics. This opens a new playground to study a wealth of phenomena far from equilibrium including non-classical light sources, ultra-strong charge-light interactions, and quantum phase transitions in steady state. In this talk I will discuss experimental

developments in line with the theoretical background.
More information on IFIMAC Website

Zero-energy Pinning from Interactions in Majorana Nanowires

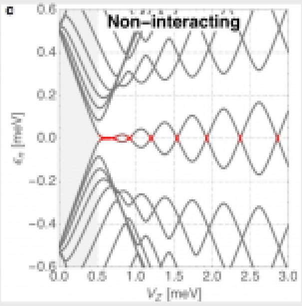


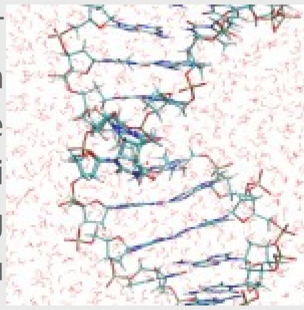
Fig. 1. (a) Proximitised Rashba nanowire of finite length with gate-tunable Fermi energy and under a parallel Zeeman field Vz. (b) Bound charges ρb arise in the dielectric surroundings, which interact with free charges in the nanowire. (c,d) Non-interacting and interacting spectra of the nanowire. Extended zero modes (in red) in (d) are the result of the interaction-induced pinning, discussed in this work, of Majoranas at zero energy around parity crossings.

Article: published in npj Quantum Materials by Alfredo Levy Yeyati IFIMAC researcher and member of the Department of Theoretical Condensed Matter Physics.

Since the early experimental efforts towards the generation and characterisation of Majorana zero modes in solid state devices, remarkable progress has been accomplished. Recently, this field has seen a revival thanks to new experiments of exceptional quality on proximitised semiconducting nanowires. These experiments provide cleaner devices, with longer mean free paths and much more robust induced superconductivity. Samples of this quality are expected to develop an unambiguous, topologically nontrivial superconducting phase. If the length of the nanowire is much greater than the Majorana length, the wire should host zero-energy Majorana states at its edges, which would be detected as e.g. zero-bias anomalies in tunnelling transport measurements. However, this is not the case of samples of realistic length (see Fig. 1a,c). In this case, the two Majoranas at opposite ends of the wire overlap substantially, which results in the annihilation of the zero energy modes through hybridization, and their topological protection is destroyed. This theoretical expectation is in stark contrast with some recent experiments reporting surprisingly stable zero-bias anomalies in transport.

A collaboration between IFIMAC and ICMM (CSIC) researches published in npj Quantum Materials has studied the problem of the stability of zero-energy Majorana states in the presence of electronic interactions including, crucially, the interactions with the dielectric environment (see Fig. 1b), which has thus far been neglected in the literature. The authors present a solution to the Majorana stability puzzle by demonstrating that interaction with image charges in the dielectric environment may efficiently stabilise Majoranas back to zero energy and charge (Fig. 1d), drastically changing the non-interacting paradigm (Fig. 1c). This interaction leads to electronically incompressible parameter regions wherein Majoranas remain insensitive to local perturbations, despite their overlap. This effect, here dubbed “zero-energy pinning”, could be of great practical importance since it may allow realistic Majorana devices to recover their topological protection against local fluctuations of the environment. It is only then that their non-Abelian statistics can be exploited for future fault-tolerant quantum computers. [Full article]

Computational Simulation of Photochemical Reactions in DNA



The figure shows a fragment of DNA, with the thymine dimer in the middle, sorrounded by the water molecules of the solvent.

Article: published in The Journal of Physical Chemistry Letters by Jesús I. Mendieta-Moreno and José Ortega, IFIMAC researchers and members of the Department of Theoretical Condensed Matter Physics.

The photostability of DNA is a key property for life. It is well-known that the absorption of ultraviolet (UV) radiation may result in harmful genetic lesions that affect DNA replication and transcription, ultimately causing mutations, cancer, and/or cell death. Luckily for us, cellular DNA presents remarkable stability against this photodamage: the huge majority of the absorbed photons are transformed into heat, which is transferred to the solvent without causing any lesion.

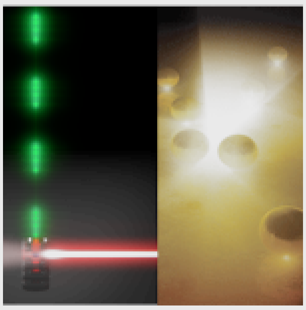
The most frequent DNA photolesion produced by sunlight is the cyclobutane thymine dimer (CTD) that is characterized by the formation of two covalent bonds between adjacent thymine bases (see Figure). In a recent collaboration, led by an IFIMAC group and published in the The Journal of Physical Chemistry Letters, this photochemical reaction has been simulated at the atomic level. The results reveal how the structure and dynamics of the DNA double-helix drastically reduce the probability of photolesion, thus protecting the integrity of the genetic code. The results also highlight the importance of properly taken into account the biomolecular environment for the study of photochemical reactions in biomolecules.

Quantum Mechanics and Molecular Mechanics

Theoretical analysis of photochemical reactions in biomolecules is a very challenging problem that requires mixing different theoretical and computational strategies. In this work, a hybrid quantum mechanics / molecular mechanics (QM/MM) method, recently developed by the authors, was used to explore the conformational and dynamical properties of the system. This method presents a very good balance between accuracy

and computational efficiency, a very important property to study complex biomolecular systems. Moreover, non-adiabatic QM/MM molecular dynamics simulations were performed to study the dynamics of photo-excited DNA and analyze the atomic mechanisms of the reaction. [Full article]
Also read on UAM Gazette.

Postdoctoral Position Available at IFIMAC and FTMC on Classical and Quantum Electrodynamics of light-matter Coupling – Closed

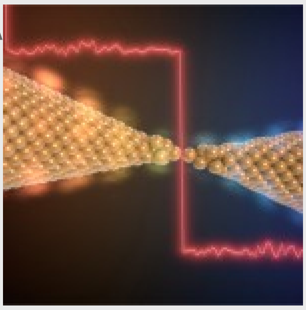


Project Title: Classical and Quantum Electrodynamics of light-matter coupling (FIS2015-64951-R).
Funding Agency: Programa Estatal de I+D+i Orientada a los Retos de la Sociedad (MINECO).
PIs: A. I. Fernandez-Dominguez, Fabrice Laussy & Elena del Valle.

A 2-year postdoctoral position is open to work on the project Classical and Quantum Electrodynamics of light-matter coupling – CLAQUE, funded by the Spanish MINECO under the Programa Estatal de I+D+i Orientada a los Retos de la Sociedad.
CLAQUE is a collaborative theoretical project designed by a team of young, leading scientists which aims to address open, fundamental and technologically-oriented problems involving classical and quantum aspects of light and light-matter interactions. CLAQUE brings together complementary areas of expertise to address currently open problems in nano- and quantum-optics. It aims at setting on foot exploratory strategies with potential ground-breaking implications, and opening new fronts of research by merging different approaches to closely related problems. The project focuses on novel phenomena emerging from the tuning and optimization of quantum correlations [1] in exciton-plasmon, and other hybrid light confining, platforms [2].
In the context of this research project, the postdoctoral researcher will work on the design and exploration of tailored nonclassical light sources through the spectral and spatial distillation of quantum correlations at the nanoscale.
For further information and to apply, please contact Elena del Valle at elena.delvalle@uam.es. Applications should include a cover letter, CV, and contact information for two references. Initial appointments will be for one year, with possible extension to the second year. Applications will be received until April 15 2017.
Official announcement.
References

C. Sanchez Muñoz, E. del Valle, A. González-Tudela, K. Müller, S. Lichtmannecker, M. Kaniber, C. Tejedor, J. J. Finley and F. P. Laussy, Nat. Photon., 8, 550 (2014).
R.-Q. Li, D. Hernangómez-Pérez, F. J. García-Vidal and A. I. Fernández-Domínguez, Phys. Rev. Lett. 117, 107401 (2016).

Quantized Thermal Transport in Single-Atom Junctions



Artistic view of quantized heat transport in a gold single-atom contact.

Article: published in Science by Juan Carlos Cuevas, IFIMAC researcher and member of the Department of Theoretical Condensed Matter Physics.

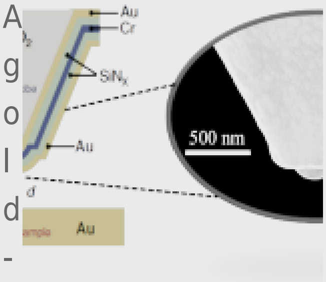
What does determine the heat flow through a single atom? This is the ultimate question in the field of nanoscale energy transport and its answer is crucial to establish the fundamental laws that should describe the thermal transport in a variety of nanoelectronic devices. In the context of electrical circuits, the atomic scale was first reached with the advent of metallic atomic-size contacts and single-molecule junctions in the 1990s. These systems constitute the ultimate limit of miniaturization and have emerged as an ideal playground to investigate quantum effects related to charge and energy transport. Thus for instance, in recent years it has been shown that transport properties of metallic atomic-size contacts such as the electrical conductance, shot noise, thermopower, or Joule heating are completely dominated by quantum effects, even at room temperature. However, the experimental study of thermal conduction in these atomic-scale systems continues to be a formidable challenge and it has remained elusive to date in spite of its fundamental interest.

This basic open problem has now been resolved in a work published in Science by a collaboration between the groups of Pramod Reddy and Edgar Meyhofer (University of Michigan), Fabian Pauly and Peter Nielaba (University of Konstanz), and the IFIMAC researcher Juan Carlos Cuevas. In this work, the authors made use of custom-designed picowatt-resolution calorimetric scanning probes to measure simultaneously the electrical and thermal conductance of gold and platinum atomic contacts all the way down to the single-atom level. This study reveals that the thermal conductance of gold single-atom junctions is quantized at room temperature in units of the universal thermal conductance quantum. It also shows that the Wiedemann-Franz law relating thermal and electrical conductance is satisfied even in single-atom contacts, irrespective of the metal. Furthermore, this work shows that all these observations can be quantitatively explained within the Landauer picture for quantum coherent thermal transport. In particular, this theory clarifies that the observations described above are due to the fact that electrons dominate the thermal conductance in these metallic nanowires, and in the gold case electrons proceed ballistically through the contacts via fully open conduction channels.

The experimental techniques developed in this work will enable systematic studies of thermal transport in atomic chains and molecular junctions, which is key to investigating numerous fundamental issues that have remained inaccessible despite great theoretical interest. [Full article]

Quantized Thermal Transport in Single-Atom Junctions

Radiative Heat Transfer in Ångström and Nanometer-sized Gaps



A gold-coated scanning thermal microscopy probe is brought into close proximity of a heated gold substrate.

Article: published in Nature Communications by Víctor Fernández-Hurtado, Johannes Feist, Francisco J. García-Vidal and Juan Carlos Cuevas, Department of Theoretical Condensed Matter Physics and IFIMAC researchers.

Radiative heat transfer between closely placed objects is attracting a lot attention for several reasons. First, recent experiments have finally verified the long-standing prediction that radiative heat transfer can be greatly enhanced over the classical far-field limit set by the Stefan-Boltzmann law for blackbodies if the gap between two objects is smaller than the thermal wavelength, which is of the order of 10 µm at room temperature. This is possible due to the contribution of the near field in the form of evanescent waves (or photon tunneling). Second, this confirmation has triggered the hope that near-field radiative heat transfer could have an impact in different technologies that make use of thermal radiation such as thermophotovoltaics, thermal management, lithography, data storage, and thermal microscopy.

In spite of the progress made in recent years in the understanding of thermal radiation at the nanoscale, several recent experiments exploring the radiative thermal transport in nanometric gaps have seriously questioned this understanding. In particular, measurements on two gold-coated surfaces with gap sizes in the range of 0.2-10 nm have suggested an extraordinarily large near-field enhancement more than 3 orders of magnitude larger than the predictions of fluctuational electrodynamics, which is presently the standard theory used for the description of near-field thermal radiation.

A possible solution to this puzzle has now been proposed in a work published in Nature Communications by a collaboration between the groups of Pramod Reddy and Edgar Meyhofer (University of Michigan) and IFIMAC researchers Víctor Fernández-Hurtado, Johannes Feist, Francisco J. García-Vidal and Juan Carlos Cuevas. In this work, the authors explore the radiative heat transfer in Ångström- and nanometer-sized gaps between an Au-coated scanning thermal microscopy probe and a planar Au substrate in an ultrahigh vacuum environment. Using the apparent tunneling barrier height as a measure of cleanliness, it was found that upon systematically cleaning via plasma-cleaning or locally pushing the tip into the substrate by a few nanometers, the observed radiative conductances decreased from unexpectedly large values to extremely small ones-below the detection limit of the probe-as expected from computational results obtained within the framework of fluctuational electrodynamics. These results suggest that the huge signal reported in recent experiments might be an artifact due to the presence of contaminants bridging the gap between the tip and the substrate, thus providing an additional path for heat transfer via conduction. Moreover, this work shows that it is possible to avoid the confounding effects of surface contamination and systematically study thermal radiation in Ångström- and nanometer-sized gaps. [Full article]

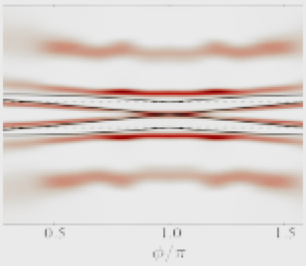
References

Study of Radiative Heat Transfer in Ångström and Nanometre Sized Gaps, L. Cui, W. Jeong, V. Fernández-Hurtado, J. Feist, F.J. García-Vidal, J.C. Cuevas, E. Meyhofer, and P.

Reddy, Nature Communications 8, 14479, (2017). [URL]

Fractional Spin And Josephson Effect In Time-reversal-invariant Topological Superconductors

Title: Fractional Spin And Josephson Effect In Time-reversa-
-invariant Topological Superconductors.
When: Friday, February 17, (2017), 12:00.
Place: Departamento de Física Teórica de la Materia Condensada,
Facultad Ciencias, Module 5, Seminar Room (5th Floor).
Speaker: Liliana Arrachea, International Center for Advanced
Studies Universidad de San Martín, Argentina.



Time reversal invariant topological superconducting (TRITOPS) wires are known to host a fractional spin hbar/4 at their ends. We investigate how this fractional spin affects the Josephson current in a TRITOPS-quantum dot-TRITOPS Josephson junction, describing the wire in a model which can be tuned between a topological and a nontopological phase. We compute the equilibrium Josephson current of the full model by continuous-time Monte Carlo simulations and interpret the results within an effective low-energy theory. We show that in the topological phase, the 0-to-pi transition is quenched via formation of a spin singlet from the quantum dot spin and the fractional spins associated with the two adjacent topological superconductors.

More information on IFIMAC Website