GENERAL SCIENTIFIC MEETING
OF THE
BELGIAN PHYSICAL SOCIETY
MONS UNIVERSITY – CAMPUS PLAINE DE NIMY
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This annual one-day conference brings together physicists from Belgian universities, Belgian high schools and higher education schools, as well as from Belgian industries and companies. Its main aim is to establish links and stimulate collaborations between research groups working at different research institutions within Belgium, and to provide a platform for Belgian high school teachers to get updated on the current state of the art in physics.

Confirmed plenary speakers
Prof. Magali Deleuil (Laboratoire d’Astrophysique de Marseille, Université d’Aix-Marseille, France) « Exoplanets and the search for Earth nr.2 »
Prof. Bruce Allen (Max Planck Institute for Gravitational Physics, Albert Einstein Institute, Hannover, Germany) « Direct observations of gravitational waves with Advanced LIGO »

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Deadline for early registration : 2nd May 2017
Deadline for abstract submission : 2nd May 2017
Grands Amphis et Centre V sale, 20, Avenue du Champ de Mars, 7000 Mons
www.umons.ac.be/bps2017
Plenary Session 1 (9:10 – 10:00)
Van Gogh lecture hall
Chairman: Prof. Jozef Ongena (RMA)
Direct Observation of gravitational waves from the merger and inspiral of two black holes

Prof. Dr. Bruce Allen (MPI für Gravitationsphysik, Hannover, Germany)

This talk describes the advanced LIGO observations of gravitational waves emitted by the final few orbits and merger of two black holes. I present our main results, as well as some of the “behind the scenes” details of the 14 September 2015 discovery, and briefly describe our 26 December 2015 detection of somewhat weaker gravitational waves from a similar system. The consistency of these observations with the predictions of General Relativity, and our expectations for the second observing run O2 (which began at the end of 2016) and for future observing runs are also discussed.

References:
B. P. Abbott et al.,
Phys. Rev. Lett. 116, 22110;
Ann. der Physik 529, No. 1-2, 1600209, 2017
Plenary Session 2 (10:00 – 10:50)
Van Gogh lecture hall
Chairman: Prof. Jozef Ongena (RMA)
Exoplanets and the search for Earth nr.2

Prof. Magali Deleuil (Laboratoire d’Astrophysique de Marseille, Marseille, France)

The first exoplanet orbiting a sun-like star was discovered barely 25yr ago. Since then there has been tremendous progress both in the discovery of new planetary systems and in their characterisation which belies the difficulty in their detection. In this talk, I will review our current knowledge of exoplanets and the challenges they present. I will discuss the known habitable zone exoplanets (including Trappist-1a/f and Proxima Centauri b) and examine what is really known of their physical properties and as abodes for life. I will also look forward to new experiments that form the exoplanet roadmap going forward to the end of the next decade and give an outlook of what our state of knowledge will be at that time.
Young Speaker Contest (11:25 – 12:45)
Van Gogh lecture hall
Chairman: Prof. Jozef Ongena (RMA)
Controlling CO adsorption on Pt clusters by dopant induced charge transfer

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A major drawback of state-of-the-art proton exchange membrane fuel cells (PEMFCs) is that the platinum catalyst is highly susceptible to CO poisoning. CO molecules present as trace components in the fuel preferentially adsorb to Pt nanoparticles, thereby blocking the active sites and degrading the cell’s performance. It is known that CO poisoning is reduced if platinum alloys are used. However, the underlying mechanism of this phenomenon is still under debate \([1-3]\). Herein we study the CO adsorption on small doped platinum clusters in a molecular beam using reactivity measurements in a low-pressure collision cell \([4]\). As shown in the example of Figure 1, pressure-dependent measurements show, on the one hand, that Nb and Mo doping increase the dissociation rates of the formed CO complexes in the timescale of the experiment (~100μs), whereas on the other hand, Sn and Ag doping does not affect these rates. This experimental result suggests that a significant decrease in CO binding energy is induced by Nb and Mo doping, while Sn and Ag may not considerably affect the cluster-CO interaction.

Further understanding of this observed effect is obtained by complementary density functional theory calculations, showing a significant reduction in CO binding energy for Nb and Mo doped clusters, which is attributed to electron transfer from those dopants to the Pt atoms in the clusters. In contrast, calculations show that Sn and Ag dopants induce a limited charge transfer, traduced in a much weaker change in binding energy, in agreement with the experiment. Analysis of the clusters’ density of states demonstrates a correlation of dopant induced changes in the electronic structure with the enhanced tolerance to CO poisoning.

\[\text{Figure 1. Fit of normalized intensities of (CO) and (CO)}_2\text{ complexes of Pt}_{20}^+\text{ and NbPt}_{19}^+\text{ clusters as a function of } p_{\text{CO}}.\]


Thermal magnetic noise spectroscopy of magnetic nanoparticle ensembles

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The importance of magnetic nanoparticles has increased a lot over the past few years thanks to their appealing properties for biomedical applications[1]. For instance, when exposed to an alternating magnetic field, they generate heat which can be used in the destruction of cancer cells[2]. Moreover, the combination of their small size and large magnetic moment enables them to reach virtually any location in the human body, which makes them excellent candidates for use in imaging applications[3]. For these biomedical applications to work safely and reliably, the magnetic nanoparticles should be well characterised. This is typically performed by measuring the particles’ response to an external excitation like an applied field. However, such excitations are known to alter the nanoparticle’s aggregation state. For instance, external fields can induce clustering or chain formation.

Recently, we demonstrated the feasibility of measuring the thermal magnetic noise emitted by magnetic nanoparticles in the absence of any excitation[4]. The magnetic particles’ noise spectrum was recorded using a SQUID in a magnetically shielded environment. The recorded spectra were then interpreted in order to characterize the magnetic nanoparticles, and e.g., determine their moment distribution. This is an important development, as these measurements allow to quantitatively investigate the influence of the excitations used in other measurement procedures on the measurement results. To this end, we investigated the similarity and complementarity of this technique and magnetorelaxometry[5].

References

A graphene road towards robust tunable perfect electromagnetic absorbers

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The electromagnetic properties of a solid material are directly related to its electrical conductivity. This link remains true for 2D conducting materials such as graphene. The reflectance, transmittance and absorbance of this one-atom thick layer are analytically derived in this work, generalizing the Fresnel formula to the case of a 2D conducting material inserted between two semi-infinite dielectric media. Stacking several graphene monolayers, separated by a polymer spacer, is a way to control the effective conductivity of a system since the conductivity of $N$ independent layers $\sigma_N$ is equal to $N\sigma_1$, where $\sigma_1$ is the 2D conductivity of a graphene monolayer[1]. Via an optimization process based on the Fresnel relations, one may find an optimum number of layers for which the absorption of electromagnetic radiations inside the graphene layers is maximal. Accordingly, the device must satisfy some conditions, called impedance matching conditions. Such graphene-polymer heterostructures have been shown to efficiently absorb GHz electromagnetic radiation up to $\sim 50\%$ [1,2] under these conditions.

Moreover, these structures, once impedance matching conditions are verified, are robust to fabrication process defects (microscopic holes, microscopic embryos of second layer or domain boundaries) that may occur in graphene samples produced by chemical vapor deposition [2]. Rigorous coupled wave analysis is used to account for the presence of random defects in graphene. It is demonstrated that the optimum absorbance of the device does not weaken to first order in defect concentration. This finding testifies to the robustness of the shielding efficiency of the proposed absorption device.

In order to reach perfect electromagnetic absorption, the analytical relations show that the graphene/polymer heterostructure should be lying on a material possessing a refractive index close to zero [3]. This can be achieved using an epsilon-near-zero metamaterial.

Finally, tunability of the proposed absorbers is theoretically worked out by modulating the charge carrier density of graphene. An applied voltage modifies the effective conductivity of the device and a modulation of 40% of absorption/reflectance is shown using voltage below the breakdown voltage of the polymer layers [4]. The proposed strategy can be applied to any kind of 2D conducting materials on epsilon-near-zero metamaterial.

Modeling Coronal Mass Ejections in the Inner Heliosphere using the Gibson-Low flux rope model with EUHFORIA

C. Verbeke¹, J. Pomoell², S. Poedts¹

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Coronal mass ejections (CMEs) are huge explosions of magnetic field and plasma from the solar corona. They originate from highly twisted magnetic field structures, also called flux ropes. Their influence on the coronal and interplanetary dynamics and their impact on the Earth’s magnetosphere is of high importance for space satellites and terrestrial effects on f.e. our power grid or gas pipelines. Understanding their origin and evolution still remains a key goal in current space weather research. In this work, we present our first steps towards the inclusion of a magnetized flux-rope CME into the recently developed inner heliosphere model EUHFORIA.

EUHFORIA (‘EUropean Heliospheric FORecasting Information Asset’) is a three-dimensional physics-based forecasting model of large-scale dynamics in the inner heliosphere covering heliocentric distances from 0.1 AU up to 2 AU and beyond. The magnetohydrodynamics-based modeling methodology is able to capture transient structures in the solar wind such as high speed streams, co-rotating interaction regions as well as shocks driven by coronal mass ejections.

A key novel feature is to employ a data-driven magnetic flux rope model, based on the Gibson and Low model instead of the widely used cone model, which is based on a pressure and density enhancement, but does not incorporate the magnetic field structure of the flux rope. Magnetic field parameters are determined through non-potential coronal modeling while the kinematics have been constrained by fitting to coronagraph observations. We discuss results of the first magnetized flux-rope simulations as well as a comparison with the currently used CME cone model. Finally, we discuss future horizons for our model.
Parallel Session (14:15 – 18:00)
Astrophysics, Geophysics, and Plasma Physics
Chairman: Prof. Fabrice Louche (RMA)
Influence of environmental parameters on the Kelvin-Helmholtz instability at the magnetopause

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The development of large boundary layers at the solar wind/magnetosphere interface during northward interplanetary magnetic field is still not fully understood. Different configurations than can occur in the Kelvin-Helmholtz instability scenario in a three-dimensional setting are studied, with a focus on the double mid-latitude reconnection process exposed by Faganello et al. The influence of various parameters on the growth rate of the KHI and the efficiency of the DMLR is assessed. These configurations may have discernible signatures that can be recorded by spacecrafts diagnostics, therefore flows and particles data that would be recorded by spacecrafts during such events are simulated.

Introduction

The Kelvin-Helmholtz instability (KHI) being the cause of the boundary layer at the interface between the solar wind (SW) and the magnetosphere (MS) is in good agreement with the observations so far[1]. Previous works investigated the topic with interesting results but most of were considering simplified configuration and neglecting the inhomogeneities[2, 3, 4]. The full extend of the SW/MS interaction can only be represented in a three-dimensional (3D) setting, due to the Hall term in the MHD model and the fact that local perturbations can act at a distance through the frozen-in property of the near-Earth plasma[5, 6]. 3D simulations of KHIs at the flank of the MS during northward oriented SW are performed, where different parameters are varied to assess their influence on the growth rate of the KHI and consequent phenomena. These different configurations may have discernible signatures that can be identified by spacecraft diagnostics.

The simulations presented in this article were realized using the parallelised (MPI) Adaptive Mesh Refinement (AMR) Versatile Advection Code [7] simulation toolkit 1. The plasma is described by the resistive Hall-MHD model.

Parameters exploration

Due to the ‘frozen-in’ properties of the plasma, a local perturbation can have repercussions at a distance and the differential advection of field lines along the latitude will induce twisting, creating stressed field lines at on each side of the equatorial plane. Reconnection happens inside these regions, exchanging field lines between MS and SW. This process has been branded double mid-latitude reconnection (DMLR)[5, 6]. The KHI on the equatorial plane is thus the driver for this phenomenon and the quantities looked at are the volume averaged squared $x$-component of the velocity over the domain, which is linked

1 toolkit and manual available in open source at http://gitlab.com/mpi-amrvac/amrvac
to the growth rate, and the maximum of the current $J_{\text{max}}$, as it is always found in the centre of the current sheets. Increasing the density constrast does not affect significantly the growth rate, though it has an optimum around $\Delta \rho = 5$, and it increases the $J_{\text{max}}$ found during the non-linear stage. It also becomes apparent that the density profile carried by the flow can have significant variation depending on $\Delta \rho$, from coherent high density filaments to a fully mixed boundary layer. The addition of a shift between the velocity and density jump has a simple effect on the KHI evolution since the KHI will develop in the initial low or high density area of the simulation. With positive shifts (low density area), the magnetic tension is more important and the initial growth rate is reduced. The KHI finally develops as if there were no density contrast and the DMLR is almost suppressed from the early stage. For negative shifts (high density area), the KHI develops in a region where the magnetic tension is reduced (larger density), hence the larger early growth rate. Moreover, as the KHI starts as SW waves entering the MS, the fact that it develops more from the large density side induces an initial larger inclusion of SW matter into the MS. This in turn induces an enhanced mixing leading to a larger boundary layer. This is an important observation as Claudia Rossi’s thesis[8] shows that this shift happens regularly and there is evidence here that it can lead to two very different results if a spacecraft was to take measurements while crossing the boundary layer. It can be also concluded that the DMLR would be encountered more for a negative shift but mainly at the beginning of the instability, while almost no DMLR would be encountered in the positive shift case except around the late stage of the instability. The full study is published and available[9]

Simulated spacecrafts

In order to validate the model and identify the set of parameters fitting reality the closest, a number of synthetic spacecrafts were integrated in the simulations, namely a Cluster-like formation around the interface and four additionnal ones near the center of each current sheets. When compared to in situ data from Cluster crossing the magnetopause, it can be observed that the DMLR is compatible with the real life phenomenon. The addition of the current sheets spacecrafts allows to predict the profiles that would be encountered away from the equatorial plane during a DMLR and thus to determine specific signatures. However, data taken simultaneously at the equatorial plane and the mid-latitude regions are usually not available, with the consequence that assessment of the occurrence of DMLR at the magnetopause difficult.

References

Space weather event prediction models at CmPA

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Coronal Mass Ejections (CMEs) are large-scale solar eruptive events in which large amounts of plasma (up to $10^{13}-10^{16}$ g) and magnetic field are expelled into interplanetary space at very high velocities (typ. 450 km/s, but up to 3000 km/s). When sampled in situ by a spacecraft in the interplanetary medium, they are termed Interplanetary CMEs (ICMEs). They are nowadays considered to be the major drivers of space weather and the associated geomagnetic activity, causing substantial economic damage. A report from the National Research Council of the National Academies in 2008 estimates that the advent of an event such as the one which occurred in September 1859 (called the Carrington event) would cost today between 1000 and 2000 billion dollars (!) and would take 4 to 10 years in repairs to recover, an order of magnitude more than that of Hurricane Katrina. The average occurrence of such severe events is estimated to once in 100 to 200 years. The ‘normal’ space weather events, however, accumulate to an estimated economic loss in Europe of 10 billion €/year. Therefore, the modeling of CME onset and their interplanetary propagation up to the impact on the Earth’s magnetosphere (affecting the ionosphere, thermosphere, radiation belts, etc.) is a key issue for more reliable space weather forecasts which are provided on a daily basis at regional warning centers, e.g. in Uccle (at the Royal Observatory of Belgium, ROB).

We will discuss 2.5D (axi-symmetric) magnetic flux rope models and 2.5D and 3D self-consistent magnetohydrodynamics (MHD) simulation models for the onset of CMEs under solar minimum conditions, and for their interaction with coronal streamers and subsequent evolution up to 1AU. Observations are used to constrain the models by providing initial and boundary conditions. These solar observations, as well as the resulting characteristic plasma parameters they produce at 1AU compared to (ACE) observations, provide excellent tools to validate the models. These advanced CME models have been integrated in the new physics-based forecasting-targeted inner heliosphere model Euhforia (‘European heliospheric forecasting information asset’), we are developing. We are in the process of validating the model by comparing with observational data of a selection of well-documented cases as well as with ENLIL results. The current state-of-the-art will be reviewed.
Observations of astrophysical jets show evidence of a structure in the direction perpendicular to the jet axis. Most two-component jets are believed to consist of a highly relativistic inner and a slower – but still relativistic – outer part, surrounded by an unmagnetized environment. These jets can be susceptible to a relativistic Rayleigh-Taylor-type instability that decelerates the jet. We simulate such a scenario also including a non-zero toroidal magnetic field with different values of magnetization $\sigma$. Above a certain level of magnetization, the toroidal field can stabilize the jet against these instabilities and the deceleration of the jet is constrained.

Introduction

Astrophysical jets have been extensively observed and studied on multiple scales, ranging from young stellar object jets (YSO jets) and gamma ray bursts (GRBs) to active galactic nuclei jets (AGN jets). The formation, acceleration and collimation of jets was addressed in the beginning analytically and (relatively) recently via numerical simulations, in different regimes, ranging from simple hydrodynamic (HD) to relativistic and general relativistic magnetohydrodynamics (RMHD and GRMHD). AGN and GRB jets are relativistic, with Lorentz factors of $\gamma \sim 10$ and $\gamma \sim 100$ respectively, while YSO jets are non-relativistic, with typical velocities of $\sim 100$ km/s. It has also been argued that astrophysical jets are not always homogeneous but rather display a structure in the direction perpendicular to the jet axis. This structure has been observed in terms of velocity ([2, 3]) and is believed to exist in different scales, ranging from YSO to AGN jets. We try to examine the effect of this structure to the transverse jet stability and specifically focus on non-axisymmetric instabilities induced by differential rotation, as described in [5, 6].

Initial conditions

We examine a relativistic, two-component jet in which the two parts of the outflow are differentially rotating, with an initial toroidal velocity profile as follows:

$$V_\phi(R) = \begin{cases} 
 v_{\phi in} \left( \frac{R}{R_{in}} \right)^{\alpha_{in}/2}, & R \leq R_{in} \\
 v_{\phi out} \left( \frac{R}{R_{in}} \right)^{\alpha_{out}/2}, & R_{in} < R < R_{out} 
\end{cases}$$

(1)

where $\alpha_{in} = 0.5$, $\alpha_{out} = -2$ and $v_{\phi in} = v_{\phi out} = 0.01$ (normalized to the speed of light and $c = 1$). The outer radius of the jet is set to $R_{out} = 0.1$ pc (implied by [1] for M87).
and we arbitrarily chose $R_{in} = R_{out}/3$. We assume that the Lorentz factor for the inner & outer component is $\sim 30$ and $\sim 3$ respectively, meaningful values for AGN jets ([1]). The density ratio between the components is $\frac{\rho_{out}}{\rho_{in}} \sim 10^4$, with values corresponding to a kinetic luminosity flux of $10^{46}$ ergs/s. The poloidal magnetic field is constant in each part of the jet and the toroidal magnetic field component has the same form as (eq. 1). We examine the case of a kinetically dominated jet, so we focus on values of magnetization $\sigma = \frac{B_\phi^2}{\rho p} < 1$. Finally, we assume a total pressure equilibrium in every interface (inner & outer jet, outer jet & external medium). The inner jet is relativistically hot, with an effective polytropic index of $\Gamma = 4/3$ and the outer jet is cold, with $\Gamma \approx 5/3$.

We perform 2.5D simulations using a cartesian domain of size $-0.3 \text{pc} < x, y < 0.3 \text{pc}$, where the base resolution is set to $128 \times 128$ with 3 levels of adaptive mesh (AMR). In all cases we assume a Synge type equation of state and we use a third order limiter and an hllc solver. The simulations are performed using the relativistic MHD module from the open source, parallel, grid adaptive, MPI-AMRVAC code ([4, 7]).

Results & Conclusions

We perform 2.5D simulations of relativistic, two component jets, assuming differential rotation and a toroidal magnetic field component of different magnitude in each case, with parameters corresponding to AGN jets. Depending on the choice of the maximum magnetization, we result in a different final state, in terms of mixing between the components, the average Lorentz factor and the effective radius of the jet. For low $\sigma$ ($\leq 0.01$), the centrifugal force is dominant and the jet decelerates to an average Lorentz factor of $\sim 11$ for $\sigma = 0.1$. We notice strong mixing between the two jet components, which ultimately leads to a non-collimated, decelerated outflow. Moreover, the effective radius of the jet increases with time. Increasing the magnetization (and thus the magnetic tension), the deceleration is less prominent, with an average Lorentz factor of $\sim 22$ for $\sigma = 0.1$. For higher $\sigma$, we also notice that the two components remain distinguishable (almost no mixing) and the jet is still collimated. We also examine two asymptotic cases: a slower inner jet ($\gamma \approx 10$) or a very slow rotation ($v_\phi \sim 10^{-6}$). In the first case, the inertia of the inner jet is reduced, while the second case greatly reduces the centrifugal force. In both scenarios, the jet is very stable, even for very low values of magnetization.

References

Parallel Session (14:15 – 18:00)
Atoms, Molecules, Optics and Photonic
Chairman: Prof. Pascal Quinet (UMONS)
I will discuss the physics at work for Bose gases in optical lattice. In the first experiment, we realize a distributed Bragg reflector for matter waves [1], and a matter wave cavity using the concept of spatial gaps [2,3]. The second experiment provides a method to directly measure the tunneling delay time in an optical lattice [4]. In the third experiment, we modulate the phase of the optical lattice to renormalize the tunneling rate and observe the emergence of a phase order in space for which the neighbouring wells have opposite phases. We report on the nucleation of this new quantum phase.

References
Snake instability of dark solitons in superfluid Fermi gases

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In this work, we study the snake instability mechanism for dark solitons in superfluid Fermi gases in the context of a recently developed effective field theory [1]. We perturb the nodal plane of the stable soliton solution by adding a transverse modulation and estimate the instability growth rate and the maximal radial size that the atomic cloud can have in order to preserve the stability. The analysis of the effect of spin-imbalance on this critical size reveals a stabilization of the soliton with increasing imbalance.

Introduction

The properties and features of superfluid Fermi gases have been the subject of a great deal of theoretical and experimental research. A considerable amount of this attention has been focused on the study of dark solitons, localized density dips that propagate on a constant background. While dark solitons are stable in 1D configurations, it has been observed both theoretically and experimentally that solitons in superfluid systems with a finite radial width decay through the so called snake instability mechanism. This instability causes the depletion plane of the soliton to oscillate in the direction transverse to the plane until it decays into one or multiple vortex-structures.

In our recent work [2], we have investigated the snake instability mechanism by means of a recently developed finite temperature effective field theory [1], which has already proven suitable to study dark solitons in 1D Fermi superfluids across the BEC-BCS crossover. This theory has the advantage of being applicable in an extended range of temperatures and easily incorporates the possible presence of a population-imbalance between the spin-components of the Fermi gas.

Methodology

From the effective field action functional for the superfluid order parameter \( \Psi \) of the ultracold Fermi gas, we obtain an equation of motion for the pair field that can be solved exactly for the case of stable solitons in a 1D configuration [3]. To describe the deformation of the soliton plane that leads to its decay, we add to the stationary 1D soliton solution a transverse perturbation which is assumed to consist of a combination of wave-like deformations of the soliton’s depletion plane. Inserting this perturbed solution into the equation of motion and performing an expansion around the stationary solution up to first order in the perturbation leads to a system of coupled nonlinear differential equations in the perturbation amplitudes. The associated eigenvalue problem for the perturbation frequency can then be solved numerically to identify the unstable modes of the soliton.
Main results

Based on the instability dispersion relations we can estimate the maximal radial width the condensate can have in order for the soliton to be stable. When comparing the EFT predictions with the outcomes of previous theoretical studies, we do not only find a good agreement with the available results on both the BEC- and BCS-side of the interaction regime, but we also observe that our results seem to be the only ones at present to correctly characterize the change of the relevant length scale from the healing length in the BEC limit to the coherence length in the BCS regime.

Furthermore, an analysis of the effect of imbalance between the different spin populations on the instability of the soliton reveals that the presence of spin-imbalance increases the maximal width of the condensate for which the soliton is expected to be stable. This prediction could provide the experimental community with a new method to stabilize solitons in ultracold 3D Fermi gases, without reducing the system dimensionality.

References


About the structure of a vortex in superfluid atomic gases

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The goal of this talk is to study several aspects of vortices in superfluid atomic gases. At the beginning of the talk a brief introduction to superfluidity and vortices is given, underlining the general properties of the single-vortex state. First the radial structure is discussed, for which usually the hyperbolic tangent is used as a variational model. Next the angular structure is studied, looking at elliptical deformations of the vortex core. The talk is concluded with a discussion of the radial oscillation modes of the vortex core.

Introduction: Why superfluid vortices in atomic gases?

The superfluid state is characterized by a quantization of the circulation; this results in individual, singly quantized vortices with a circulation equal to $\frac{h}{m}$. The physics of these vortices is paramount for the description of superfluidity. On one hand the spontaneous creation of vortex-anti vortex pairs will result in the destruction of the superfluid condensate; also known as the Berezinskii-Kosterlitz-Thouless phase transition. On the other hand the vortices can be created by the rotation of the superfluid (either direct or using a gauge field), where an excess of vortices again destroys superfluidity; this is equivalent to loss of superconductivity in a type-II superconductor due to a strong magnetic field. In both cases a accurate description of the individual vortex core structure is needed in order to get reliable results. The above yields the motivation for the thorough study of the vortex structure, presented in this talk.

Superfluid atomic gases (or quantum gases) on the other hand are a versatile playground for thoroughly testing the physics of superfluids. Due to the high tuneability it is possible to experimentally implement a wide range of idealized model systems. Using an effective field theory[1], the TQC research group is able to describe these superfluid atomic gases theoretically. The effective field theory yields the possibility to see how the different vortex structures change for different experimental regimes. In the study of the single-vortex structure both the radial and angular structure of a vortex will be tested. A primer to superfluidity, the formation of vortices and the Kosterlitz-Thouless phase transition can be found in Ref. [2].

The radial structure of a vortex

A frequently made assumption when studying superfluid vortices is that the macroscopic wave function $\Psi(r)$ is of the form $\Psi_{\infty} f(r) e^{i\phi}$; with $\Psi_{\infty}$ the bulk-value of the condensate, $f(r)$ the vortex core profile and $(r,\phi)$ polar coordinates. Moreover for the radial dependence of the vortex structure the commonly used variational model is given by $f(r) = \tanh(\frac{r}{\sqrt{2} \xi})$. 

As a first part of the study of the vortex core structure this hyperbolic tangent was tested against the true (numerical exact) vortex core structure. From this analysis the conclusion that the hyperbolic tangent indeed yields an accurate fit for the circular single-vortex structure can be drawn. The article with results can be found in Ref. [3].

The angular structure of a vortex: Vortex core deformations

Next to a radial structure, a vortex can also have an angular structure. An angular structure corresponds to a deviation from a perfectly circular vortex shape, as was assumed in the previous. In this first simple approach an elliptical deformation is introduced (figure on the right). Where the elliptical core is described by the orientation (or angle $\theta$) and the streching (given by the ratio $\xi_x/\xi_y$).

Using this extension to the variational model mentioned above, it is possible to look for experimental setups in which a vortex core deformation will be expected. This type of deformation has not yet been studied within the frame of superfluid atomic gases. The motivation to study this type of vortex structures comes from a similar study in superconductors, see Ref. [4]. In superconductors the elliptical deformation resulted in an attractive component in the inter vortex potential, leading to a variety of experimentally seen vortex patterns. The goal of this research is to see whether the same phase diagrams can be constructed for vortex patterns in superfluid atomic gases using the effective field theory. We present our recent progress on this topic.

Vortex oscillations in Bose-Einstein condensates

The talk is concluded with a discussion on the radial oscillations of a vortex core. Since vortex cores have a finite size in atomic gases, it is to be expected that oscillations of this core will have a finite energy. In this study the energy of the radial oscillations is estimated and compared to the well known axial oscillations (or Kelvin modes). We conclude that the energy of the radial oscillations is still higher than the Kelvin modes, making the Kelvin modes still the preferred oscillation mode of the vortex core [5].

References

How can classical particles be in a non-classical state?

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In the last decade, there has been considerable advancement in the study of pre- and postselected quantum measurements. In the field of quantum paradoxes, these measurements point out phenomena that classical physics cannot explain. The three-box paradox has been studied with particular interest \cite{1} and it results from the certitude to find a single particle in two separated boxes. Another surprising discovery was the appearance of weak values in the description of experimental results associated to pre- and postselected ensembles during weak measurements \cite{2}. Weak values are unusual expectation values of an observable which can be complex or far outside the range of the eigenvalues.

In our research, the three-box paradox is recast in a new form, which involves quantum entanglement. To do this, the three-level quantum states involved in the paradox are transformed by the Majorana representation to symmetric states of two qubits. Thus, we present a two-particle version of this three-box paradox, where the particles are pre- and postselected in classical separable states, but are necessarily found in entangled intermediate states when opening one amongst two of the three boxes. In this representation of the paradox, an observer comes to opposite conclusions about the entanglement state of the particles. In the past, some authors investigated this paradoxical behavior with weak measurements and weak values. Similarly, we study these weak values by their polar form (modulus and argument) in terms of three dimensional vectors on the Bloch sphere \cite{3}. These investigations emphasize the non-classical origin of the recast paradox.

Sturmian bases for two-electron systems in hyperspherical coordinates

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We give a detailed account of an ab initio spectral approach for the calculation of energy spectra of two active electron atoms in a system of hyperspherical coordinates. In this system of coordinates, the Hamiltonian has the same structure as the one of atomic hydrogen with the Coulomb potential expressed in terms of a hyperradius and the nuclear charge replaced by an angle dependent effective charge. The simplest spectral approach consists in expanding the hyperangular wave function in a basis of hyperspherical harmonics. This expansion however, is known to be very slowly converging. Instead, we introduce new hyperangular sturmian functions. These functions do not have an analytical expression but they treat the first term of the multipole expansion of the electron-electron interaction potential, namely the radial electron correlation, exactly. The properties of these new functions are discussed in detail. For the basis functions of the hyperradius, several choices are possible. In the present case, we use Coulomb sturmian functions of half integer angular momentum. We show that, in the case of H, the accuracy of the energy and the width of the resonance states obtained through a single diagonalization of the Hamiltonian, is comparable to the values given by state-of-the-art methods while using a much smaller basis set. In addition, we show that precise values of the electric-dipole oscillator strengths for S→P transitions in helium are obtained thereby confirming the accuracy of the bound state wave functions generated with the present method.

Our main objective is to use this spectral approach to solve the time-dependent Schrödinger equation to treat the interaction of atoms with strong laser fields. Within this context, this approach has two major advantages. First, it can be generalized easily to the treatment of atomic systems with more than two active electrons. Indeed, the atomic hamiltonian keeps exactly the same structure as for atomic hydrogen in which the electrostatic potential is replaced by an effective charge function of various hyperangles divided by the hyperradius. Second, irrespective of the number of active electrons, there is always only one coordinate, namely the hyperradius, which is unbound. This makes easier the implementation of various methods such as t-SURFF [1] and the time-scaled coordinate method [2,3] aimed at extracting from the final many electron wave packet the information on the electron energy spectra.

References
Parallel Session (14:15 – 18:00)
Biological, Medical, Statistical, and Mathematical Physics
Chairman: Prof. Yves Gossuin (UMONS)
The Physics of cancer: new targets for nanomedicine?

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Cancer cells sense and respond to mechanical cues in tumors. Mechanobiology has recently emerged as a key determinant in malignant tumor development and progression involving complex cellular crosstalk mechanisms. The majority of mechanical stimuli stem from the tumor microenvironment (TME). Indeed, the TME represents a dynamic and evolutive niche comprising supportive stromal cells, soluble factors, vascular networks and the structural extracellular matrix (ECM) architecture to provide a tumor permissive soil. Tumors are now considered as a complex and constantly evolving ecosystem, strongly dependent on its physical and structural properties. Particularly, tumor stiffening, which stems from aberrant production and organization of extracellular matrix has been considered a predictive marker of tumor malignancy. Moreover experimental evidences suggest that tumor rigidity and altered mechanics are, per se, key modulators of tumor progression. In addition to biological outcomes, the tumor microenvironment and its physical anomalies also dramatically affect the efficiency of anticancer treatment. The aberrantly abundant and dense ECM, high interstitial pressure, chaotic vessel organization, enhanced solid stress are physical features of the TME that dramatically restrict the transport of cytotoxic therapeutic agents to the tumor cells.

Accordingly, the tumor microenvironment and its physical anomalies are becoming the target for new treatments. A new paradigm shift is the investigation of physically triggered nanotherapies to tackle physical tumor microenvironment barriers. Our group has recently shown that thermal therapy induced by nanoparticles denatures tumor stroma and softens the tumor, directly impacting on tumor permeation properties and drug/nanoparticles penetration. We evaluated the therapeutic efficacy of the photothermal therapy (PTT) mediated by carbon nanotubes by correlating tumor growth, stroma integrity and mechanical properties. At the macroscopic level, ultrasound elastography was used to assess mechanical stiffness of the tumor tissue during and after the PTT treatment. We demonstrated that tumor stiffening can be reversed by nanohyperthermia. Softening of the tumor by nanoparticle-mediated local hyperthermia could be a promising adjuvant therapy to normalize the mechanical properties of the tumor and increase the penetration of therapeutic drugs, thereby diminishing resistance to current treatments in solid tumors.


Linear and Non-Linear Fluorescence Investigation of a Beetle’s Photonic Structure

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Many living systems found in nature are known to give rise to fluorescence emission when they are illuminated by ultraviolet light. The origin of such light emission is the presence of fluorophores embedded in the biological materials. The confinement of fluorophores in photonic structures leads to modifications of fluorescence properties such as the intensity and the spatial distribution. Using linear and non-linear fluorescence techniques, we investigate here the case of the Hoplia coerulea beetle. The photonic structures found on its body comprise fluorophores. These structures control both the insect’s colouration and fluorescence. Contact with liquids gives rise to variations of the emission properties. The combination of linear and non-linear fluorescence techniques offers unique possibilities to investigate the effects of the local environment on, respectively, the real and virtual excited states of the fluorophores.

Introduction

Natural photonic materials such as found in many animals including insects, birds or fish are known to exhibit a large variety of optical properties, among which coherent scattering leading to structural colours \cite{1} and fluid-induced colour change \cite{2}. These properties are due to photonic structures made of biopolymers. Clearly, these biological devices challenge the human imagination that has at its disposal a wide range of materials but is limited so far to the design of comparatively rather simple structures. Besides, fluorescence is found in a lot of living systems including arthropods (e.g., butterflies, beetles and scorpions), fish or plants \cite{3-5}. These organisms emit visible light when they are illuminated by UV light. This phenomenon is due to fluorophores embedded within the biological materials constituting the living organisms. The confinement of fluorophores in natural photonic structures enables the so-called controlled fluorescence, which is known to lead to modifications of fluorescence properties such as the intensity and the spectral distribution of emission \cite{3-5}. Upon contact with liquids, variations in the fluorescence emission were observed in the linear regime \cite{5} while in the non-linear regime, the effects of the surrounding environment on emission are significantly smaller.

Controlled fluorescence in a natural photonic structure

In this work, the case of male \textit{H. coerulea} beetle was investigated. This species displays an iridescent blue-violet colouration \cite{2} due to photonic structures located in the circular scales covering its body (Fig. 1a). These structures contain embedded fluorophores and control their emissions \cite{4,5}. Thanks to electron microscopy, the structures that control
the fluorescence emission in these living organisms were identified. It was approximated by a 1D photonic crystal. Measurements of the emission and excitation spectra from the beetle’s elytra in dry state and upon contact with water allowed to observe a blue-shift of the emission peak wavelength of the elytra upon contact with water whereas the reflectance peak wavelength was measured to red-shift [2,5]. Following these measurements, optical simulations performed with models elaborated on the basis of the electron microscopy observations allowed to relate the structures’ morphologies to the measured optical and fluorescence properties [5]. In addition, time-resolved measurements of the fluorescence intensity, together with optical simulations of the optical local density of states, confirmed that the radiative emission is controlled by a naturally engineered photonic bandgap [5]. Conventional fluorescence microscopy (Fig. 1b) and, for the first time in the context of the investigation of insects’ fluorescence, two-photon excitation and Second Harmonic Generation (SHG) microscopies (Fig. 1c,d) were used to compare the effects of the presence of liquids on real and virtual exited states. Conventional fluorescence was found to be much more sensitive to the surrounding environment than two-photon excitation microscopy.

![Image]

**Conclusion**

In addition to displaying a structural blue-violet colouration, male *H. coerulea* beetle is a specifically interesting example of fluorescence emission controlled by natural photonic structures through the confinement of fluorophores within these structures [5]. This variety of structures and optical effects found in nature and optimized for millions of years of evolution allows the elaboration of new concepts and devices through a bioinspiration approach in order to develop industrial and technological applications such as LED, VCSEL diodes, solar cells, sensors or biosensors.

**References**

Interactions of aqueous imidazolium based ionic liquid mixtures with solid-supported biomimetic membranes

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Despite the environmentally friendly reputation of ionic liquids (ILs), their safety has been recently questioned given their potential as cytotoxic agents. The fundamental mechanisms underlying the interactions between ILs and cells are less studied and by far not completely understood. Biomimetic films are here important biophysical model systems to elucidate fundamental aspects and mechanisms relevant for a large range of biological interaction ranging from signaling to drug reception or toxicity. Here we use dissipative quartz crystal microbalance QCM-D to examine the effect of aqueous imidazolium-based ionic liquid mixtures on solid-supported biomimetic membranes. Specifically, we assess in real time the effect of the cation chain length and the anion nature on a supported vesicle layer of the model phospholipid DMPC. Results indicate that interactions are mainly driven by the hydrophobic components of the IL, which significantly distort the layer and promote vesicle rupture. Our analyses evidence the gradual decrease of the main phase transition temperature upon increasing IL concentration, reflecting increased disorder by weakening of lipid chain interactions. The degree of rupture is significant for ILs with long hydrophobic cation chains and large hydrophobic anions whose behavior is reminiscent of that of antimicrobial peptides.

References
Electron paramagnetic resonance as a tool for studying dye-decolorizing peroxidases

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Dye-decolorizing peroxidases (DyPs) are heme \textit{b} containing proteins, able to degrade a wide range of substrates including bulky textile dyes and lignin. It makes them suitable for a variety of industrial applications such as waste water treatment. Here, electron paramagnetic resonance (EPR) is used to probe the electronic and geometric structure of the heme site in the different catalytic states of the enzyme.

Dye-decolorizing peroxidases

Dye-decolorizing peroxidases (DyPs) occur in the genomes of several fungi and bacteria and can be divided into three distinct classes (A, B, C). They belong to the peroxidase-chlorite dismutase superfamily as they express a ferredoxin-like fold to which the heme group is linked by a histidine residue [1]. In their enzymatic cycle, DyPs first reduce \( \text{H}_2\text{O}_2 \) to form the active Compound I (Cp I) state consisting of an oxoiron(IV) porphyril radical. However, as a result of a long range electron transfer, a protein-based radical is proposed as well since this would facilitate degradation of bulky substrates at the protein surface. Subsequent one-electron oxidation of two substrate molecules brings the enzyme back to its resting state [2, 3].

A B-type DyP from \textit{K. pneumoniae}

Here we have studied KpDyP, a class B enzyme from the bacterium \textit{Klebsiella pneumoniae}, which has been expressed recombinantly in \textit{E. coli}. Both steady-state and presteady-state kinetic studies demonstrated that (i) Cp I can be formed with equimolar \( \text{H}_2\text{O}_2 \), (ii) is extremely stable and (iii) does not react with typical DyP substrates or artificial peroxidase electron donors. This challenges the hypothesis that KpDyP follows the conventional peroxidase cycle in which the formation of the Cp I state is followed by the reduction steps.
EPR as our main tool

Electron paramagnetic resonance (EPR) enables us to study the environment of a paramagnetic center exploiting the Zeeman effect. Since the resting state enzyme consists of a high-spin Fe(III) and the Cp I of a porphyrin radical, EPR is highly suited to probe this type of proteins during the different steps of their enzymatic cycle. Moreover, site-directed mutations were used to examine the influence of the distal residues Arg232 and Asp143 on the heme iron. Multi-frequency continuous-wave and pulsed EPR were used to gain insight into the heme site architecture in the resting state ferric forms and the radical formed in the Cp I state.

References


Parallel Session (14:15 – 18:00)
Condensed Matter and Nanostructure Physics
Chairman: Prof. Bjorn Maes (UMONS)
Colloidal semiconductor nanocrystal: From single objects to artificial solids

C. Delerue

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Semiconductor nanocrystals (NCs) can be presently synthesized with a plethora of sizes, shapes and compositions thanks to the development of colloidal chemistry approaches. NCs have received huge attention because their electronic and optical properties can be tuned just by changing their size. This tunability results from the effect of the quantum confinement on the electron states. As a consequence, the NCs are often considered as artificial atoms because their electronic spectra are characterized by discrete energy levels. Promising applications of these NCs have emerged such as solar cells, optical displays, photo-detectors and molecular sensing [1]. In this context, it is particularly tempting to (self)-assemble NCs to realize new materials with tailored properties. In this talk, I will review recent developments in this field. Conventional arrays of NCs are simply coupled through the (in)organic ligands that saturate their surface. My presentation will focus on more advanced materials, i.e., almost perfectly crystalline 2D superlattices synthesized by oriented attachment of NCs [2,3,4], which have potentially much better electrical properties [5]. I will also present theoretical studies showing that, by combining the original band structure of the bulk semiconductor and the effects of the nano-structuring, these materials could be characterized by exotic band structures, including Dirac cones, flat bands, band touching points and topological bandgaps [6].

References

Atomic collapse in graphene quantum dots

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Graphene is a 2D material in which the carriers behave relativistically offering very interesting thermal and electrical properties. In this paper a graphene quantum dot with a Coulomb impurity is studied. The addition of this impurity induces two very distinct regimes: the subcritical and supercritical regime. We show here that the behaviour of the electronic states turns out to be very different between the two regimes. This suggests that the analogue of the relativistic atomic collapse occurs in graphene quantum dots.

Introduction

The atomic collapse with heavy nuclei, having a large atomic number \( Z \), is a well-studied problem in quantum electrodynamics (QED). Solving the Dirac equation for an atomic nucleus, treated as a point charge, gives the energy of the 1S atomic bound state, \( E_{1S} = m_e[1 - (Z\alpha)^2]^{1/2} \), where \( m_e \approx 511 \text{ keV} \) is the electron rest mass and \( \alpha \approx 1/137 \) the fine structure constant. Beyond \( Z_c \alpha = 1 \), i.e., \( Z_c \approx 137 \), the energy of the 1S state becomes imaginary. This collapses the wave function and the bound state ceases to exist. However, taking into account the finite size of the nucleus truncates the Coulomb potential and removes the divergence. This extends the stability of the 1S state up to a new critical value \( Z_c \approx 170 \). The range of stability \( Z < Z_c \) is referred to as the subcritical regime and that for \( Z > Z_c \) as the supercritical regime. In the latter the electron state leaves the discrete spectrum and tunnels into the positron continuum. (see left Fig. 1) That is, the bound state acquires a finite lifetime and becomes a narrow resonance. This is referred to as the atomic collapse. A stable nucleus with \( Z > 170 \), not found in nature, is possible to realize, for a very short time, in high-energy collisions of very heavy ions but experiments with uranium atoms provided no direct proof of the expected supercritical positron emission.

The difficulties mentioned above can be drastically alleviated in graphene in which the charge carriers (electrons) are massless and exhibit relativistic behaviour with the speed of light replaced by the much smaller Fermi velocity \( v_F \approx c/300 \). This leads to the same atomic collapse physics of QED but at a much smaller energy scale and in two dimensions (2D). The effective fine-structure constant becomes \( \alpha_g = c/v_F \kappa \approx 2.2/\kappa \approx 1 \), where \( \kappa \approx 2.5 \) is the dielectric constant of graphene with its 3D environment. Correspondingly, the critical charge \( Z_c \) is expected to be much smaller, i.e. of the order of unity, and the energy scale changes from MeV to sub-eV. Accordingly, charged impurities in graphene could play the role of supercritical nuclei. The recent observations of the expected resonances around artificial nuclei and the realization of tunable artificial atoms at supercritically charged vacancies in extended graphene sheets confirmed the analogue of the QED atomic collapse and gave new impetus for further studies. Given that graphene is experimentally accessible, one can further study this analog of the atomic collapse by varying other...
parameters such as back-gate voltage, defects, influence of a magnetic field, etc., and better understand confinement in graphene. Motivated by these results on bulk graphene, we study the influence of confinement on the atomic collapse by placing a Coulomb impurity in a gapped or gapless graphene quantum dot (QD) and investigate how the usual bound states induced by the dot are modified upon varying the impurity strength. QDs in graphene have been the subject of a considerable number of theoretical and experimental studies. QDs in monolayer graphene (MLG) have been fabricated by direct etching of pristine graphene sheets into small flakes. In these structures the shape and edges of the sample can strongly influence the confined states. The electronic and transport properties of such QDs with different shapes and edges have been investigated extensively.

**Figure 1:** Left figure: first 5 bound states of an atom plotted as function of the strength of the nucleus charge. Above some charge the bound states dive into the hole continuum and cease to exist. Figure adopted from Ref. [?]. Right figure: in this figure all the bound states are plotted for the angular momenta $m = 0$ (blue), $m = -1$ (red) and $m = 1$ (green). It can be clearly seen that the behaviour of the bound states is very different in the case when $|m + 1/2| > Z\alpha$ (subcritical regime) compared to when $|m + 1/2| < Z\alpha$ (supercritical regime). For the $m = 0$ and $m = -1$ states the boundary between the two regimes is at $Z\alpha = 0.5$ for the $m = 1$ state it is at $Z\alpha = 1.5$.

**Atomic collapse in circular quantum dots**

We studied the problem of a Coulomb charge at the centre of a circular graphene QD with a ZZBC or IMBC. Within a continuum approach we considered both a point-size and a finite-size impurity, obtained analytical expressions for the wave functions, and derived expressions for the energies. Due to the confinement of carriers in a finite-size QD, we found discrete real energy states in both the subcritical ($Z\alpha < |km + 1/2|$) and supercritical ($Z\alpha > |km + 1/2|$) regimes, with $k = \pm 1$ distinguishing the $K$ and $K'$ valleys and $m$ the angular momentum label. This is in contrast with the case of a Coulomb impurity in a bulk graphene sheet where the eigenvalues are complex in the supercritical regime. However, we found that the wave functions start to oscillate near the Coulomb impurity in the supercritical regime indicating atomic collapse in graphene QDs. In this regime the lowest electron state for each $m$ turns into a hole state and the spectrum shows anticrossings between the energy levels. We further demonstrated that the energy levels have a $1/R$ dependence in the subcritical regime. This dependence no longer exists in the supercritical regime and the levels decrease as function of $R$ in a nonmonotonic manner showing the signature of atomic collapse in graphene QDs.
References

Exciting Fano resonances in structured hyperbolic metamaterials

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Interplay between a slowly varying background and a narrow resonant process gives rise to Fano resonances, scattering phenomena with typical asymmetric line-shape. We show Fano resonance excitation in multilayered hyperbolic metamaterials thanks to interference between a propagating and an evanescent mode inside a slanted cavity. Because of the extremely high value of the effective indices, this features is also useful for ultra-compact subwavelength cavities as small as 5 nm.

Introduction

Metamaterials are engineered materials with subwavelength features that allow to control light in a way that is impossible with natural optical materials [1, 2]. Among them, there is a large interest in hyperbolic metamaterials (HMMs) because of their multiple interesting properties such as a very large density of states [3], extreme refractive indices and negative refraction [4]. Periodic stacks of subwavelength metallic and dielectric are the typical structures with these properties. In this work, we show the possibility to excite Fano resonances inside cavities based on slanted hyperbolic periodic stacks. Interference between a slowly varying background and a narrow resonant process is the key for their excitations [5].

Results

We numerically investigate (with finite element method) the scattering properties of light for normal incidence along the x direction ($k_y = 0$) of a HMM with a finite cavity made of tilted layers in the center (inset of Fig. 1). The tilted section is referred to as an “asymmetric hyperbolic metamaterial” (AHM). We use silver (Ag) as the metal with a lossless Drude model and a dispersionless TiO$_2$ as dielectric with $n_{TiO_2} = 2.7$. The thickness of Ag layers is 10 nm and 20 nm for TiO$_2$. The conservation of the transverse momentum at the interface between the HMM and AHM implies that both an evanescent and a propagative mode are excited inside the cavity. The interferences between these two modes are responsible for the asymmetric Fano resonances appearing in Fig. 1. Indeed, the evanescent wave gives rise to a slowly varying background while the propagative mode generates the narrow Fabry-Perot oscillations. Thanks to the very high value of the effective index of the propagative mode inside the cavity, we can design very compact cavities as small as 5 nm that still have the Fano resonances. We can show that these resonances survive even in presence of losses in the metal [6].
Figure 1: Reflection map at normal incidence ($k_y = 0$) in function of the tilt angle $\alpha$ and the length of the tilted layers. Inset shows the geometry of the structure under study.

References


Effective field theory and vortices in rotating multi-component Fermi superfluids

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In the present work, integer and fractional vortex states are investigated for a rotating two-band Fermi gas in the BCS-BEC crossover confined to a parabolic trapping potential, using the recently developed finite-temperature effective field theory \cite{1}. The study is aimed to reveal novel observable features which appear due to interband interactions.

Vortices in multiband superconductors and in rotating Fermi condensates are a subject of an intense experimental and theoretical study recent years. Multiband condensates represent a specific interest due to a rich variety of observable phenomena, such as fractional vortex states. The goal of the present investigation is to reveal novel vortex phenomena which can appear in a two-band Fermi gas, that are arguably easy to verify experimentally. Here, the finite-temperature effective field theory (EFT) developed in Refs. \cite{2, 3} is applied to vortices in a two-band Fermi gas with the s-wave pairing. The fermion system is confined to a cylindrically symmetric parabolic trapping potential. The stabilization of vortices is achieved by rotating the fermionic system. As distinct from the one-band system, a rich spectrum of vortex states is realizable in a two-band Fermi gas. Fractional vortices (the states with different winding numbers in the two band-components of the condensate) are stable in this system for sufficiently weak interband couplings. When the interband coupling exceeds a critical value, which is dependent on the frequency of rotation, only integer vortices and vortex clusters can be found.

Fig. 1 shows the vortex phase diagrams for the canonical ensemble with the numbers of particles per unit length (along the \textit{z} direction) \(N_1 = N_2 = 500\). The boundaries of the areas of stability for different vortex configurations exhibit a non-monotonic dependence on the rotation frequency and the reentrant dependence as a function of the temperature. The explanation of this bendover behavior of critical rotation frequencies is related to a decrease of a radius of the superfluid core for a trapped Fermi gas when the rotation frequency becomes close to the confinement frequency.

We have found that the grand canonical ensemble (when the numbers of particles \(N_1\) and \(N_2\) are determined from the common chemical potential) is more favorable than canonical one for fractional vortices. This difference is explained by the effect of a depletion of a “weak” band \cite{3}, which is a feedback of the gap parameter to the relative band populations.

In a one-band system, the sequence of different vortex configurations in phase diagrams is such that the areas of stability for higher winding numbers lie completely inside the areas of stability for lower winding numbers \cite{1}. For a two-band system, this ordering of vortex states can be violated. At \(T < T_{c,2}\) we can observe the “normal” sequence of stability areas, where integer vortex configurations change to fractional states with an
increasing temperature. For \( T > T_{c,2} \), the “anomalous” sequence becomes possible, where fractional states change to integer states when temperature rises.

The obtained manifestations of the non-monotonic behavior of the healing length in the “weak” band-component of the condensate through kinks of phase boundaries and the “anomalous” resonant sequence of stability areas in vortex phase diagrams can be experimentally accessible.

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**References**


Novel emergent inhomogeneous phases in coupled electron-hole bilayer graphene sheets

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Recently proposed accurate correlation energies are used to determine the phase diagram of strongly coupled electron-hole graphene bilayers. In addition to the electron-hole superfluid phase we find two new inhomogeneous ground states, a one dimensional charge density wave phase and a coupled electron-hole Wigner crystal which are completely determined by the electrons and holes interacting through the Coulomb interaction. The experimental parameters for the new phases lie within attainable ranges and therefore coupled electron-hole bilayer graphene presents itself as an experimental system where novel emergent many-body phases can be realized.

Coupled electron-hole bilayer graphene sheets

We propose two strongly coupled two-dimensional (2D) bilayers of graphene (BLG), one bilayer containing electrons and the other holes, as an experimentally accessible system to observe a strongly-coupled one-dimensional CDW (1D-CDW) and a coupled electron-hole Wigner crystal (c-WC) besides the superfluid phase discussed in Refs. [1, 2]. This system is currently attracting a lot of experimental interest, for examples see the recent works in Refs. [3, 4]. An electron and hole BLG has a quadratic low energy dispersion around and the electron and hole densities are controlled by top and back metal gates. The electric field from the metal gates opens up an energy band gap between the parabolic conduction and valence bands. We consider BLG embedded in a hexagonal Boron Nitride (h-BN) dielectric which is important to ensure high charge mobility and a large potential barrier between the graphene bilayers. The separation barrier between the bilayer sheets can be as little as \( d = 1 \) nm with no significant leakage from tunneling.

Methods

In a recent work [5], a new and fast interpolation scheme was introduced to obtain accurate correlation energies for the one-layer 2DEG. The method gives excellent agreement with quantum Monte Carlo correlation energies for both one-valley and two-valley two-dimensional-electron-gas systems.

In this approach the correlation energy \( E_c[ρ] \) is determined by an interpolation of \( W_α[ρ] \), the potential energy functional of \( ρ \) without the Hartree contribution, of a fictitious system that interacts with a Coulomb interaction scaled by a coupling constant factor \( α \). The interpolation is between \( W_{limα=0}[ρ] \) (weakly-interacting) and \( W_{limα=∞}[ρ] \) (strongly-interacting)[6],

\[
E_c[ρ] = (W_0 - W_∞) \left[ \frac{\sqrt{1 + 2X} - 1}{X} - 1 \right], \quad X = \frac{dW_α/dα|_{α=0}/(W_∞ - W_0)}{W_∞ - W_0}.
\]

Here, we extend the approach from Ref. [5] to coupled electron-hole BLG sheets. For the two bilayers, we use the Random Phase Approximation that is exact in the weakly-interacting limit, \( α \to 0 \) [5].

In the limit of strong interactions, \( α \to ∞ \), the ground state is the classical WC. We can treat the classical crystal as a collection of neutral unit cells, each cell with an electron or hole at its centre and surrounded by a charged disk of uniform neutralizing background of radius \( r_0 = 1/\sqrt{4πρ} \). Then \( W_∞ \) consists of the electrostatic energies between the electron, hole, positive and negative charged disks.
Figure 1: Phase diagram for the ground state of the coupled electron-hole BLG system as a function of layer density parameter $r_s$ and the separation between the layers $d$.

Having $W_0$ and $W_\infty$ we obtain the correlation energy $E_c[\rho]$ using Eq. (1). To obtain the total ground state energy $E[\rho]$, we employ a Density Functional Theory within the Local Density Approximation (LDA) formalism, for which

$$E[\rho] = K[\rho] + E_{\text{coul}}[\rho] + E_x[\rho] + E_c[\rho] + E_i,$$

where $K[\rho]$, $E_{\text{coul}}[\rho]$, and $E_x[\rho]$ respectively denote the non-interacting kinetic energy, intra-layer Coulomb energy, and exchange energy functionals discussed in Ref. [5]. $E_i$ is the inter-layer Coulomb interaction.

We use Eq. (2) to obtain the ground state energy per particle $\varepsilon[\rho] = E[\rho]/\int d^2r \rho_{0}$ for the liquid phase with uniform density $\rho(r) = \rho_0$, and for the non-uniform density distribution $\rho(r)$ of the c-WC and the CDW phases. For the c-WC phase, we take the variational form for the density distribution,

$$\rho(r) = \rho_0 \beta_{\text{WC}} \sum_{m,n} \exp[-\beta_{\text{WC}}(r - ma_1 - na_2)^2],$$

where $m$ and $n$ are integers, and $a_1 = a(1,0)$ and $a_2 = a(-1/2, \sqrt{3}/2)$ are the lattice vectors for the two-dimensional hexagonal lattice, with the lattice constant $a = a_{\text{WC}} = \sqrt{2/\sqrt{3}\rho_0}$ fixed by $\rho_0$. $\beta_{\text{WC}}$ is our variational parameter that determines the degree of localization on each lattice site.

For the 1D-CDW phase, we set in Eq. (3), $a_2 = 0$ and replace the integer $m$ by $\gamma \in \mathbb{R}$. Now the amplitude $\beta$ and the periodicity $\gamma$ are the two variational parameters.

**Phase diagram**

Figure 1 shows the phase diagram as a function of the inter-particle spacing $r_s = 1/\sqrt{\pi \rho_0}$ within each bilayer sheet and the separation $d$ between the bilayer sheets. We see that for large $d/a_B^* \gtrsim 15$, the Fermi liquid is the ground state down to density $r_s \approx 31$, where the transition to the c-WC occurs. This is as expected, since the coupling between the sheets is weak when $d/a_B^* \gg 1$, and consequently the results become similar to the results for a single isolated sheet [5].

When $d$ decreases, a new CDW phase interposes itself between the Fermi liquid and c-WC phases. We find that the 1D-CDW, with density modulations in one planar direction, is always more stable than the two-dimensional CDW. At sufficiently small $d$, the electron-hole attraction becomes strong enough for electron-hole bound pairs to form in significant numbers, and these should condense into a coherent superfluid state [1, 2].

**References**

Composition dependent self-organization in $\text{Au}_x\text{Ag}_{1-x}$ phase segregated nanostructures

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Bimetallic $\text{Au}_x\text{Ag}_{1-x}$ clusters with various compositions ($x = 0.2$ to $0.9$) are synthesised in the gas phase and then deposited on amorphous $\text{SiO}_2$ wafers and TEM grids. Detailed structural characterization was performed by a combination of aberration corrected high angle annular dark field scanning transmission electron microscopy (HAADF-STEM) and synchrotron radiation-based total reflection mode extended X-ray absorption fine structure (ReflEXAFS) at Ag K edge (25514 eV).

$\text{Au}_x\text{Ag}_{1-x}$ Clusters with an average diameter of $3.0 \pm 0.6$ to $3.7 \pm 0.7$ nm were produced using dual-laser ablation of pure Ag and Au metal targets under UHV conditions. Control over the bimetallic clusters composition was achieved in the gas-phase prior to deposition by fine tuning of the laser energy densities of two lasers. Composition was monitored by reflectron time-of-flight mass spectrometry and determined by a binomial combination model. Clusters were then deposited in soft landing mode with a low coverage of 0.1 atomic monolayer (ML) to minimize aggregation on TEM grids and $\text{SiO}_2$ wafers for HAADF-STEM and ReflEXAFS measurements, respectively. HAADF-STEM and ReflEXAFS results are in excellent agreement and show phase segregated structures for all the investigated compositions. A systematic composition-dependent inversion of the element in the core and the shell, with an alloy core enriched by the minority element and a nearly pure majority element shell, was observed.

Experimental results were combined with DFT calculations to unravel the growth process of these phase segregated clusters in the gas phase which show that the formation of binary clusters is dominant in the small size region. The computations suggest that $\text{Au}_x\text{Ag}_{1-x}$ clusters follow a two-step growth process: first, small binary aggregates are formed; second, small binary aggregates serve as nuclei for condensation of majority material, hence resulting in composition dependent shell inversion.

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Strain controlled valley filtering in multi-terminal graphene structures

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Valley-polarized currents can be generated by local straining of multi-terminal graphene devices. The pseudo-magnetic field created by the deformation allows electrons from only one valley to transmit and a current of electrons from a single valley is generated at the opposite side of the locally strained region. We show that valley filtering is most effective with bumps of a certain height and width. Despite the fact that the highest contribution to the polarized current comes from electrons from the lowest sub-band, contributions of other sub-bands are not negligible and can significantly enhance the output current.

Mechanical deformations in graphene can lead to the generation of pseudo-magnetic fields (PMFs) that exceed 300 T [1]. The generated PMF has the opposite direction for electrons originating from different valleys [2]. This property can be used in order to separate electrons from the two valleys and obtain a valley-polarized currents [3] - a prerequisite for valleytronics. We show that straining graphene locally into a Gaussian bump by e.g. an STM (scanning tunneling microscopy) tip [4], it is possible to obtain highly tunable polarized valley currents in two realistic device settings: a two-probe nanoribbon and a Hall bar. The pseudo-magnetic field created by the deformation [5] allows electrons from only one valley to transmit and a current of electrons from a single valley is generated at the opposite side of the locally strained region, as sketched in Fig. 1(a). In Fig. 1(b) we plot the change of the transmission probabilities \(T_K\) and \(T_{K'}\) together with the polarization \(\tau_K = T_K / (T_K + T_{K'})\) with the width of the bump \(\sigma\). Figure shows that both transmissions decrease with increase of \(\sigma\) up to a certain value after which only \(T_K\) increases and \(\tau_K\) approaches unity. In this regime, valley polarized conduction channels open inside the bump and the system behaves as a valley filter. We show that valley filtering is most effective with bumps of a certain height and width. This is shown in Fig. 1(c) where we plot valley polarization \(\tau_K\) versus the parameters of the bump. Notice that the valley filtering regime occurs only for \(c_1 < \sigma < c_2\), with \(c_1 \approx 0.8\) while the upper limit depends on the values of the Fermi energy and width of the collector. Despite the fact that the highest contribution to the polarized current comes from electrons from the lowest sub-band, contributions of other sub-bands are not negligible and can significantly enhance the output current.
Fig 1. (a) Cartoon drawing of the flow of electrons from different valleys through the bump. (b) Probabilities $T_K$, $T_{K'}$, and $\tau_K$ versus the width of the Gaussian bump using $h_0 = 20$ nm, $E_F = 0.1$ eV and a Hall bar geometry. (c) Contour plot of valley polarization $\tau_K$ versus the width and the height of the bump.

References


Parallel Session (14:15 – 18:00)
Fundamental Interactions, Particle and Nuclear Physics
Chairman: Prof. Claude Semay (UMONS)
Nuclear Physics from Lattice QCD

Jaume Carbonell (IPNO Orsay)

We will first consider the complexity of the conventional Nucleon-Nucleon interaction either in the traditional meson exchange or in the EFT framework. Then we will review the recent progress in Lattice QCD calculations applied to nuclear physics and show how this - a priori unlikely - approach results into a disarming simplicity for the description of light nuclei and some simple nuclear reactions.
Modeling quasielastic neutrino–$^{40}$Ar scattering.

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For neutrino oscillation experiments it is of paramount importance to have a thorough understanding of neutrino–nucleus interactions. Quasielastic scattering, an important reaction channel in this context. Through application of the Continuum Random Phase Approximation (CRPA) approach, we calculate results for $^{40}$Ar, an important nuclear target in current and future experiments.

Background

Neutrinos attract a lot of attention owing to the fact that they oscillate: they change from one kind into another as they move forward. In order to find out more about this phenomenon and determine the parameters that govern this behavior, one needs to perform experiments, e.g. accelerator–based ones. In these experiments, a beam of neutrinos of one type (muon neutrinos $\nu_\mu$, in this instance) travels between a near and far detector. By counting neutrinos at each detector, one can observe the disappearance of $\nu_\mu$ due to oscillations, giving access to the aforementioned parameters.

In order to perform oscillation analyses, the neutrinos need to be detected. This is challenging, as they only interact through the weak interaction. In accelerator-based experiments, the main detection mechanism is neutrinos scattering off atomic nuclei. Self–evidently, theoretical models of neutrino-nucleus interactions are a crucial ingredient to advance this research. Besides nuclear targets such as $^{12}$C and $^{16}$O, one of the most important nuclei in current and future experiments is argon ($^{40}$Ar). Liquid argon time projection chambers (LArTPCs) detectors show a lot of potential for high-precision experiments. Examples of current and planned experiments using this detector technology include MicroBooNE, ArgoNeuT, DUNE, etc.

In these experiments, neutrinos are produced as the decay products of a primary pion beam. As a matter of fact, they come with a broad energy distribution. They can therefore interact with nuclei in a variety of ways, but one of the most important reaction mechanisms at intermediate neutrino energies (between a few hundred MeV and a few GeV) is charged-current quasi–elastic (CCQE) scattering, where after collision, a single proton is changed into a neutron, and is subsequently knocked out of the nucleus. The neutrino changes into a muon ($\mu^-$) and is measured. It is our goal to model this reaction.

Theoretical Modeling and Results

In modeling CCQE neutrino–$^{40}$Ar reactions, we make use of the Continuum Random Phase Approximation (CRPA) framework, a model used in the Ghent group that has been
Figure 1: Double differential cross section for CCQE neutrino–argon scattering folded with the MicroBooNE flux, in function of the muon scattering angle $\theta_\mu$ and kinetic energy $T_\mu$.

used successfully in the past for the description of various nuclear processes [1, 2, 3]. The model, which was benchmarked against inclusive to electron–nucleus scattering data, introduces long-range correlations in the nuclear many-body system, going beyond a so–called mean field approach where nucleons move independently in the theoretical description. These are crucial to model processes with low energy transfer. Relativistic effects are also taken into account in an effective way. With this theoretical framework, we make predictions for quasielastic neutrino–$^{40}$Ar scattering cross sections[4]. The double differential cross section for MicroBooNE[5] kinematics is shown in Fig. 1

References


Status of the SoLid experiment  
and sensitivity to sterile neutrinos

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Although neutrino oscillations were discovered more than 10 years ago, some anomalies, such as the reactor antineutrino anomaly, still remain in the neutrino oscillation data. The existence of a light sterile neutrino could explain these anomalies. The SoLid experiment aims to resolve the inconsistencies in the neutrino oscillation sector and to test the sterile neutrino hypothesis.

To be able to perform this sensitive measurement a novel detector technology is used, based on the combination of solid scintillator PVT cubes in combination with $^6$LiF:ZnS screens. Compared to standard Gd doped liquid scintillator detectors this technology will allow for a better background rejection capability, neutron identification and localization of the inverse beta decay.

During the past 2 years the SoLid collaboration has build 2 prototype detectors and it is now in the process of building a full scale 1.5 ton detector. This talk covers the novel technology used in the SoLid experiment, discusses the improvements made on the design and electronics for the construction of the full SoLid detector and gives a prediction of the sensitivity that SoLid will be able to achieve.

The reactor neutrino anomaly

It is not expected for $\bar{\nu}_e$ produced by nuclear reactors to have significant oscillations at distances less than 100m from the core. At short baselines, one would therefore expect the number of neutrinos reaching the detector to be the same as the amount created in the reactor’s core. Due to a recent re-evaluation of reactor antineutrino spectra, a deficit in the number of detected neutrinos at short baselines has appeared [1, 2].

Some explanations to the reactor neutrino anomaly are the many uncertainties in reactor neutrino spectrum calculations or detector effects. One could also invoke a new flavour of neutrinos to explain the deficit but due to precise measurements of the Z boson cross section at LEP in the early nineties, the number of active neutrino flavours is fixed at three. The term ‘sterile’ neutrino originates from this lack of coupling to the Z-boson.

The SoLid experiment

SoLid, short for “Search for Oscillation with a $^6$Li Detector”, aims to resolve the reactor anomaly within a few years of detector operation at SCK•CEN’s BR2 reactor in Mol, Belgium. A precise measurement of the $^{235}$U $\bar{\nu}_e$ spectrum will also be made to help understand the distortion at 5 MeV seen by several experiments [3].

The BR2 reactor is an ideal place to perform both measurements. Unlike commercial nuclear reactors, it has a compact core and allows close access to it. The compact core allows for a more precise distance calculation between the generation and detection point
of the reactor, an important factor in the oscillation analysis. SoLid can operate at distances as small as 5.5m from the core, this is uncharted territory for this measurement. BR2 uses highly enriched Uranium as fuel, ideal for the $^{235}$U spectrum measurement and easing the complexity of the oscillation analysis.

Antineutrinos from the core will be detected via inverse beta decay (IBD, $\bar{\nu}_e + p \rightarrow e^+ + n$). The detector mainly consists of $5 \times 5 \times 5$ cm cubes of PVT, an organic scintillator. The cubes provide Hydrogen atoms that act as neutrino target, they generate light as the positron deposits energy and they provide mass for the neutron to thermalize. Once a neutron is thermalized, it can capture on a $^6$Li atom in the $^6$LiF:ZnS screens lining the PVT cubes. In the capture process, an alpha and a tritium particle are created from the neutron and the $^6$Li atom, which scintillate in the ZnS part of the screen. A neutrino signal is thus characterized by a prompt positron peak from the PVT and a delayed neutron signal from ZnS.

There is a large difference in scintillation time between PVT (fast) and ZnS (slow), allowing easy identification of the scintillator when light is detected. This vastly reduces the required number of readout channels as one channel can service both PVT and ZnS scintillator material. Therefore a detection cell is a PVT cube lined with two $^6$LiF:ZnS screens and wrapped in Tyvek paper for optical isolation. In each PVT cube, four groves (two in X and two in Y) are carved to allow wavelength shifting fibers to extract the light and guide it to Silicon photomultipliers (SiPM) at the end of the fiber. Detection cells are placed into $16 \times 16$ cube frames and fibers are run through the aligned groves. The coincidence of signal from at least one X and one Y fiber gives the location of an event, resulting in a 5cm position resolution.

**SubModule I and the full SoLid detector**

A small proof of concept detector was built in 2013. To demonstrate the large scale use of the detector technology a large prototype SubModule 1 (SM1) was constructed. This module consisted of 9 planes, each of $16 \times 16$ cubes, giving a total of 2304 PVT cubes and a weight of 288kg. This prototype was successfully calibrated and commissioned at the BR2 reactor and data taking was performed under realistic conditions. The data taking has proven the stability and our understanding of the detector performance. The experience gained with SM1 was used to improve on the design for the full SoLid detector.

The full SoLid detector will consist of 5 modules of 10 planes each with a total detector mass of 1.6 tonnes. The amount of fibers and $^6$LiF:ZnS screens are doubled compared to the SM1 prototype to improve the light output and neutron capture efficiency. A cooled container will provide reduced thermal noise and water shielding around it reduces the neutron background. Construction is ongoing, the first modules are being calibrated and data taking should start during summer 2017.

**References**


Search for dark matter in final states with jets or a hadronically decaying weak boson and large missing energy with the CMS detector

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A key question in physics is to understand the nature of Dark Matter (DM). Unfortunately, those particles only interact through weak and gravitational forces: DM produced in proton-proton (pp) collisions would escape the detector without leaving any signal. Therefore, DM particles must be produced alongside with a detectable object that would balance the missing energy. We present a search for DM using events with large missing transverse momentum and energetic jets in a data sample of pp collisions at 13 TeV of center-of-mass energy, collected with the CMS detector at the LHC in the first half of 2016.

Physics motivations

A key question in modern physics is to understand the origin and the nature of Dark Matter (DM). The CMS collaboration has a broad experimental program to try to detect DM particles. Unfortunately, those particles are thought to be interacting only through weak and gravitational forces, which makes them invisible to the CMS detector. If the LHC was to produce DM particles in proton-proton collisions, they would escape the detector without leaving any signal, exactly as neutrinos do. In order to be sensitive to this kind of exotic signal, DM particles must be produced alongside with a detectable object: those events are labeled as “mono-X”, where X stands for the object balancing the missing energy carried away by the DM.

The Monojet analysis

In this context, a search for dark matter is performed using events with large missing transverse momentum and one or more energetic jets in a data sample of proton-proton collisions at 13 TeV of center-of-mass energy, collected with the CMS detector at the LHC in the first half of 2016. The main backgrounds for this analysis are SM events with neutrinos in the final states, as Z boson plus jets production with the boson decaying to neutrinos. Results are presented in terms of limits on the dark matter production in association with jets using simplified models. In those models, DM particles interact with SM matter through vector or axial-vector mediators. Mediators with masses up to 1.95 TeV are excluded at 95% confidence level.
References

[1] The CMS collaboration, "Search for dark matter in final states with an energetic jet, or a hadronically decaying W or Z boson using 12.9/fb of data at 13 TeV", CMS PAS EXO-16-037
Four top production at CMS

Denys Lontkovskyi (VUB)

The Standard Model four top quarks production is one of the rarest processes that can be observed at the LHC. Many models addressing the hierarchy problem of particle physics predict the enhancement of the four top quarks production cross section in the proton proton collisions, therefore direct searches for this process constitute an important component of the new physics program at the LHC. The proton proton collisions resulting in four top quarks in the final state are characterized by large hadronic activity and b quark multiplicity. These features were exploited to train a dedicated MVA discriminator to separate the signal from the background. The search presents the results from the analysis of 2.3 fb\(^{-1}\) data collected by the CMS experiment at the LHC. The analysis is performed in the single lepton and opposite sign dilepton channels and the results are combined with those obtained in the like sign dilepton events. No deviations from the no signal hypothesis are observed and the observed (expected) limit of 69 (91\(^{+38}_{-24}\)) fb was set.
The study of interactions between the top quark and the Higgs boson is of particular interest due to the largeness of the top quark Yukawa coupling and expected strong sensitivity to new physics phenomena. While flavor-changing neutral currents (FCNC) are strongly suppressed in SM, these interactions could be significantly enhanced in various beyond SM scenarios. The talk focuses on discussion of the latest experimental results on top-Higgs FCNC searches at the LHC as well as outlines the prospects for future experiments.

A recently discovered new fundamental particle and its measured properties are currently consistent with the Standard Model (SM) predictions for the Higgs boson particle [1, 2, 3, 4]. However, the measurement of the top quark Yukawa coupling has been done so far only in indirect searches via its presence in the loops in the Higgs gluon-gluon production process, as well as in the $H \rightarrow \gamma\gamma$ decay channel. Due to the large mass of the top quark in comparison to other fundamental particles, the Yukawa coupling strength is close to unity which makes processes of top-Higgs interaction an ideal place to search for new physics. In SM, flavor-changing neutral currents (FCNC) are strongly suppressed by Glashow-Iliopoulos-Maiani (GIM) mechanism at tree level [5] with the SM branching ratio of $t \rightarrow H q$ to be predicted of $O(10^{-15})$ [6, 7, 8]. Several extensions of SM incorporate significantly enhanced FCNC that can be directly probed at the LHC [8]. FCNC processes that correspond to top-Higgs interactions are described with the following effective lagrangian:

$$L = \sum_{q=u,c} \frac{g}{\sqrt{2}} \kappa_{Hqt} (f_{Hq}^L P_L + f_{Hq}^R P_R) q H + h.c.,$$

where $P_L$ and $P_R$ are chirality projectors in spin space, $\kappa_{Hqt}$ — effective coupling, $f_{Hq}^L$ and $f_{Hq}^R$ — left and right-handed complex chiral parameters with unitarity constraint of $|f_{Hq}^L|^2 + |f_{Hq}^R|^2 = 1$.

FCNC associated with $\kappa_{Hqt}$ has been probed in top quark decays in $t\bar{t}$ events by ATLAS [9] and CMS [10]. From the search at ATLAS that considers $H \rightarrow \gamma\gamma, H \rightarrow WW^*$, and $H \rightarrow \tau\tau$, the observed (expected) limits on the $t \rightarrow Hu$ and $t \rightarrow Hc$ branching ratios of 0.45% (0.29%) and 0.45% (0.25%) were set, respectively. Analysis done by CMS that considers Higgs decays to either dibosons or difermions, resulted in 0.55% (0.40%) and 0.40% (0.43%) for the observed (expected) limits on respective branching ratios.

References


CMS Tracker performance in 2016
H. Delannoy\(^1\), on behalf of the CMS collaboration

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In 2016, the CERN Large Hadron Collider (LHC) reached a peak instantaneous luminosity of 1.5\times10^{34} \text{cm}^{-2} \text{s}^{-1}, going above the original design value of 1.4\times10^{34} \text{cm}^{-2} \text{s}^{-1} and reaching on average 40 interactions per bunch crossing. Under those conditions the CMS tracker managed to have a ~98\% efficiency for the data taking period of 2016. This talk will present the performance of the CMS tracker in 2016, for both the Pixel and Strip sub-detectors.

Data taking conditions - the CERN LHC
In 2016, the CERN Large Hadron Collider (LHC) delivered proton-proton collisions with a center of mass energy of 13\text{TeV} with a spacing of 25\text{ns} per bunch crossing, reaching a maximum of 2208 colliding bunches. The delivered integrated luminosity reached 40.5/fb with 37.3/fb recorded by the Compact Muon Solenoid detector (CMS), leading to 92\% efficiency for the full CMS detector. This luminosity is more than what was recorded during the LHC Run I: ~29/fb. To reach such value of integrated luminosity, the LHC worked with high peak luminosity reaching 1.5\times10^{34} \text{cm}^{-2} \text{s}^{-1}, which is twice higher than for the Run I (0.7\times10^{34} \text{cm}^{-2} \text{s}^{-1}). Under those conditions, a high number (40 on average) of hard interactions per bunch crossing (pile-up) was recorded.

Overview of the CMS Tracker
The CMS detector is a general purpose detector operating at LHC and composed of several sub-detectors. It has a cylindrical geometry with a barrel and two endcaps and is made of, from the center to the edges, a tracker, an electromagnetic calorimeter, a hadron calorimeter, a 3.8T solenoid magnet and muon chambers. In particular, the tracker is made of a two main components: the silicon pixels and the silicon strips. The silicon pixels tracker has been completely changed for 2017. In 2016, it was made of 3 barrel layers (at 4.3, 7.2 and 11cm from the Interaction Point (IP)) and 2 endcap disks on each end. In total it consisted of 48 + 18 million pixels of 100x150 µm\(^2\). The silicon strips tracker has a total active area of 206 m\(^2\) and is made of 10 layers in the barrel and 3 inner disks plus 9 endcap disks. In total the silicon strips tracked consists of 9.6 million read-out channels, with 300/500 µm sensor thickness with a pitch ranging from 83 to 205 µm.

Status of the CMS Tracker in 2016
The tracker operated with very good performance during 2016, only ~2\% of the runs were certified as bad due to issues with the tracker. For the silicon pixels, the hit efficiency stayed above 99\% for outer layers. Only the barrel layer 1 showed a decrease in the hit efficiency with the instantaneous luminosity, going down to ~95\% at high instantaneous luminosity. This dynamic inefficiency was expected and already seen in
Run 1 due to the read-out chips (ROC) buffer overflowing at high rate due to the current ROC design. The hit resolution kept steady below 10 µm in the bending \((r-\phi)\) plane. The main issue for the pixel tracker was a problematic sector in layer 2 which could not be turned on at high magnetic field. In total less than 1.8% of the pixel barrel had bad components while the forward pixel had only 2 ROCs marked as bad (i.e. 99.95% good fraction).

For the silicon strips, the hit efficiency was above 99% excluding bad components, with a resolution between 15 and 42 µm, depending on the pitch. A total fraction of 3.6-3.8% of bad components for this year was seen, which is close to what was observed in Run I. A decrease of signal over noise ratio associated to loss of tracking hits has been observed in late 2015 and part of 2016 with the effect increasing with instantaneous luminosity and occupancy. The problem was initially believed to be due to heavily ionizing particles (HIPs) but was eventually traced to saturation effects in the pre-amplifier of the APV chip. This was fixed in mid-August by changing the discharge time of the APV chip. In the end, about 20/fb of data was affected but this effect was mitigated by reprocessing the data with relaxed quality cuts on tracks.

![Figure 1: Strip dynamic inefficiency recovery after applying the new APV settings [1]](image)

**Preparation for the Pixel phase 1 upgrade**

The beginning of the year 2017 is marked by the installation of a brand new pixel sub-detector, with more barrel layers (4) and endcap disks (3 on each side), so-called phase 1 upgrade of the pixel detector. This detector has new digital ROC designed to cure the dynamic efficiency losses. In order to be prepared for this period, a pixel pilot blade was equipped with phase 1 modules and inserted in CMS in 2014, giving valuable information towards the commissioning of the upgraded detector.
Conclusions

CMS Tracker successfully took physics data in Run II even at the highest luminosity going beyond LHC nominal conditions and reaching 98% efficiency. Some issues were encountered due to the very high instantaneous luminosity both in silicon pixel sub-detector (expected and will disappear with phase 1 pixel detector in 2017) and in silicon strip sub-detector (solved and performances are back to normal).

References

A new perspective on gravity

Vincent Min (KU Leuven)

Gravity is perhaps the most well known force among the four fundamental forces that control our universe. Surprisingly, it is also the least understood force. It is extremely weak compared to the other forces and we need to introduce a mysterious new class of particles called "dark matter" in order to find agreement with cosmological observations. Recent advances in high energy physics seem to suggest that gravity requires us to adopt a drastically different mindset to truly understand this force. In this talk I will explain the obstacles for why gravity has defied a complete understanding until now. Furthermore, I will introduce a promising new mindset which aims to understand gravity by considering information and its effects on geometry.
Parallel Session (14:15 – 18:00)
Physics and Education
Chairwoman: Prof. Mieke De Cock (KUL)
Universities can play an important role in increasing the attractiveness of the STEM areas at the level of secondary education. We here present a package consisting of course material wherein basic physics principles are explained in the context of nuclear fusion science. The principles are illustrated with a number of simple physics experiments and a mobile app.

The role of universities in high-school STEM education

Education in the STEM disciplines (Science, Technology, Engineering and Mathematics) is essential to support a society driven by knowledge and technology. In order to attract students and address the gender imbalance in the STEM areas in higher education, and to cultivate a general interest in the natural sciences, it is important to begin stirring children’s interests in the STEM fields at an early age. Here, university science and engineering faculties can play a key role, as knowledge base for a wide range of STEM topics and research centers at the forefront of scientific exploration and technological application.

The faculty of Engineering and Architecture at Ghent University (UGent) recently started a new initiative for promoting STEM towards pupils in the two final years of secondary education. As part of this initiative, the faculty is developing a number of packages with teaching material concerning a range of engineering topics. Accessible through a dedicated website [1], each of these packages can be used by high school teachers on a stand-alone basis in their classes. One of these packages is centered around the science and technology of fusion energy.

Fusion science in STEM education

Controlled nuclear fusion concerns the development of a clean, safe and plentiful energy source based on fusion of light nuclei in a hot plasma confined by strong magnetic fields. It is an area of ‘big science’ that is presently culminating in the construction of the ITER tokamak in France. Fusion energy appeals to the imagination of not only the authors of science-fiction novels, but also high school students. A comprehensive understanding of fusion plasmas builds on almost all areas of physics, and the scale and complexity of engineering is impressive. Moreover, fusion science touches upon several topical issues such as energy supply, climate change and the data deluge. As such, fusion is an ideal candidate for demonstrating the principles and societal impact of various disciplines, including physics, chemistry and information science.

Within the department of Applied Physics at UGent, we are developing fusion-related course material to be used as a guideline by (mainly) physics teachers at Flemish high schools. The underlying motivation is to illustrate, in the context of fusion plasmas, a number of basic physics principles that most students traditionally encounter in their
physics curriculum. The goal is to arouse the interest of pupils for subject matter that might otherwise be perceived as relatively abstract or dry.

In this talk, I will present the topics that are discussed in the course material, followed by the illustration of some basic physics principles by means of a few very simple experiments. I will conclude with a demonstration of a mobile app, developed within the fusion community, that allows students to conduct their own experiments in a virtual tokamak.

References

Outreach activities of the SCK•CEN Academy for Nuclear Science and Technology for high school pupils and their teachers

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The Belgian Nuclear Research Centre SCK•CEN is one of the largest research centres in Belgium with more than 60 years of experience in nuclear science and technology. SCK•CEN performs research on themes that are important for the society of both today and tomorrow and delivers services to industry, healthcare, government and other third parties. Through the SCK•CEN Academy for Nuclear Science and Technology education and training activities are provided at national and international level, covering all topics that are part of the R&D portfolio of SCK•CEN.

Pupils have a wide attention span and are eager to learn. The SCK•CEN Academy interacts with pupils and their teachers of secondary schools and informs them about the scientific and technological aspects of nuclear research and technologies, and also of the pluralistic societal context in which this is embedded. In some cases, these actions also inspire pupils to effectively choose for an academic STEM related study.

For third-grade pupils in secondary education, the SCK•CEN Academy organises technical visits to the laboratories at SCK•CEN. SCK•CEN experts explain the state-of-the-art solutions which require the integration of multiple disciplines in STEM. A dedicated website supports pupils and teachers with educational material and information and prepares them for the visit. The SCK•CEN Academy further supports high school teachers via its contributions to educational workshops organised by the professional associations.

The SCK•CEN Academy is also contributing to the Flemish Physics Olympiad with a one-day lecture on nuclear and particle physics and by offering a visit at the SCK•CEN premises for the finalists and their teachers. In this visit, the students get the unique opportunity to execute two experiments under supervision of SCK•CEN experts, to prepare them for the final of the olympiad.

In the next school year 2017-2018, the first edition of a nuclear contest will be organised in collaboration with the Joint Research Centres of the European Commission. This high school team contest will be open for student teams from all Belgian schools. The teams are challenged to invent and make an educational game in which nuclear sciences and applications are the central topic. The educational game can be developed at school during a period of 6 months. A jury of experts will grade the submitted educational games and the winners will be invited to an award ceremony.

This presentation will give an overview of the outreach activities for high school pupils and their teachers, with a special focus on the first edition of the nuclear contest.
Teaching, Fast and Slow: Balancing Creative Thinking and Deep Conceptual Understanding in Physics Education

V. Ginis

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In this contribution, we apply Kahneman’s conceptual framework to develop a novel scientific didactic approach. We introduce the concepts of fast thinking and slow thinking and plead that teaching should use didactic methods and conceptual approaches that excite one of both states depending on the type of task at hand.

Facing our fallibility

In 2002, Daniel Kahneman and Vernon L. Smith were awarded the Nobel Memorial Prize in Economic Sciences for their fundamental insights from cognitive psychology regarding human behavior under uncertainty [1]. Based on a sequence of groundbreaking psychological experiments, they demonstrated how human thinking is fundamentally flawed and clouded by biases, including but certainly not limited to the priming effect, anchoring, confirmation and combination bias [2].

The experiments can be explained surprisingly well using a binary model of human thinking. Kahneman and Smith thus introduced the enigmatic concepts of System 1 (thinking fast) and System 2 (thinking slow) to identify the two different ways of thinking underlying human behavior. System 1 drives our fast, irrational and intuitive brain processes, whereas System 2 is in charge of the slow, logical and energy-consuming thoughts. Many biases and cognitive fallacies occur when System 1 is behind the steering wheel. Unfortunately, this is in many circumstances the default state of our brain, explaining the many illogical, incoherent and irrational decisions and thoughts made by humans, even when they are highly skilled in the subject under consideration, e.g., graduate students in exact sciences giving the wrong answer in “the ball and the bad problem” [3]. This fast thinking is obviously detrimental when learning novel scientific concepts that are clouded by misconceptions.

Teaching fast and slow

Interestingly, several experiments have demonstrated how external factors can influence the switching between the fast and the slow thinking. Generally, cognitive ease puts System 1 in charge, whereas cognitive strain favors System 2 [3]. Repeated experiences, clear visualizations and relaxing circumstances are primers for cognitive ease [4]. Shane Frederick’s cognitive reflection test is one of the most famous examples of how various boundary conditions affect the swapping between cognitive states [5].

Naively, one might think that it is important to constantly excite slow thinking in the classroom, trying to keep the irrational fast thinking on the background. However, it is known that System 2 is notoriously bad at some tasks that require a more holistic or creative problem solving approach, not incidentally the type of tasks where System 1 champions [6].
Conclusion

In the author’s opinion, the real challenge in science education thus lies in finding the correct balance between cognitive ease and cognitive strain when dealing with creativity and interdisciplinary tasks, on the one hand, and misconceptions and logical derivations on the other hand: teaching fast and slow.

References

The Wilson cloud chamber or how to observe natural radioactivity?

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It is difficult to talk about nuclear, particle or cosmic ray physics because we cannot see or feel objects as alpha, beta, gamma radiations or muon, pion particles.

Cloud chambers intend to show these particles/radiations live, to convince that they are real physical objects with measurable properties; they allow demonstrating that these ionizing particles can be detected via an interaction with a sensitive medium through which they leave a track of their passage like a plane leaves a track of its passage in a bright sky [1].

Cloud chambers are detectors invented by the Scottish physicist Charles Wilson (*) in 1911. They consist of a container filled with a gas-vapour mixture, e.g. air-alcohol mixture, at the vapour saturation pressure. By means of an adiabatic expansion or by lowering the temperature, the vapour gets supersaturated. When a charged particle traverses the chamber, it will ionize the supersaturated gas which will then condense on seeds or positive ions producing droplets of vapour which can be illuminated to show the particle trajectory [2].

Numerous physics experiments have been conducted using expansion type cloud chambers leading to great discoveries like that of the antielectron and that of the muon lepton or "heavy electron" in the 30s [3]. This kind of detectors are no more in use nowadays in experiments but nevertheless, diffusion type cloud chambers are often operated for exhibition in order to attract people or students towards the subatomic world.

Experiments with a diffusion cloud chamber can be used to approach or to extend the knowledge in several areas of the physics lessons, essentially related to modern physics: thermodynamics, nuclear physics, particle physics, cosmic-ray physics, special relativity, ionizing radiation detection …

We will present the history and the principle of operation of the Wilson cloud chambers and then focus on home-made cloud chambers, explaining "how to build a cloud chamber?” and "how to operate it in a classroom?”. One home made cloud chamber will be showed in details followed by its operation using cosmic rays.

(*) awarded a Nobel Prize in Physics in 1927 for his invention, more exactly for "his method of making the paths of electrically charged particles visible by condensation of vapour”

References
Schematic representation of our home-made cloud chamber

Photos

https://icecube.wisc.edu/outreach/activity/cloud_chambers

**From teachers for teachers: easy and affordable experiments.**

Created in 2000, Science on stage Europe is a European science teacher's network; Science on Stage Belgium is part of it. Science on Stage Belgium, brings together science teachers of Belgium and all Europe to share the best practice in science teaching.

3 members of the Belgian association will present affordable experiments, easy to perform and to be used in the classrooms and make the students think.

- Stijn Lichtert, physics teacher at the KA Ekeren, will present experiments about waves, using Smartphones and computers (Swings, Doppler effect, interferences, sound speed, spectra, ...)
- Bernadette Anbergen, physicist in Charleroi, will perform experiments about optic in the infra-red, the difference between sound and noise, the Seebeck effect, ...
- Philippe Wilock, science teacher at the Collège du Sacré Coeur of Charleroi, presents nice experiments about energy transfer, measuring the mass of an astronaut, the human battery, ...
Poster Session (12:45 – 14:15)
Rotation and magnetic field effects on the stability of two-component jets: extension in 3D

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Observations of astrophysical jets show evidence of a structure in the direction perpendicular to the jet axis. Most two-component jets are believed to consist of a highly relativistic inner and a slower – still relativistic – outer part, surrounded by an unmagnetized environment. Simulations in 2.5D indicated that in the absence of a strong toroidal magnetic field, these jets can be susceptible to a relativistic Rayleigh-Taylor-type instability. We simulate in 3D selected cases including a toroidal magnetic field. Even in cases where the effective inertia and the toroidal field result in a stable jet, Kelvin-Helmholtz instabilities can be observed.

Introduction

Astrophysical jets have been extensively observed and studied on multiple scales, ranging from young stellar object jets (YSO jets) and gamma ray bursts (GRBs) to active galactic nuclei jets (AGN jets). The formation, acceleration and collimation of jets was addressed in the beginning analytically and (relatively) recently via numerical simulations, in different regimes, ranging from simple hydrodynamic (HD) to relativistic and general relativistic magnetohydrodynamics (RMHD and GRMHD). AGN and GRB jets are relativistic, with Lorentz factors of \( \gamma \sim 10 \) and \( \gamma \sim 100 \) respectively, while YSO jets are non-relativistic, with typical velocities of \( \sim 100 \) km/s. Astrophysical jets display a structure, at least in terms of velocity ([2, 3]), in the direction perpendicular to the jet axis, which affects their stability. Simulations in 2.5D showed that stability against Rayleigh-Taylor type instabilities –induced by differential rotation– relates to the magnitude of the toroidal magnetic field (in other words, the magnetization \( \sigma = \frac{B^2}{\rho c^2} \)), with stronger fields resulting in stable jets. This study was an extension of previous work ([5, 6]), where the magnetic field was purely poloidal.

Initial conditions

We extend our 2.5D work in a full 3D study of a relativistic, two-component jet. We maintain the main assumptions for the configuration of the jet: the two parts of the outflow are differentially rotating, with an initial toroidal velocity profile as follows:

\[
V_\phi(R) = \begin{cases} 
  v_{\phi in} \left( \frac{R}{R_{in}} \right)^{\alpha_{in}/2}, & R \leq R_{in} \\
  v_{\phi out} \left( \frac{R}{R_{in}} \right)^{\alpha_{out}/2}, & R_{in} < R < R_{out}
\end{cases}
\]  

(1)
where $\alpha_{in} = 0.5$, $\alpha_{out} = -2$ and $v_{\phi in} = v_{\phi out} = 0.01$ (normalized to the speed of light and $c = 1$). The outer radius of the jet is set to $R_{out} = 0.1 \text{pc}$ (implied by [1] for M87) and we arbitrarily chose $R_{in} = R_{out}/3$. We focus on two asymptotic cases, based on our 2.5D results, which represent the most unstable and most stable cases respectively. These cases differ in the maximum magnetization value and the Lorentz factor of the inner jet. We maintain all the other parameters from the 2.5D work: the density ratio between the components is $\rho_{out}/\rho_{in} \sim 10^4$; the inner jet is relativistically hot, with an effective polytropic index of $\Gamma = 4/3$; the outer jet is cold, with $\Gamma \simeq 5/3$. The poloidal magnetic field is constant in each part of the jet and the toroidal magnetic field component has the same form as (eq. 1). All cases refer to kinetically dominated jets ($\sigma < 1$). Finally, we assume a total pressure equilibrium in every interface (inner & outer jet, outer jet & external medium).

In the first case, the Lorentz factor for the inner & outer component is $\sim 30$ and $\sim 3$ respectively, meaningful values for AGN jets ([1]). We choose a magnetization value of $\sigma = 0.001$. For the second case, we modify the Lorentz factor of the inner jet ($\sim 10$) and the maximum magnetization ($\sigma = 0.1$).

The computational domain is a cartesian domain of size $-0.3 \text{pc} < x, y < 0.3 \text{pc}$ and $0 < z < 1 \text{pc}$, with a uniform resolution of $256 \times 256$ and periodic boundary conditions on the $z$ axis. We assume a Synge type equation of state and we use a third order limiter and an hllc solver. The simulations are performed using the relativistic MHD module from the open source, parallel, grid adaptive, MPI-AMRVAC code ([4, 7]).

**Results & Conclusions**

We perform 3D simulations of relativistic, two component jets, assuming differential rotation and a toroidal magnetic field component of different magnitude in each case, with parameters corresponding to AGN jets. We examine the 2.5D extension of a very unstable case (high inertia in the inner jet, weak toroidal magnetic field) and of a very stable one (lower inertia, strong toroidal field). Our results are in agreement with the 2.5D simulations, with higher magnetization resulting in stable jets, with respect to Rayleigh-Taylor type instabilities. In both scenarios however, Kelvin Helmholtz instabilities between the outer jet and the external medium, develop early in the simulation (at $t < 1$ rotation of the inner jet).

**References**


Aharonov-Bohm oscillations of bosonic matter-wave beams in the presence of disorder and interaction

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We study the one-dimensional (1D) transport properties of an ultracold gas of Bose-Einstein condensed atoms through Aharonov-Bohm (AB) rings [1–3]. Our system consists of a Bose-Einstein condensate (BEC) that is outcoupled from a magnetic trap into a 1D waveguide which is made of two semi-infinite leads that join a ring geometry exposed to a synthetic magnetic flux $\phi$. We specifically investigate the effects both of a disorder potential and of a small atom-atom contact interaction strength on the AB oscillations. The main numerical tools that we use for this purpose are a mean-field Gross-Pitaevskii (GP) description and the truncated Wigner (tW) method [4, 5]. We find that a correlated disorder suppress the AB oscillations leaving thereby place to Aronov-Al’tshuler-Spivak (AAS) oscillations. The competition between disorder and interaction leads to a peak inversion at $\Phi = \pi$, that is a signature of a coherent backscattering (CBS) peak inversion. This is confirmed by truncated Wigner simulations.

References

The main goal of the present work is to estimate the effects of plasma environment on the atomic parameters associated with the K-vacancy states in oxygen ions within the astrophysical context of accretion disks around black holes. In order to do this, relativistic atomic structure calculations have been carried out by considering a time averaged Debye-Hückel potential for both the electron-nucleus and electron-electron interactions. A first sample of results related to the ionization potentials, the transition energies and the radiative emission rates is reported for all the ionization stages of oxygen, from O I to O VII.

Astrophysical motivations

X-ray emission lines from accreting black holes, most notably K-lines, have observed widths and shifts which imply an origin very close to the compact object [1]. The intensity of these lines can provide insight into the effects of special and general relativity in the emitting region as well as insight into some properties of the compact object itself. According to the magnetohydrodynamic simulations of accreting black holes \((M = 10 M_{\text{Sun}}, \text{accretion rate} = 0.1)\) due to Schnittman et al. [2], the plasma conditions in such an environment should be characterized by an electronic temperature, \(T_e\), ranging from \(10^5\) to \(10^7\) K and an electronic density, \(n_e\), ranging from \(10^{18}\) to \(10^{21}\) cm\(^{-3}\). This may affect the atomic structure and processes corresponding to the ionic species present in the plasma.

Theoretical methods used

In order to estimate the influence of plasma environment on the atomic parameters in oxygen ions, a time averaged Debye-Hückel potential for both the electron-nucleus and electron-electron interactions has been considered within the framework of two independent atomic structure computational approaches, namely the purely relativistic multiconfiguration Dirac-Fock (MCDF) method [3,4] and the Breit-Pauli relativistic approximation, as implemented in the AUTOSTRUCTURE code [5,6].

Results

A new set of results related to the plasma environment effects on ionization potentials, K-thresholds, K-line transition energies and radiative emission rates in all oxygen ions, from O I to O VII, will be presented at the conference. A comparison between the
atomic parameters obtained using both MCDF and AUTOSTRUCTURE approaches will also be reported and discussed in detail.

References
MCDHF Calculations of Isotope Shifts in Neutral Antimony

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Ab initio multiconfiguration Dirac–Hartree–Fock (MCDHF) calculations have been carried out in order to determine the isotope shifts of all the fine-structure transitions belonging to 5s² 5p³ – 5s² 5p² 6s, 5s² 5p² 6s – 5s² 5p² 6p and 5s² 5p² 6s – 5s² 5p² 7p transition arrays in neutral antimony (Sb I). The theoretical predictions have been compared to laser spectroscopy measurements available in the literature showing a good agreement between theory and experiment.

Motivations

The spectroscopic measurements of isotope shifts (IS) for any element are carried out to test the atomic structures, to deduce the changes in the nuclear mean-square charge radius and to give information on electron behaviour inside the nucleus.

Antimony (Sb), the element of the Periodic Table with Z = 51, has only two stable isotopes ¹²¹Sb and ¹²³Sb with natural abundances of 57.21% and 42.79%, respectively. It also has 36 known radioactive isotopes with mass numbers A ranging from 103 to 140 and with corresponding half-lives spanning from 93 ms (¹³⁹Sb) to 2.7586 years (¹²⁵Sb) [1]. By constrast, the mean nuclear charge radius, \( \langle r^2 \rangle^{1/2} \), is only known for the two stable isotopes, i.e. 4.6802±0.0026 fm for ¹²¹Sb and 4.6879±0.0025 fm for ¹²³Sb [2]. To our knowledge, there are only two measurements of IS published in the literature and they concern exclusively the stable isotopes [3, 4].

Theoretical method and results

In the present study we have used the fully-relativistic multiconfiguration Dirac–Hartree–Fock (MCDHF) method [5] to calculate the IS electronic parameters, \( K_{RNMS} \), \( K_{RSMS} \) and \( F \), for 49 fine-structure levels belonging to the configurations 5s² 5p³, 5s² 5p² 6s, 5s² 5p² 6p and 5s² 5p² 7p in Sb I. These parameters can be used to determine IS of the transitions involving these levels for any pair of Sb isotopes along with their different NMS (Normal Mass Shift), SMS (Specific Mass Shift) and FS (Field Shift) contributions and to deduce the corresponding changes in mean-square nuclear charge radius.

Our ab initio calculations agree very well with the recent measurements of Sobolewski et al [4] and also show the importance of the relativistic effects on the different IS contributions confirming the breakdown of the scaling law for the NMS [6, 7].
References

[1] Table of Nuclides, Nuclear Data Center at KAERI (Korea Atomic Energy Research Institute) [http://http://atom.kaeri.re.kr/nuchart/ (last accessed February 17, 2017)]


New identification of energy levels in the astatine atom, the rarest element on Earth

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A theoretical investigation of the atomic structure of neutral astatine is reported for the first time in the present contribution. This work allowed us to establish the intermediate-coupling composition and to fix the spectroscopic designation of six excited levels within the 6p⁷7s and 6p⁷7p configurations which had been located, but not clearly identified, in previous experimental studies. In addition new tentative identifications of four levels belonging to the 6p⁴9p and 6p⁴10p configurations are reported in this work together with predicted level energies along the 6p⁴np and 6p⁴nd Rydberg series up to n = 50.

Astatine, the most badly known neutral atom of the periodic table

In view of the high radioactivity of all its isotopes, astatine (Z = 85) is the rarest naturally occurring element on the Earth's crust with an estimated total abundance of less than one gram at any given time [1]. Because of its extreme rarity, the chemical and physical properties of astatine are almost totally unknown. Many of these have only been estimated based on its position in the periodic table, making of At the heaviest of halogens, i.e. the group of elements including fluorine, chlorine, bromine and iodine. As regards its electronic structure, the ground state of the astatine atom is 6p⁵ ²P⁳/₂ while the lowest excited configurations are of the type 6p⁴nl (with nl = 7s, 7p, 6d, 5f, ...). Nevertheless, only two excited levels (6p⁴7s ⁴P⁴) were clearly classified until now [2], although some additional tentative identifications of higher-lying states were suggested from recent laser spectroscopy experiments using the resonance ionization laser ion source (RILIS) of the ISOLDE radioactive beam facility at CERN [3] or using the Isotope Separator and Accelerator (ISAC) facility at TRIUMF [4]. As support to further experimental investigations of astatine, it is however useful to know the atomic structure of this element in the most complete possible way.

Newly identified energy levels

In the present work, different physical models based on the pseudo-relativistic Hartree-Fock method including intravalence, core-valence and core-core electron correlation [5-7] have been used for modeling the atomic structure and for computing radiative parameters in neutral astatine. These calculations allowed us to provide for the first time a reliable spectroscopic designation to some energy levels experimentally observed [3,4] but not clearly classified in the 6p⁵, 6p⁴7s, 6p⁴7p, 6p⁴9p and 6p⁴10p configurations. Moreover, a semi-empirical approach based on the quantum defect formula has also been used for predicting level energies along the 6p⁴np and 6p⁴nd (n = 8 – 50) Rydberg series. This new theoretical investigation is expected to provide a useful support to future laser-spectroscopy experiments at ISOLDE and to check other theoretical methods that will be used to model the atomic structure and radiative processes in At I.
References
The quantum three-box paradox with a two-qubit system

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We study the three box paradox in a new form, by replacing the single three-level quantum system by a system of two qubits in a symmetric state. Each box is characterized by a maximally entangled Bell state. The initial and final states are symmetric and separable. We develop a method based on weak measurements to evaluate the probability to find the system of two qubits in one of the three boxes A, B, or C.

The original three-box paradox \cite{1,2,3}

The original three-box paradox involves three indistinguishable boxes (A, B, C) and a ball. First, Alice prepares the initial state of the system (pre-selection). Then, the system is transmitted to Bob, who performs an intermediate measurement to know if the ball is in box \( k = A, B, C \). At the end of the experiment, Alice realizes a final strong measurement on the system. She keeps only the systems that end in a chosen final state (successful post-selection). Surprisingly, the conditional probability to find the ball in box \( k \) between pre- and post-selection is contextual. The value attributed to each conditional probability is different if Bob opens the three boxes simultaneously or only one box during the experiment. Paradoxically, if Bob opens one amongst the two boxes A and C, he finds with certainty the ball. Now, let’s say that Bob measures weakly the system in box \( k \) at the intermediate time which involves small interaction strength between the system and the meter. The result of the weak pre- and post-selected measurement is related to what is called the weak probability to find the ball in box \( k \). The weak probability looks like an expectation value of the related box projector but depends on initial and final states. Weak probabilities can take values outside the range of the eigenvalues of the projectors. They are non-contextual and the same rule holds.

The paradox in a new form

Using unitary transformation and the Majorana representation \cite{4,5}, the three-level quantum states involved in the original three-box paradox are transformed to symmetric two-qubit states \cite{6}. We study the three-box paradox in a new form where initial and final states are separable but each box is characterized by a maximally entangled state, one of the Bell states. If we open box A (or B) between the pre- and post-selection, we observe the system in a maximally entangled intermediate state. We have conceived a method to realize this new version of the three-box paradox in a laboratory. The system (polarization) and the meter (spatial degree of freedom) interact weakly at a beam splitter (characterized by a small reflectivity) in a Hong-Ou-Mandel interferometer. Coincidence counting is used to measure a conditional probability related to the weak probability to find the photon pair in one of the Bell state.

References
Colour Variations in Beetle’s Photonic Crystal Induced upon Contact with Liquids and Vapours

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In nature, exposure of photonic structures to fluids can give rise to striking colour changes. This is the case of the structure causing the blue colour of the scales covering the body of the male Hoplia coerulea beetle. This structure consists of a periodic porous multilayer encased by a 100 nm-thick envelope. In spite of the envelope, which prevents direct contact between the structure and fluids, the colour of this beetle is notable for changing from blue to green upon contact with liquids. Recently, we observed similar colour changes induced by vapours. Both kinds of colour changes were explained by liquid penetration through the envelope and into the structure. Moreover, colour changes induced by water and ethanol may seem counterintuitive. They can be explained by taking into account cuticle properties, i.e. the permeability of chitin and the presence of salts. Reminiscent of the role of a biological membrane, we term this natural structure a “photonic cell”.

Introduction

In nature, the contact of photonic structures (e.g., found on insect wings) with fluids can give rise to striking colour changes [1]. The male cerulean chafer beetle Hoplia coerulea (Scarabaeidae) is notable for displaying an iridescent blue colour, changing to green upon contact with water [2]. The photonic structure giving rise to the blue colour of this insect’s scales is specific, since it consists of a periodic porous multilayer encased by a 100 nm-thick envelope [3].

Fluid-induced colour changes in H. coerulea’s photonic structure

In spite of the envelope, which prevents direct contact of the structure with fluids, reversible changes in colour are induced in this beetle by various liquids [4] and vapours [5,6]. In our investigation, the colour changes in the appearance of this insect were characterised upon contact with water, methanol, ethanol, 2-propanol, propanone, acetonitrile, methylbenzene and ethoxyethane in liquid phase, as well as with water, ethanol, 2-propanol and methylbenzene vapours, using spectrophotometry [4,5] and environmental ellipsometry [6]. This response to fluid exposure was marked by a redshift of the reflectance peak wavelength that was associated with a decrease in peak reflectance intensity upon contact with liquids and with an increase upon exposure to vapours.

Different physico-chemical processes such as the swelling of the structure enacted by the fluids, the presence of a liquid film on the macropore walls, capillary condensation or a combination of them were investigated to explain, specifically, the increase in reflectance intensity: a property not usually associated with vapour-induced optical
signature changes. Colour changes associated both with liquids and vapours were explained by liquid penetration through the encasing envelope and into the structure. In the case of vapours, this phenomenon follows the physisorption of a liquid film on the scale’s envelope and simulations indicate the optical response arises only from the filling of micropores within the body of the photonic structure [5]. In the case of liquids, both micropores and macropores are filled.

Finally, the nature of the colour changes induced by water and ethanol may seem counterintuitive: changes enacted by water are much faster than those by ethanol, in spite of ethanol’s more rapid spread across the elytral surface. This can be explained by taking into account cuticle properties, i.e. the permeability of chitin and the presence of salts in the scale material [4]. The chemical composition of the beetle’s scales was indeed analysed in detail. Sodium, potassium and calcium were detected using X-ray photoelectron spectroscopy (XPS).

**Conclusion**

The case of male *H. coerulea* beetle is an interesting example displaying fluid-induced colour change properties, which were investigated comprehensively. In addition to the investigation of the physico-chemical phenomena at their origin, we highlighted the role of the envelope encasing the porous photonic structures within the scales that cover the beetle’s wings. Reminiscent of the role of a biological membrane, we termed this natural structure a “photonic cell”: namely, a biocompatible photonic structure that is encased by a permeable envelope which mediates fluid-induced colour changes in the photonic structure. These remarkable effects could revolutionise technological fields such as those involving the monitoring of cell-metabolism, vapour sensing applications and smart environment-responsive coatings [7-10].

**References**


Finding the refraction law using the ant colony algorithm and the Fermat’s principle

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The Ant Colony Algorithm (ACA) is applied to classical optics to find back the Snell law of refraction. For sufficiently small simulation space, the algorithm rapidly converges to the optimal solution and the refraction law is recovered. For larger and more realistic systems, the right solution is still approximately found but simulations are more time-consuming. This illustrates that these optimization problems, which can be analytically treated with ease, are still difficult to be fully solved by these algorithms.

The ACA is an optimization algorithm, proposed by Dorigo in 1996 [1], which is based on the collective behavior of ants which are able to find the shortest path between their colony and food [2]. Each ant leaves some pheromones on its way which influences the decisions of the other ants. After a while, the shortest path is covered by the largest amount of pheromones and most of the ants follow this optimal way.

The Fermat’s principle postulates that light always follows the path that minimizes its duration. This principle allows to recover classical optical laws such as light reflection or refraction. In this last phenomenon, light is supposed to cross two media which are characterized by different light speeds (or refractive index). Simple calculus leads to the Snell law, which links the incidence and the refraction angle values.

In this work, we propose to check the Snell law applying the ACA to the Fermat’s principle. The algorithm is limited by the compromise between the size of the simulation space and the computation time. For small simulation sizes, the ACA is able to find the shortest path predicted by the Snell law. For largest simulation spaces, an approximation of the optimal way is found after a long computation time. This illustrates the difficulty of the algorithm to be applied to more complex and realistic systems for the current computers.

References
Effect of the synthetic malaria pigment hematin on water NMR relaxation times: implications for malaria diagnosis by NMR

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About 200 million patients suffer from malaria¹, a parasitic disease caused by protozoans of the genus Plasmodium transferred to humans by mosquito bites. Reliable diagnosis is crucial since it allows the early detection of the disease, thereby increasing the efficiency of treatments. In this context the development of new rapid, sensitive and low-cost diagnosis tools is an important research area². Recently different studies focused on the detection of hemozoin, a major by-product of haemoglobin detoxification by the parasite. Hemozoin and its synthetic analog, β-hematin, have comparable structures and properties. They both form paramagnetic crystals including Fe²⁺ ions. A new detection method of malaria, evaluated by two different groups, takes advantage of the paramagnetism of hemozoin through the effect that such magnetic crystals can have on Nuclear Magnetic Resonance (NMR) properties of neighbouring water protons⁴,⁵. Indeed, magnetic nano- and micro-particles cause a shortening of the relaxation times $T_1$ and $T_2$. In contrast with former data, a recent study proposed, for the first time, a superparamagnetic model for hematin³. In the present work, the magnetic properties of two types of β-hematin are assessed at different temperatures (down to 1.75K) and at different magnetic fields (up to 5 T), to discriminate between paramagnetic and superparamagnetic behaviours. The pure paramagnetism of hematin is confirmed by the results of these magnetic measurements. The NMR relaxations (both $T_1$ and $T_2$) of hematin suspensions are also studied at different magnetic fields. The effect of echo time on the transverse relaxation is evaluated. Our results may help to identify the best experimental conditions for the hemozoin detection by NMR relaxometry: $T_2$ must be chosen, if possible at large magnetic fields and for long echo times, even if this may not be easy to implement with low resolution micromagnetic resonance systems. Indeed these often use low magnetic fields and very short echo times to limit the influence of magnetic field inhomogeneities.

References
Electron paramagnetic resonance study of globin proteins incorporated in mesoporous materials for biosensing applications

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The goal of this project is the encapsulation of myoglobin (Mb) and neuroglobin (NGB) in SBA-15-type silica and titanium oxide (TiO₂) for the fabrication of biosensors. These biosensors can be applied to detect small molecules like H₂O₂ and NO. However, the incorporation of these globin proteins can alter the heme group and thus the protein activity. Electron paramagnetic resonance (EPR) is used to investigate the effect on the heme group before and after the immobilization.

Introduction

The incorporation of globins in mesoporous materials is an important and promising direction for biosensing. The immobilization cannot only stabilize the heme proteins but also improve the activity in the appropriate environment. In particular, the properties of these immobilization matrices should avoid loss of the protein activity and leaching or degeneration of the proteins. The electrochemical activity is enclosed in the heme group of the globin, where the change of the oxidation state of the heme iron can be detected in biosensing applications. These type of biosensors can be used for the detection of small molecules like H₂O₂ and NO. Two different globins will be incorporated, namely horse heart myoglobin (hhMb) and human neuroglobin (NGB). Mb, one of the best-known proteins, is an oxygen-storage protein found in muscle cells with dimensions about 45 x 35 x 25 Å [1]. Mb also facilitates the diffusion of oxygen from blood capillaries to the mitochondria. In contrast, the function of NGB is still uncertain [2]. NGB is predominantly expressed in the nervous system and the structure of NGB displays the typical globin fold as Mb. NGB is extremely stable under pH and temperature conditions known to denature other globins and, under in vitro conditions, it is redox active.

Encapsulating globins in porous materials

Mb and NGB differ in the coordination number of their heme iron (pentacoordinated for Mb, hexacoordinated for NGB). For the encapsulation of Mb and NGB, SBA-15-type silica and titanium dioxide (TiO₂) are used. These mesoporous materials show high biocompatibility and good retention of the protein activity. Besides the large surface area and pore volume, the size and
the morphology of the mesopores are easily fine-tuned. Although simple optical absorption techniques can be used to follow the adsorption and incorporation of the heme proteins, the faith of the proteins inside the pores needs to be addressed by different techniques. Electron paramagnetic resonance (EPR) allows to study the ferric heme center and thus check the stability and state of the globin and its heme group before and after immobilization. Surprising differences in the behavior of the two proteins upon incorporation become apparent via this technique.

References
Unconventional Two-dimensional Vibrations of a Decorated Carbon Nanotube Under Electric Field

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Carbon nanotubes resonators offer unique electromechanical properties, which enables their applicability as advanced mass and force nanosensors. Small quantities of adsorbed mass can be detected by distinct shifts in the frequency of vibrations, which enables diverse biotechnological applications, e.g., DNA sequencing and detection of early stage diseases. Furthermore, such properties can be enhanced by the functionalization with nanoparticles. We show that a carbon nanotube decorated with different types of charged metallic nanoparticles exhibits unusual two-dimensional vibrations when actuated by applied electric field. Such novel vibrations and diverse possible trajectories are not only fundamentally important but also have minimum two characteristic frequencies that can be directly linked back to the properties of the constituents in the considered nanoresonator. Namely, those frequencies and the maximal deflection during vibrations are very distinctively dependent on the geometry of the nanotube, the shape, element, mass and charge of the nanoparticle, and are vastly tunable by the applied electric field, revealing the unique sensing ability of devices made of molecular filaments and metallic nanoparticles.
Multiband effects in the BEC-BCS crossover of double bilayer graphene

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We investigate the effect of the existence of the two energy bands in bilayer graphene on the properties of the density induced BCS-BEC crossover in double bilayer graphene. We characterize the BCS-BEC crossover by calculating the superfluid gap, the condensate fraction and the evolution of the chemical potentials as functions of the density and of the energy band gap between the conduction and valence bands.

There is currently interest in the existence of electron-hole superfluidity in double bilayer graphene and related nano-thin materials[1, 2, 3, 4].

We studied a system consisting of two parallel bilayer graphene sheets doped with electrons and holes and separated by a thin hexagonal Boron Nitride insulating layer[5]. We investigate the crossover phenomena between the high density, weakly interacting BCS regime and the low density, strongly interacting Bose-Einstein condensate (BEC) regime.

We use mean field at zero temperature and a multiband approach that includes intra-band pairing.

Tuning the energy gap between the conduction and the valence bands, it is possible to investigate how the proximity of the two bands affects the electron-hole pairing. The multiband character of the system gives origin to two superfluid gaps. The BCS-BEC crossover can be characterized by studying the superfluid gaps, the condensate fractions and the evolution of the chemical potentials as functions of the carrier densities.

For high density, all the results are insensitive to the energy band gap between the conduction and valence bands. In this case the multiband effects are small and the behaviour of the system can be approximated by a one band system.

In contrast, however, for low density, the results are very sensitive to the energy band gap and the multiband effects become important. At low densities, we predict a superfluid transition only when there is a sufficiently large energy band gap between the conduction and valence bands. With a very small gap we observe the phenomenon of electrons excited from the valence band to the conduction band. This leads to a very high density of electrons in the conduction band, resulting very strong screening that totally suppresses the superfluidity.[5]

References


Localized dealloying phenomena on Cu$_3$Au (100) with hybrid alkanethiol SAMs

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Dealloying is a corrosion process taking place in alloys consisting of elements having sufficiently different equilibrium potentials. During dealloying in a corrosive environment, the less noble component is selectively dissolved yielding a nanoporous network of the nobler component. For a clean Cu-Au alloy, dealloying results in the formation of homogenous nanoporous Au above the so-called critical potential [1]. When this binary alloy is modified by a self-assembled monolayer (SAM) of organic thiol inhibitors [2], localized dealloying takes place yielding localized nanoporous regions, often with micro-sized cracks [3]. The microcracks formation on the surface is due to the internal stress caused by volume shrinkage during nanoporosity formation. The development of the cracks depends on the surface orientation and on the nature and stability of the organic inhibitor SAM layer [4]. To date, the initiation and subsequent formation of localized corrosion remains poorly understood.

In this work, we studied localized dealloying on a Cu$_3$Au (100) surface modified by hybrid SAMs combining microcontact printing and subsequent molecular adsorption of different alkanethiols. With a surface-science approach to prepare atomically flat Cu$_3$Au (100) surfaces, the atomically well-defined surfaces were modified by microcontact printing with 1-octadecanethiol and later backfilled with 1-butanol. This approach results in spatially well-localized regions covered with different alkanethiols. Electrochemical AFM measurements were performed to follow localized dealloying, while ex-situ high-resolution FIB-SEM imaging provided an overview of the dealloyed regions. Localized dealloying was visible on Cu$_3$Au (100) surfaces, exhibiting clear differences between long-chain thiol-covered areas and short-chain thiol-covered areas. Sub-surface characterization of the dealloyed area morphology by FIB-SEM showed anisotropic growth of the dealloying front, growing faster laterally along the surface than vertically into the bulk.

References


Paradoxical electron transport in mesoscopic networks

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Paradoxical electron transport is encountered in two-terminal mesoscopic network patterned in a two-dimensional electron system (2DES). Decreasing locally the electron density in a network can lead to an increased network electrical conductance (G). We propose here to shed light on the physical mechanisms behind these counter-intuitive behaviours thanks to a scanning gate microscopy (SGM) technique. We find that paradoxical transport stems either from 1D channel acting as Fabry-Perot cavities, from attenuated ballistic back-scattering due to a smoothed hard wall potential or from the presence of disorder-induced localized states governing electron transport through Coulomb blockade mechanism.

1D electron systems [1] are archetypal building blocks of nanoscale quantum devices. Although electron transport through such systems has been intensively studied for more than 25 years, few studies focused on complex networks of 1D channels. Are there unexpected mechanisms ruling electron transport in mesoscopic networks? We discuss here several occurrences of peculiar apparently paradoxical physical behaviour in these systems, and address the question of their origin by means of a scanning gate microscopy (SGM) technique. We find that paradoxical transport stems either from 1D channel acting as Fabry-Perot cavities, from attenuated ballistic back-scattering due to a smoothed hard wall potential or from the presence of disorder-induced localized states governing electron transport through Coulomb blockade mechanism.

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behaviour analogous to the Braess paradox: the suppression of an axis in a transport network can surprisingly improve the overall network performances. Indeed as shown along the dashed red line in Fig. 2c, $G$ exhibit a non-monotonous behaviour when the polarised tip depletes the central channel (only). The robustness of this puzzling behaviour is inspected by varying the global 2DES density with an electrostatic backgate, magnetic field and the tip-surface distance [4]. Depending on the overall 2DES density, we show that either Coulomb Blockade resonances due to disorder-induced localized states or Fabry-Perot interferences tuned by the tip-induced electrostatic perturbation can generate Braess-like behaviours.

Figure 1: a) Micrograph of a network patterned using electron beam lithography and wet etching in an InGaAs/InAlAs heterostructure (etched part in dark grey). b) SGM mapping of the network presented in a). c) Tight-binding simulation of an SGM mapping of the network. Conductance enhancements (brighter dots) are present in both SGM measurement (b) and simulation (c).

Figure 2: a) AFM topography of the network embedded in an artist’s view of the tip-network system. The different parameters present in our SGM experiment are shown: the tip potential ($V_{tip}$) and the tip-sample surface distance ($d_{tip}$). b) Micrograph of the network whose conductance ($G$) is measured. c) Conductance measurement as a function of $V_{tip}$ with the tip scanned along the dashed white line seen in b) for $d_{tip} = 80$ nm.

References

Kinetics of irreversible polymer adsorption

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The irreversible adsorption of macromolecules onto solid substrates may affect several physical properties of thin polymer layers (for thickness < 200 nm). To untangle the origin of this phenomenon, we have studied irreversible adsorption of several polymers onto silicon substrates using the ellipsometry technique. Irreversible adsorbed layers were obtained by washing off non-adsorbed chains in a good solvent of previously spincoated thin polymer films and after annealing the system at temperatures above the glass transition. To elucidate the role of polarity on adsorption, we have considered a series of polystyrene analogues, with different dipole moment of the monomer. We show that, regardless of the polarity, the formation of an adsorbed layer follows the same kinetics, characterised by a crossover between a linear regime at short times and a logarithmic regime at longer times. Remarkably, we observe system dependent deviations from the expected scaling for the maximum adsorption amount of system.
Imaging ellipsometry and BRDF experiments of gold nanoparticles embedded in a polymer matrix

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Nano-objects and more particularly metal nanoparticles (NPs) play a central role in the development of nanotechnology-based optical devices. The collective oscillations of their conduction electrons are at the origin of their optical properties. In this study, we investigated the kinetics of growth of these NPs in real time with imaging ellipsometry and with the bidirectional reflectance distribution function.

Introduction

Numerous studies were carried out to investigate the optical properties of plasmonic nanocomposite materials from the experimental, theoretical as well as numerical points of view [1]. One can use Au NPs in spectral selective coatings to block solar infrared radiation [2], in random lasers [3], in non-linear optical applications [4] and more recently as saturable absorbers in passive Q-switch systems [5]. In the latter systems, the transmitted intensity is given by

\[ \alpha = \frac{\alpha_0}{1 + I / I_0} \]

where \( \alpha_0 \) is the linear absorption coefficient, \( I \) and \( I_0 \) the intensity and the intensity at saturation, respectively. The absorption coefficient decreases due to the depletion of the ground level in the absorbing system. One the other hand, intensity losses (and among others the scattering of the incident radiation) are drawbacks for saturable absorbers. We have focused this study on the global optical effect of growing nanoparticles in polymer films in terms of scattering and of local optical response. More specifically, the local optical properties and the topography of the films were studied by imaging ellipsometry (IE) and atomic force microscopy (AFM), respectively. The scattering properties were studied through the bi-directional reflection distribution function (BRDF).

Materials and methods

There are numerous synthesis methods for such materials which globally belong to two categories: the synthesis of NPs in a liquid medium which provides more control during their growth or their \textit{in situ} synthesis e.g. by thermal annealing of a noble metal-doped solid phase. Our plasmonic nanocomposites embedding gold nanoparticles were \textit{in situ} prepared by thermal annealing of spin-coated poly-(vinyl) alcohol (PVA) film containing HAuCl\(_4\), the polymer acting both as a stabilizing and as a reducing chemical agent. Coating conditions were adjusted to obtain a film thickness of about 380 nm. The gold
concentration in the PVA matrix was 2% (w:w) which corresponds to a volume fraction $f_{Au} = 0.13\%$ in the dry film. The gold nanoparticles were imaged by AFM. A typical image at the $5 \mu m \times 5 \mu m$ resolution is presented in Fig. 1b. The optical scattering of the nanocomposite films was analysed by the bi-directional reflection distribution function (BRDF). The BRDF was measured in collimated mode ($\lambda = 570 \pm 10$ nm) with an angle of incidence of $\theta_i = -20^\circ$ (Fig. 1b).

**Results**

As evidenced by the diffuse reflection of a 658 nm laser beam at the surface of a nanocomposite film deposited on silicon (Fig. 1a), annealing of the samples at 135 °C induces the growth of gold NPs (Fig. 1b). It increases the roughness of the film as well as the light scattering at the surface. The BRDF shows that annealing samples induces an important back-reflection of the incident light (Fig. 1c). In parallel with the increase of the scattering, the locally resolved $\Psi$ and $\Delta$ ellipsometric angles are also strongly modified by the annealing process and a diffraction pattern corresponding to local modifications of the optical properties gradually appears. This diffraction pattern is the optical signature of the nanoparticles growth and it can be quantified by measuring the skewness of the ellipsometric angles statistical distributions as a function of the time.

![Figure 1](image1.png)

**Figure 1**: (a) Diffuse reflection image of a 658 nm laser beam reflecting on a Au-PVA nanocomposite (Incidence: 45 deg., Detection: 0 deg.) – (b) AFM topography image of a PVA matrix embedding in situ synthesized gold NPs. (Image size: $5 \mu m \times 5 \mu m$) – (c) Experimental BRDF at $\theta_i = -20$ deg. and $\lambda = 570$ nm: sample annealed 90 min at 135 °C (irradiation from right to left).

**References**


**Acknowledgments**

Thanks are due to S. Wuyckens (UMONS) for some imaging experiments.
How to detect the invisible: Dealing with missing energy in the CMS detector at CERN

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A key question in physics is to understand the nature of Dark Matter (DM). Unfortunately, those particles only interact through weak and gravitational forces: DM produced in proton-proton (pp) collisions would escape the detector without leaving any signal. Therefore, understanding how missing energy can arise in the CMS detector is crucial. Neutrinos are a genuine source of missing energy that must be modeled. Moreover, experimental issues can add “fake” missing energy: dead regions in the detector, cosmic rays, etc. In this poster, a summary of the main sources of missing energy and how they are dealt with is presented.

Physics motivations

A key question in modern physics is to understand the origin and the nature of Dark Matter (DM). The CMS collaboration has a broad experimental program to try to detect DM particles. Unfortunately, those particles are thought to be interacting only through weak and gravitational forces, which makes them invisible to the CMS detector. If the LHC was to produce DM particles in proton-proton collisions, they would escape the detector without leaving any signal, exactly as neutrinos do. In order to be sensitive to this kind of exotic signal, DM particles must be produced alongside with a detectable object: those events are labeled as “mono-X”, where X stands for the object balancing the missing energy carried away by the DM.

Sources of missing energy

In this context, understanding how missing energy can arise in an event recorded by the CMS detector is of primary importance. First of all, neutrinos created in the collision and escaping the detector are an irreducible and genuine source of missing energy. This must be precisely modeled using simulations of SM processes based on Monte Carlo methods. On top of this, experimental issues can add “fake” missing energy to the balance: dead regions in the detector due to deficient electronics, cosmic rays, beam halo muons, etc. In this poster, I present a summary of the main sources of missing energy, how they are dealt with and what analyses do they have an impact on.

References

A search for a new narrow resonance decaying to an electron pair or a muon pair is performed using 13 TeV proton-proton collision data collected by the CMS experiment at the LHC Run 2. The dielectron event sample corresponds to an integrated luminosity of 12.4 fb$^{-1}$ while the dimuon event sample corresponds to an integrated luminosity of 13 fb$^{-1}$. The results are interpreted in terms of the possible presence of a new massive narrow spin 1 boson decaying into electron or muon pairs, for different new physics scenarios beyond the Standard Model [1].

References

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Search new physics in final state with an electron and a muon in proton-proton collisions at 13 TeV

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The lepton flavour violating (LFV) processes are predicted by several scenarios of new physics beyond the Standard Model. In particular, the LFV decay of a heavy state into an electron-muon pair would be a clear signature that might be observable at the LHC. A search for high mass resonances decaying into the electron-muon final state using 2015 data with an integrated luminosity 2.7/\text{fb} in proton-proton collisions at 13 TeV collected by CMS detector is presented. The selection of the interesting events is detailed, as well as the main backgrounds coming from the top-antitop production and from diboson processes. No evidence for physics beyond the Standard Model is observed in the invariant mass spectrum of selected electron-muon pairs. The results are interpreted in terms of two different models, the R-parity violating SUSY model [1] and the Quantum Black Hole model [2].

References


Discovery of a Mathematical Error in Albert Einstein’s Paper 1904 Entitled “ON THE GENERAL MOLECULAR THEORY OF HEAT” and Calculating the New Order of Magnitude of the Radiation Wavelengths (black-body radiation)

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Abstract
I have recently discovered a mathematical error in Albert Einstein’s derivation [Einstein 1904] of equation $T^c \sqrt[kv]{3} (2^3) = T^c$ (Equation 28 in his paper, k and c are universal constants for ideal gas law and Stefan-Boltzmann law). Because of this mathematical error [Einstein 1904] in the equation, his prediction of $(0.420/T)$ for the order of magnitude of the radiation wavelengths is incorrect. I have derived the correct form of equation [28] given in his original 1904 paper. The correct equation is $\sqrt[kv]{3} = (\frac{\sqrt[k]{k}}{\sqrt[c]{c}})^{\frac{3}{2}}$ and calculated the new value for the order of magnitude of the radiation wavelengths as $(0.263/T)$.

This new value is based on the solution of the first order differential equation,
\[
\int \frac{dE}{E^2} = \int \frac{dT}{T^2} \quad \text{for the value of } E.
\]

Correcting this mathematical error indeed shows that Einstein’s prediction for the order of magnitude of the radiation wavelengths is more accurate than he thought during his life time.