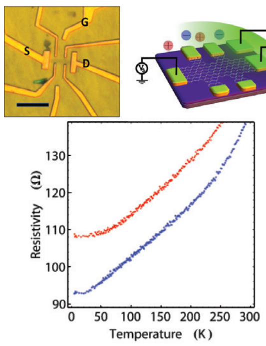
Highlights from the previous volumes

Graphene transport at high carrier densities using a polymer electrolyte gate

The electronic properties of graphene have received wide recognition, most notably the award of the 2010 physics Nobel Prize. In graphene's two-dimensional hexagonal lattice, the electrons behave as massless chiral fermions obeying the Dirac equation. The exotic nature of these quasi-particles and their low carrier density is at the heart of several interesting phenomena, including the unconventional quantum Hall effect and Klein tunneling. Raising the density of charge carriers in graphene can have several implications including the possibility for van Hove singularity driven high-T_c superconductivity. From a fundamental point of view, the high carrier densities substantially modify the interactions between quasi-particles in this two-dimensional crystal.

In this report, graphene devices in Hall-bar geometry are gated with a polymer electrolyte to realize carrier densities an order of magnitude higher than achieved by conventional methods. At these densities, the carriers sufficiently screen the long-range interactions. This allows to fully appreciate the importance of various neutral defects on the graphene lattice. In contrast to metals, the temperature scale for quantum suppression of acoustic-phonon scattering in graphene is significantly gate-tunable. The phenomenon is readily observed to high temperatures at high carrier densities.



The figure shows the temperature dependence of graphene resistivity at high (red) and intermediate (blue) carrier densities. Since phonon modes follow the Bose-Einstein law, the scattering of electrons from acoustic phonons is strongly suppressed at low temperatures, thus leading to power-law dependence. The temperature scale that determines this suppression increases linearly with the Fermi level. At high doping, the resistivity is weakly density-dependent. A detailed analysis shows there is an important contribution from neutral weak scatterers. Top panel: optical image and schematics of graphene device coated with polymer electrolyte gate.

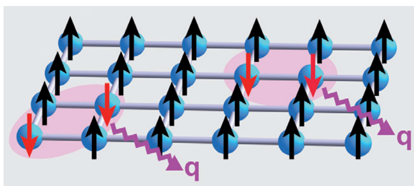
Original article by PACHOUD A. *et al.*
EPL, **92** (2010) 27001

Bose-Einstein condensation of bound magnon pairs

Strong quantum fluctuations can destroy conventional dipole-type magnetic ordering. A quantum magnet remains, then, in a disordered spin-liquid state down to zero temperature. The enhanced fluctuations may also stabilize magnetic analogues of liquid crystals, states with partially broken rotational symmetries characterized by tensor order parameters. The prime candidates for such exotic spin-nematic states are frustrated magnetic systems with competing interactions.

In our paper, we investigate theoretically a microscopic mechanism for the spin-nematic ground state based on the competition of ferro- and antiferromagnetic interactions. In a strong magnetic field, local magnetic moments become completely polarized. Elementary excitations are single spin-flips or magnons. In the majority of quantum antiferromagnets spin-flips repel each other. Upon decreasing external field this leads to single-particle condensation, which can be regarded as an analog of the Bose-Einstein condensation discovered for cold atomic gases in optical traps. Various exotic quantum states of bosonic particles find their analog in conventional magnetic structures.

The above conventional scenario changes if some of the exchange bonds are ferromagnetic. In this case, spin flips gain the interaction energy by occupying two adjacent sites. This may lead to formation of bound magnon pairs. Because of their lower energy, the bound pairs start to condense prior to the onset of single-particle condensation (see figure). We have developed the microscopic description of the Bose condensation of bound magnon pairs, which form a quantum state analogous to the condensate of electron pairs in superconductors. Our theory predicts the presence of such a spin-nematic phase in the frustrated chain material $LiCuVO_4$. The pulsed-field measurements on $LiCuVO_4$ and other related compounds should lead to the first observation of this exotic off-diagonal order in solid-state systems.



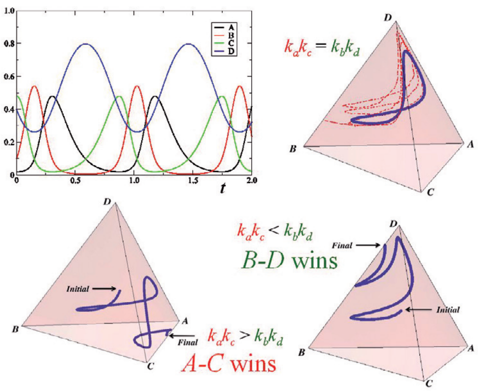
In the spin nematic state, bound pairs of magnons (down-spins shown by red arrows) propagate coherently in the polarized ferromagnetic background.

Original article by ZHITOMIRSKY M. E. and TSUNETSUGU H.
EPL, **92** (2010) 37001

Cyclic competition of four species: Mean-field theory and stochastic evolution

Population dynamics is a venerable and widely applicable subject. Over the last two centuries, many studies provided valuable insights into various phenomena, *e.g.*, the emergence of biodiversity and fitness/extinction, while novelties are continually being discovered. Specifically, recent investigations of three species competing cyclically (*e.g.*, rock-paper-scissors game) revealed rich and complex behaviors, whether the populations are well mixed or dwelling on one- or two-dimensional lattices. Indeed, the well-mixed system displayed surprising survival probabilities: the species with the slowest consumption rate wins, leading to a popularized headline "Survival of the Weakest". Fascinating properties were also found in systems with spatial structure, including formation of complex patterns and mobility effects. Many aspects can be understood by exploiting techniques from statistical physics and non-linear dynamics.

Our work focuses on *four* cyclically competing species. Unlike the 3-species case, ours allows final states with coexisting pairs. The reason is simple: resembling the game of Bridge, the four form two opposing teams of ally-pairs. For each pair, the *product* of their consumption rates determines if it wins or loses. From a master equation for the full stochastic problem, we derive an approximate set of rate equations (ODEs). Predictions from the latter typically agree well with simulations. Instead of the weakest surviving, our observations support a different maxim: "The prey of the prey of the weakest is the least likely to survive". Intuitively reasonable, this principle also applies to the special 3-species case! Meanwhile, a variety of intriguing extinction probabilities, discovered through simulations, provides numerous challenges for future research.



Opposing pairs (A-C, B-D) of equal strength evolve deterministically on a closed orbit (blue loop), oscillating endlessly (upper left). An example of stochastic trajectories is shown in red (dashed line). Lower panels display systems with identical initial conditions but different strengths, ending at opposite edges.

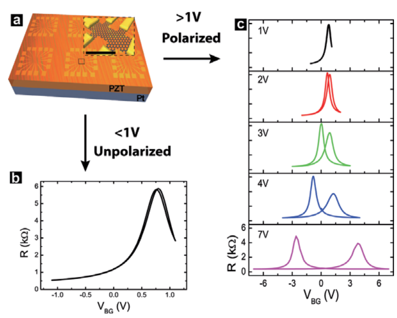
Original article by Case S. O. *et al.*
EPL, **92** (2010) 58003

Wafer-scale graphene/ferroelectric hybrid devices for low-voltage electronics

The soaring demands on non-volatile memory for ultra-portable electronic devices have grown NAND flash into a multi-billion dollar business. As a Si-CMOS–based technology, NAND flash provides the most aggressive scalability, closely following the state-of-art semiconductor manufacturing process. NAND flash also takes advantage of its relatively simple floating-gate structure and seamless integration with Si-CMOS logics, leading to significant lower production cost over other competing non-volatile technologies such as FeRAM and MRAM.

Graphene, with its ultra-high mobility and almost unlimited scalability down to atomic scale, is considered now as one of the most promising candidate materials for replacing Si. Graphene-based non-volatile memory has also been demonstrated very recently. However, a seamless solution for integrating graphene transistors and non-volatile memory remains a challenge.

In this report, Zheng *et al.* demonstrate the wafer-scale patterning and device operations of Cu-CVD graphene-ferroelectric field effect transistors (GFeFETs) on ferroelectric $Pb(Zr_{0.3}Ti_{0.7})O_3$ (PZT) substrates, integrating both transistor and non-volatile memory functionalities on the same chip by controlling the local ferroelectric polarization magnitude. In the linear regime of PZT, ultra-low-voltage operations of GFeFETs within ± 1 V can be used as controlling transistors for addressing and reading/writing of memory unit cells. After polarizing PZT, the hysteretic switching of GFeFETs is ideal for ultra-fast non-volatile data storage. The combination of high-quality Cu-CVD graphene and functional substrates will not only greatly speed up the studies of all graphene-based electronics but also open up a new route in exploring new graphene physics and functionalities.



The figure shows the device operations of GFeFETs on PZT (a) with different local ferroelectric polarization magnitude. In the linear regime of PZT (b), ultra-low-voltage operation of graphene field effect transistors within ± 1 V with maximum doping exceeding $10^{13}\,cm^{-2}$ and on-off ratios larger than 10 times is demonstrated. After polarizing PZT (c), switching of graphene field effect transistors is characterized by pronounced resistance hysteresis, suitable for ultra-fast non-volatile electronics.

Original article by Zheng Yi *et al.*
EPL, **93** (2011) 17002