Séminaires de Physique de Clermont Ferrand.

Geometrical effects in solid state physics and photonics

Institut Pascal, CNRS, UCA, Sigma.

4 - 5 mai 2017

Salle 119 du Pole Physique

Jeudi 4 mai

14h15-15h15 Jean-Noel FUCHS, Frederic PIECHON, Gilles MONTAMBAUX
Laboratoire de Physique du solide, Orsay.
Geometry of Bloch states probed by Stückelberg interferometry

15h15-15h40 Break

15h40-16h40 Guillaume MALPUECH, Olivier BLEU, Dmitry SOLNYSHKOV,
Institut Pascal-Photon, Clermont-Ferrand
Topological and geometrical effects in honeycomb polaritonic lattices

Vendredi 5 mai

9h-10h Frederic PIECHON, Jean-Noel FUCHS, Gilles MONTAMBAUX,
Laboratoire de Physique du solide, Orsay.
Geometrical description of the orbital magnetic susceptibility: quantum metric and Berry curvature

10h-10h20 Break

10h20-11h20 Anton NALITOV
School of Physics and Astronomy, University of Southampton
Spontaneous Polariton vorticity and weak lasing

Geometry of Bloch states probed by Stückelberg interferometry

Jean Noel Fuchs, Frederic Piechon, Gilles Montambaux.

Inspired by recent experiments with cold atoms in optical lattices, we consider a Stückelberg interferometer for a particle performing Bloch oscillations in a tight-binding model on the honeycomb lattice. The interferometer is made of two avoided crossings at the saddle points of the band structure (i.e. at M points of the reciprocal space). This problem is reminiscent of the double Dirac cone Stückelberg interferometer that was recently studied in the continuum limit. Although the two problems share similarities -- such as the appearance of a geometric phase shift -- lattice effects, not captured by the continuum limit, make them truly different. The particle dynamics in the presence of a force is described by the Bloch Hamiltonian H(k) defined from the tight-binding Hamiltonian and the position operator. This leads to many interesting effects for the lattice Stückelberg interferometer: a twisting of the two Landau-Zener tunnelings, saturation of the inter-band transition probability in the sudden (infinite force) limit and extended periodicity or even non-periodicity beyond the first Brillouin zone. In particular, Stückelberg interferometry gives access to the overlap matrix of cell-periodic Bloch states thereby allowing to fully characterize the geometry of Bloch states, as e.g. to obtain the quantum metric tensor.

Topological and geometrical effects in honeycomb polaritonic lattices

Olivier Bleu, Dmitry Solnyshkov, Guillaume Malpuech
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In this presentation I will consider honeycomb lattices for exciton-polaritons and analyze the topological properties of the 1s band against:

-The staggering of the lattice.
-The photonic spin orbit coupling (SOC) related to the TE-TM splitting.
-The Zeeman field (either induced by a magnetic field, or self induced).
- The presence of an interacting quantum fluid in the media.

Most of these studies have been performed in the last decades by solid state physicists, the main difference with the photonic/polaritonic case being the specific symmetry of the TE-TM SOC with respect to the Rashba SOC, and the experimental accessibility of the polaritonic platform. For instance, I will show, throughout this presentation, simulations showing experimentally accessible real space wave-functions and propagation of protected edge modes.

The staggering of the lattice allows to emulate an Hamiltonian close to the one of Transitional Metal Dichalcogenide monolayers (TMD) [1,2]. A gap opens and the bands show non zero Berry curvature and orbital angular momentum at K and K' but with opposite signs in each Valley. This Valley contrasting physics is at the origin of the unique optical selection rules in TMDs and the so-called Valley Hall effect. One can define a non-zero Valley Chern number (opposite in each valley), but the total Chern number is null. As a result, an interface between two staggered lattices with opposite staggering supports chiral Valley polarized states whose existence can be explained by the difference between the Valley Chern numbers, which is a Z2 topological invariant. The related effect can be called **Quantum Valley Hall effect** . One should notice that these states are not protected from disorder induced inter-valley scattering [2].

The combination of the TE-TM SOC and of a Zeeman field also opens a band gap, but this time, the Berry curvature has the same sign at K and K' and the bands are topologically non-trivial characterized by a non zero Chern number. The sample supports one way edge states with a full topological protection (**Quantum Anomalous Hall effect**) [3]. I will show that tuning the magnitude of the Zeeman splitting and TE-TM SOC leads to a topological transition having no equivalent in electronic systems [4]. Both the direction of propagation and number of edge modes can be tuned by just tuning the pumping strength of an external laser. An optically controlled chiral valve (CHIVAL) for light can be organized based on this effect.

Finally, I will show that at an interface between a staggered and a regular honeycomb lattice in the Quantum Anomalous Hall phase, one can organize a perfect Valley filter, namely topologically protected Valley polarized one way states. This is a Valley polarized version of the CHIVAL.

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[2] O. Bleu, D.D. Solnyshkov, G. Malpuech, arXiv:1703.05104.
[3] A. Nalitov et al. **Phys. Rev. Lett. 114**, 116401 (2015).
[4] O. Bleu, D.D. Solnyshkov, G. Malpuech, **Phys. Rev. B, 93**, 085438 (2016), **Phys Rev. B, 95,** 115415 (2017).

Geometrical description of the orbital magnetic susceptibility: quantum metric and Berry curvature

Frederic Piechon, Jean Noel Fuchs, Gilles Montambaux.

The orbital magnetic susceptibility measures the equilibrium response of a spinless electronic system to an external magnetic field B. For a single band model, the orbital susceptibility is given by the Landau-Peierls (LP) formula and is entirely determined by the energy spectrum. In particular, it is diamagnetic at parabolic band edges but appears strongly paramagnetic at a Van-Hove singularity. For multi-band systems we have recently developed a general formalism that goes beyond the LP formula. This formalism allows the study of the possible strong inter-band effects that are encoded in the geometric structure of Bloch states. In particular, for two-band models, it appears that the inter-band susceptibility is composed of essentially two distinct contributions. The first contribution is entirely determined by the Berry curvature. It is paramagnetic inside the bands and exhibits a diamagnetic plateau in a gap separating two bands. The second contribution depends on the quantum metric tensor defining the distance between Bloch states. Interestingly, this second contribution always exists even for systems with a vanishing Berry curvature. It is shown that it can be tuned to exhibits either a diamagnetic or a paramagnetic plateau in a gap. The heuristic interpretation of these two inter-band contributions is quite distinct. This first contribution may be understood as measuring the reciprocal space fluctuations of the Berry curvature and orbital magnetic moment. In contrast, by introducing a magnetic field dependent shift to the Berry connection, it is shown that this second contribution may be interpreted as an induced magnetization.

Spontaneous polariton vorticity and weak lasing

Anton Nalitov
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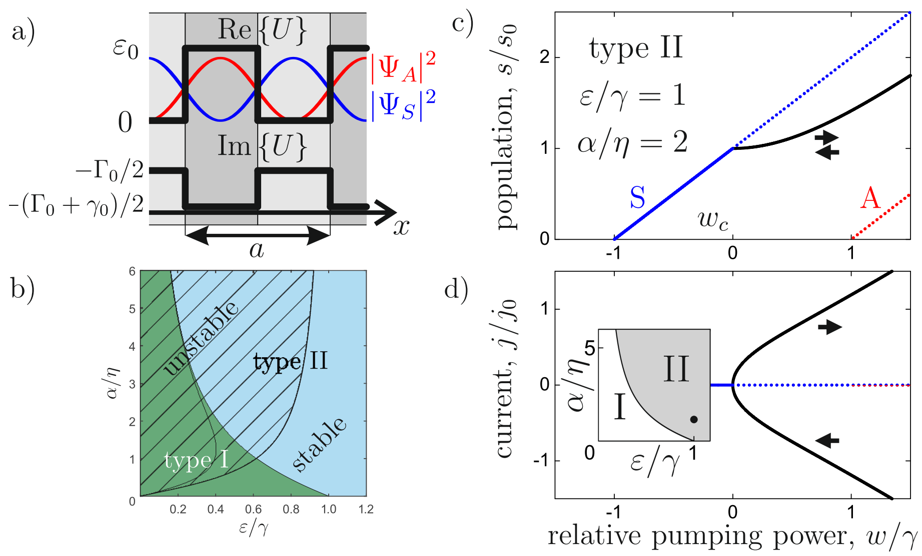

Figure 1: a) Non-Hermitian periodic potential for polaritons. Two states at the edges of the first minigap form the condensate. b) Stability diagram of possible phase transitions. Two relations span the parameter space of the system. c) Typical phase transition towards spontaneous current weak lasing state. d) Bistability of spontaneous polariton currents.

Exciton-polaritons are half-light half-matter quasi-particles that appear due to extreme confinement of light in semiconductor nanostructures. Combining properties of matter particles and photons, they are able to mimic Bose-Einstein condensates on one hand and lasers on the other hand. At the same time, polariton condensates fundamentally differ from both, as the are not bound to obey neither energy nor losses minimization principles, which govern the physics of BECs and lasers respectively. This is vividly demostrated in recently predicted [1] and observed [2,3] weak lasing phase, emergent from strong polariton repulsion dominating in the stabilization mechanism of nonequilibrium condensates. Transition to this phase is accompanied with spontaneous translational [2] or time-reversal [3] symmetry breaking. We predict that this mechanism can also be responsible for spontaneous vorticity and $\mathcal{PT}$-symmetry breaking in trapped polariton condensates [4], stochastic polariton currents and counter-intuitive spin and density patterns.

References

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[2] H. Ohadi et al., Phys. Rev. X **5**, 031002 (2015)
[3] L. Zhang et al., PNAS, **112** E1516 (2015)
[4] A.V. Nalitov et al., arXiv:1612.01185 (2016)