Collective Phenomena in Condensed Matter Physics

Symposium in Honor of Philippe Nozières

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Discovery of “topological states of quantum matter” in the ILL Collège de Théorie, 1977-81

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The 2016 Nobel Prize for physics was in part awarded for discoveries I made while in the theory group led by Phiilippe Nozières.

Starting from the Kondo problem that Philippe was actively interested in (and which was the subject of my Ph. D Thesis), I was gradually led to study “bosonization”, and to formulate the theory of Luttinger liquids, which in turn led to applications to quantum spin chains, a subject of both experimental and theoretical interest at the ILL, culminating in the unexpected discovery that the spin-1 Heisenberg antiferromagnetic chain has a gapped ground state, contrary to all prevailing opinion of the time.

Though the initial manuscript reporting this discovery was rejected for publication by a number of journals, this state is now regarded as the simplest prototype of a “topological quantum state”. The environment of the ILL theory group, Philippe’s guidance, and the possibility of discussions with the numerous leading scientists who visited, played a key role in nurturing these discoveries.

Spacio-temporal patterns of dynamical phase transition to the excitonic insulator state

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Phase transformations induced by short optical pulses is a mainstream in studies of cooperative electronic states. We present a semi-phenomenological modelling of spacio-temporal effects expected when optical excitons are coupled to an order parameter as it happens e.g. in organic compounds with neutral-ionic ferroelectric phase transitions. After the initial pulse of photons, a quasi-condensate of excitons can appear as a macroscopic quantum state which then evolves interacting with other degrees of freedom prone to an instability. The self-trapping of excitons enhances their density which can locally surpass a critical value to trigger the phase transformation. The system is stratified in domains which evolve through dynamical phase transitions and may persist even after the initiating excitons have recombined.

A conceptual complication appears here, where both the excitation and the ground sate ordering are built from the intermolecular electronic transfer. To describe both thermodynamic and dynamic effects on the same root we adopt for the phase transition a view of the Excitonic Insulator - a hypothetical phase of a semiconductor which appears if the total energy of an exciton becomes negative. We call for the possible dynamic realization of this once exotic conjecture in circumstances of fast optical pumping.

Nucleation of diffusion controlled phase transformations in the solid state, beyond or beside classical nucleation theory ?

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First order phase transformations in metallic alloys may occur in a number of ways, depending if the composition is conserved or changed, and depending on the mechanisms of structural transformations from one crystallography to another. When the transformation is diffusion controlled, it may occur by the amplification of concentration fluctuation (spinodal decomposition) , or by nucleation and growth of the new phase. The classical nucleation theory, developed initially for liquids and solids, have been adapted to solid state transformations in pure metal and binary alloys. In alloys having more than three elements, where the diffusion coefficients may differ by orders of magnitude, the situation is more complex, both for the growth mechanisms , but also for the nucleation mechanisms. Recent experimental observations and simple calculation show the necessity to revisit classical nucleation theory in this context.

Non-traditional phase transitions in liquid crystals

Efim.I. Kats

Borrowed from textbooks on thermodynamics and statistical physics wisdom gives a classification of phase transitions into two types: continuous or second-order phase transitions, where the latent heat is zero, and the 1-st order phase transitions, where it is not zero. In some more advanced modern textbooks and monographs referred to another standing alone (and in the world of two-dimensional systems) Berezinskii - Kosterlitz - Thouless transitions having some features of the 1-st and 2-nd order transitions. In this work one example from the realm of liquid crystals (smectic A - Hexatic smectic phase transition) of non-traditional thermodynamic behavior is discussed. We propose and theoretically describe mechanisms for such non-conventional behavior, and new predictions following from the consideration.

A new problem in biophysics: How to reroute a cell signaling pathway

Bertrand Fourcade

Supersolidity in ultracold atomic gases

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Philippe Nozières, to whom this talk is dedicated, had always the passion for the role of symmetries and conservation laws in the context of many-body physics. In a perspective paper, published in 2011 on JLTP [1], he also anticipated crucial issues concerning the phenomenon of supersolidity, a novel state of matter which has now become an active field of experimental and theoretical research in ultra cold atomic gases [2].

In my talk I will review some of the most important achievements concerning supersolidty in dipolar gases, which include, among others, the observation of coherence of the modulated density profiles [3], caused by the spontaneous breaking of translational invariance, and of the Goldstone modes [4], reflecting the nature of the broken symmetries (gauge symmetry and translational invariance).

Propagation of sound in these systems is well described by hydrodynamic theory of supersolids, accounting for the coupling between superfluid and crystal phonons [5].

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[4] L. Tanzi, et al.: Supersolid symmetry breaking from compressional oscillations in a dipolar quantum gas. Nature **574**, 382 (2019); M. Guo et al.: The low-energy Goldstone mode in a trapped dipolar supersolid. Nature **574**, 386 (2019); G. Natale et al.: Excitation spectrum of a trapped dipolar supersolid and its experimental evidence. Phys. Rev. Lett. **123**, 050402 (2019)

[5] M. Sindik, T. Zawislak, A. Recati and S. Stringari: Sound, superfluidity and layer compressibility in a ring dipolar supersolid, arXiv:2308.05981 (2023).

Discussing physics with Philippe

Bernard Castaing

I shall evocate the discussions I had with Philippe Nozières, in the late seventies and eighties. It concerns Polarized ^{3}He, and the liquid-solid interface of ^{4}He. I shall particularly emphasize the question of the interfacial mass.

Beyond X-Rays absorption experiments

Yves Petroff

ESRF

My first contact with Philippe Nozières dates back to 1964. At the time, I was doing my thesis at the ENS Laboratory in Paris and I went to ask him questions about plasmons in semiconductors. Later on, in 1971, I was beginning to take an interest in synchrotron radiation possibilities and I had some questions on his famous paper, written with C. T. De Dominicis on the absorption of X-rays in metals, which had been verified by experiments on Na at the Hamburg synchrotron (DESY) by the R. Haensel'group. At that time, synchrotron radiation experiments were done on synchrotrons, only allowing absorption measurements. It is only in the beginning of the 1970s, with the appearance of stable beams on collision storage rings and later on with the use of undulators, allowing to gain a factor 10^4 in brightness, that it was possible to develop completely new techniques like Angle Resolved Photoemission Spectroscopy, Resonant Inelastic Scattering in soft X-Rays, Inelastic Scattering in hard X-Rays with 1 meV resolution, extremely high pressure Diffraction and Spectroscopy. This allowed to do some experiments that, previously, could be done only with neutrons. I will describe some recent results showing the enormous evolution of these possibilities. From 1992, being DG of the ESRF between 1993 and 2OO2, I interacted more with Philippe, especially after 2004, having offices side by side, which allowed me to see him and ask some stupid questions.

Patterns formation in low dimensional electronic crystals

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The reported work was motivated by STM experiments on visualization, manipulation and tracing the evolution of defects (polarons, solitons, and domain walls) embedded into electronic super-lattices in solids ([1] and rfs. therein). Particularly, the layered materials demonstrate a vast collection of electronic crystals, including an enigmatic "polaronic Wigner-crystalline Mott insulator" in TaS2, which are prone to formation of globules or a network of charged domain walls. The Monte Carlo simulation [2] of the 2D classical charged lattice gas recovered an ordering phase transitions followed by a gradual coalescence of point defects into interconnected segments of domain walls which branch at vertices possessing the vorticity. The effective attraction developing from the purely repulsive Coulomb interactions follows from the charge fractionalization across the domain wall. Examples of formations of walls' globules in our modeling and in experiments are shown in figures below.

Spatial patterns should also appear in quasi-1D charge density waves when the optical pumping or charge injection or spin polarization form a concentration of topological defects like the solitons at the primary level of isolated 1D chains. Under cooling, the ensemble of solitons in a coupled array of chains passes through two phase transitions: i. the confinement of individual solitons into bound pairs and ii. the aggregation of microscopic solitons into macroscopic domain walls. This was confirmed [3] by the Monte Carlo modelling including the destructive role of long range Coulomb interactions.

References:

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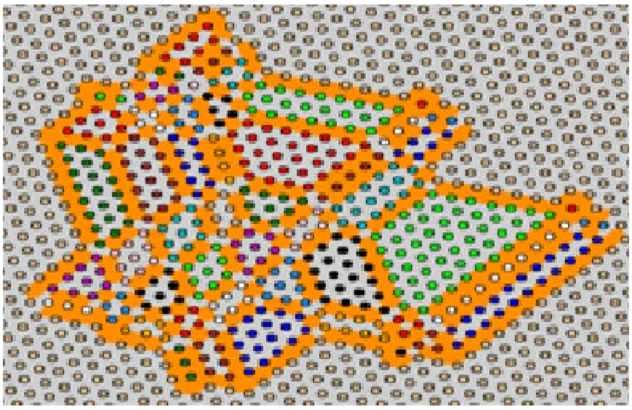

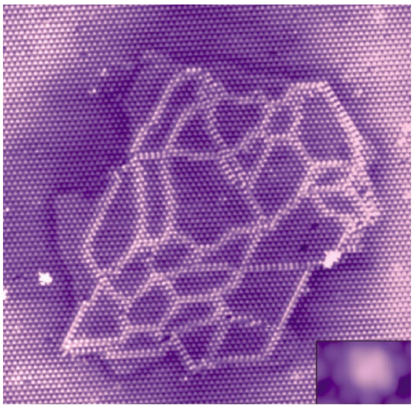

Quantum transport and cold atomic gases

Thierry Giamarchi

Quantum transport through a system between two reservoirs, at e.g. different chemical potentials, although routinely observed, is a very challenging theoretical question since it is one the most common but also most important ways to put a quantum system out of equilibrium.

Such a situation is relevant not only for charge transport but also for other transport properties such as spin transport or Hall transport for systems which are put under a magnetic field. These questions crucial for the condensed matter community have been boosted recently by other realizations coming from ultracold gases, which allow also to deal with perturbations such as time dependent noise or losses of particles as well.

I will discuss in this talk various incarnations of such quantum transport, and their theoretical solutions or challenges. I will show how techniques inspired from the seminal paper of Caroli, Combescot, Nozieres and Saint-James, computing the tunneling current in Metal-Insulator-Metal junctions, allow to deal with several of such problems. I will review the experimental realizations and discuss the challenges that remain to be addressed.