

Solid state plasmas

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Magnetic fusion devices operate at regimes characterized by extremely high temperatures and low densities, for which the charged particles motion is perfectly described by classical mechanics, with quantum effects playing virtually no role (except in the calculation of the collision cross-sections). This is not true, however, for solid-state metallic objects: Their density approaches 10^{28} m^{-3} , so that the average interparticle distance is shorter than the de Broglie wavelength, which characterizes the extension of the electron wave function. Under these conditions, the conduction electrons behave as a true quantum plasma even at room temperature.

These quantum features become even more apparent for metallic objects of nanometric size, such as metallic nanoparticles, thin films, and nanorods, which have stimulated a huge amount of scientific interest in the last two decades, both for fundamental research (they are at the border between classical and quantum physics) and for potential technological applications that range from physical chemistry, to biology and medicine. For instance, “plasmonic resonances” – i.e., electronic oscillations near the plasma frequency – are routinely observed in metallic nanoparticles, and their properties (resonance width, damping, dipole and quadrupole modes, ...) are studied experimentally using ultrafast spectroscopy techniques. Indeed, as the plasma period in metallic nanoparticles is of the order of one femtosecond (10^{-15} s), the recent development of femto- and attosecond laser sources has opened up a vast domain of research (“nanoplasmonics”) that is still being explored [1, 2].

In this talk, I will first review some of the basic aspects of solid-state electron plasmas, with particular emphasis on the different levels of description – from exact approaches (many-body Schrödinger equation), to mean-field models (Hartree equations, density-functional theory, Wigner phase-space methods), down to macroscopic models of the hydrodynamic type.

Secondly, I will present new advances related to recent experiments [3] on the coherent coupling between a femtosecond laser pulse and the magnetization of a ferromagnetic thin film. For strong enough pulses, the magnetic field of the pulse can couple directly to the electron spin, leading to the rapid demagnetization of the sample. Further, the electrons can be so strongly accelerated by the fields that relativistic effects come into play, also contributing to the spin dynamics (spin-orbit coupling). This complex scenario requires the modelling of the nonlinear dynamics of a quantum-relativistic system of many electrons interacting with an electromagnetic field. Some recent results based on the Dirac and Pauli equations will be presented [4].

References

- [1] M. I. Stockman, *Nanoplasmonics: Past, Present, and Glimpse into Future*, Opt. Express **19**, 22029 (2011).
- [2] J. A. Scholl et al, *Observation of Quantum Tunneling between Two Plasmonic Nanoparticles*, Nano Lett. **13**, 564–569 (2013).
- [3] J.-Y. Bigot et al, *Coherent ultrafast magnetism induced by femtosecond laser pulses*, Nat. Phys. **5**, 515 (2009).
- [4] A Dixit et al, Phys. Rev. A **88**, 032117 (2013); Y. Hirschberger et al, Phys. Lett. A **376**, 813 (2012).