Electron dynamics: charges and spins

Giovanni MANFREDI

This course offers an introductory survey of the electron dynamics in metallic objects of nanometric size. After briefly recalling the main physical properties of metallic nanoparticles and their applications, we describe the features of the linear electron response in the framework of the Mie theory. The typical space, time, and energy scales are derived and discussed. We then turn to the nonlinear electron response, which is relevant whenever the electron population is strongly excited, e.g. by a laser pulse. We present an overview of the principal time-dependent models utilized to describe the electron dynamics, with particular emphasis on mean-field theories in the phase space (Wigner functions) and quantum hydrodynamics. Beyond-mean-field methods, such as the density functional theory, are briefly mentioned and discussed.

The second part of the course deals with magnetization and spin effects. After a short reminder on the quantum-relativistic origin of the spin (Dirac equation), we concentrate on the weakly relativistic regime that is most relevant to nanophysics. We discuss the Zeeman, spin-orbit, and other effects in the framework of the Pauli equation. For many-body systems, we show how the spin and magnetization dynamics couple to the Maxwell equations. The above phase-space and hydrodynamic models will be extended to the spin dynamics.

As an illustrative example, we analyze the electron dynamics in a thin metal film excited with an ultrashort laser pulse, both in the case of a nonmagnetic and a ferromagnetic material.