Light-Matter Interaction

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Materials can ideally be studied by monitoring their response to an excitation with coherent radiation. Experimental techniques have been improved and perfected over a period of many years, which has led to the establishment of a broad range of highly sensitive spectroscopic techniques that are able to provide, in a nondestructive way, detailed insight in physical properties or processes.

The underlying concept is the light-matter interaction, which holds the key to understanding the outcome of spectroscopic investigations. In these lectures we shall treat the light-matter interaction at several different levels of complexity. One of the main aims of the lectures is to achieve a fundamental understanding of how coherent radiation interacts with spin and orbital magnetism in a magnetic material and can thus be exploited to accurately probe magnetism.
We first consider the *macroscopic* formulation of light-matter interaction, given by the Maxwell-Fresnel theory, which forms the foundation of classical materials optics. On this level it is already possible to understand the basics of many nonmagnetic and magnetic spectroscopies, such as magnetic circular and linear dichroism, Faraday and Voigt effects and magneto-optical Kerr effect. The description of electromagnetic waves in materials will be considered, in relation to the wavelength of the radiation. We shall explore in which ways magnetism can be probed in this framework.

As a next step, we move to electron-based *quantum theory* of spectroscopy. We briefly consider the Drude-Lorentz model, to continue with the quantum formulation of light-matter interaction. We derive the Hamiltonian for the coupling of light to the electron states, at various levels of sophistication (nonrelativistic, extended Pauli or Dirac Hamiltonian). To obtain a materials' specific theory it is needed to compute first the microscopic electron states, which can be efficiently done within density functional theory. Spectroscopies that measure properties being linear in the amplitude of the light's electric field can be quite well treated within linear response theory. In combination with relativistic first-principles electronic structure calculations, this provides us with an accurate, predictive description of magnetic spectroscopies, in which the determining microscopic quantities are spin-orbit and exchange interaction [1,2]. We shall compare magnetic spectroscopies at optical wavelengths with those at X-ray wavelengths [3]. Limitations of the approach will be discussed.

Moving then to nonlinear spectroscopies we consider those that probe response quantities, which are quadratic in the electric field amplitude. Among these is the inverse Faraday effect, that gives a magnetization induced in a material by circularly polarized radiation. This effect has potential for applications such as all-optical magnetization switching, in which magnetism can be controlled by femtosecond laser pulses. We end with an outlook on developments in probing and manipulating magnetism on the shortest possible time scales [4].

References

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