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Project title: Electron-beam spectroscopies for nonspherical particles: semi-analytic treatment

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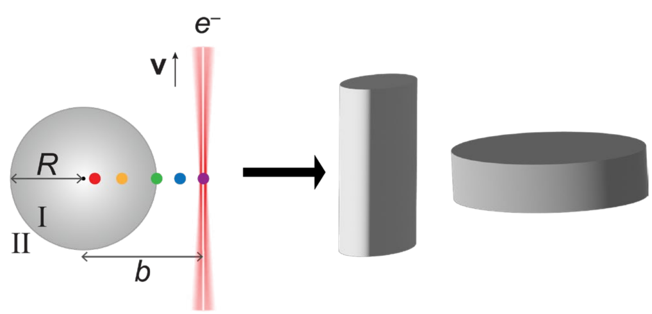
PROJECT DESCRIPTION:

The importance of electron-beam spectroscopy as an efficient tool for the optical characterisation of materials has been steadily growing in the past couple of decades [1]. Swift electrons passing through, or close by a sample, can excite the optical modes that this sample sustains—even those that cannot be directly excited by light. The excitation of these modes subsequently leads to emission of radiation from the sample, which can be collected in an optical microscope, in a technique that is known as cathodoluminescence (CL) spectroscopy. At the same time, while the electron beam interacts with the sample, it loses energy; measuring these losses is the basis of the complementary technique of electron-energy loss spectroscopy (EELS). Exploiting both EELS and CL, metallic [2] and dielectric [3] nanostructures can be probed with unprecedented accuracy. Nevertheless, exactly because electron beams are more efficient than light in exciting all optical modes in nanostructures, the interpretation of the spectra can be more challenging [4]; (semi)analytical solutions for the measured spectra are thus highly desirable. For spherical particles and external electron trajectories, such solutions exist for decades [5]. Recently, our group expanded this solution to the case of penetrating electron trajectories as well [6].

The aim of this project is to proceed with the next natural step in this treatment, i.e. to expand it for the case of nonspherical particles as well. To this end, we will keep relying on the expansion of the incident and scattered fields in spherical waves, and replace the scattering matrix of the spherical particle by the one corresponding to the nonspherical case. This can be done with the so-called extended boundary condition method (EBCM), which is described in detail in textbooks [7].



This treatment is straightforward to apply in the case of external electron-beam trajectories, and will be the focus of the project. At a first step the student will study and reproduce the Mie-theory based solution of Ref. [6]. The numerical code that is available right now is written in **Matlab** and, depending on the student's experience in programming, it might be used as it is, or it might be rewritten and optimised. Subsequently, the scattering matrix for the nonspherical nanoparticle will be introduced. Ref. [7] provides a ready-to-use code in **Fortran**; understanding of the language is therefore useful, but not a prerequisite, since the students can, in any case, code the appropriate expressions in their preferred environment. At the last stage of the project, the new code will be tested in terms of the physics, by applications in metallic or dielectric particles of elliptical or cylindrical (pillars, discs) shape.

[1] F. J. García de Abajo – Rev. Mod. Phys. **82**, 209 (2010).
[2] E. J. R. Vesseur et al. – Nano Lett. **7**, 2843 (2007).
[3] T. Matsukata et al. – ACS Photonics **6**, 2320 (2019).
[4] S. Fiedler et al. – Nano Lett. **22**, 2320 (2022).
[5] F. J. García de Abajo – Phys. Rev. B **59**, 3095 (1999).
[6] P. E. Stamatopoulou et al. – Phys. Rev. Res. **6**, 013239 (2023).
[7] M. I. Mishchenko et al. – *Scattering, Absorption, and Emission of Light by Small Particles* (Cambridge Uni. Press, 2002).