Master Physique — Condensed Matter and Nanophysics
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Orbital magnetism in ensembles of interacting gold nanoparticles

Advisors: Guillaume Weick & Dietmar Weinmann
Location: Institut de Physique et Chimie des Matériaux de Strasbourg (IPCMS)

Due to their small size, metallic nanoparticles show spectacular quantum effects that are absent in the bulk. Most of these effects stem from the confinement of the electronic eigenstates, which is important because of the large surface-to-volume ratio in particles with nanometric sizes. The resulting size effects show up in many of the physical properties of metallic clusters, e.g., in their abundance spectra, static dipole polarizabilities, ionization potentials, and optical properties.

An aspect that attracted considerable attention over the last two decades is the unusual magnetic behavior of gold nanoparticles. Indeed, while gold is diamagnetic in the bulk, several experiments have shown that ensembles of gold nanoparticles capped with organic ligands can present a ferromagnetic-like behavior of the magnetization, up to room temperature or above. Other samples show a paramagnetic-like behavior, and some others a diamagnetism which is typically stronger than in the bulk. These different magnetic properties that fluctuate from sample to sample, as well as the underlying mechanisms giving rise to these features, are a source of intense debate in the litterature [1].

Our Mesoscopic Quantum Physics Team has recently put forward that the observed paramagnetic behavior of certain samples can be explained in terms of the orbital magnetism of a noninteracting, statistically-distributed (in size) ensemble of gold nanoparticles [2]. Depending on its size, each nanoparticle in the ensemble can have a very large paramagnetic or diamagnetic response, but once the ensemble average is performed, only the paramagnetic component survives. Very recently, it was also argued by others [3] that the spin-orbit interaction, which can be quite important for gold, leads to a change from a paramagnetic behavior to a diamagnetic one of the noninteracting ensemble of particles. However, the observed ferromagnetic response of other samples is still a puzzle, and strongly suggests that the interparticle magnetic dipolar interactions should play a crucial role.

The goal of this internship is to theoretically investigate the orbital magnetism of *interacting* metallic nanoparticles employing many-body techniques. In a first step, we will develop a self-consistent model which incorporates the long-range magnetic dipolar interactions between the nanoparticles as well as the semiclassical magnetic susceptibility of the individual particles elucidated in Ref. [2]. Then, this many-body self-consistent problem will be solved numerically using fast multipole methods [4]. The student will work in the Mesoscopic Quantum Physics Team at IPCMS (R. Jalabert, G. Weick, and D. Weinmann) and in close contact with experimentalists conducting experiments on assemblies of gold nanoparticles at IPCMS. For more information, please contact G. Weick (email: guillaume.weick@ipcms.unistra.fr).

[1] G.L. Nealon *et al.*, Nanoscale **4**, 5244 (2012)
[2] M. Gomez Viloria, G. Weick, D. Weinmann, R.A. Jalabert, Phys. Rev. B **98**, 195417 (2018)
[3] B. Murzaliev, M. Titov, M.I. Katsnelson, Phys. Rev. B **100**, 0754256 (2019)
[4] R. Beatson, L. Greengard, *A short course on fast multipole methods* (Oxford University Press, 1997)