Thinking out of the box in nanoplasmonics

In classical optics, the interaction of metal particles with light can be expressed using the refractive index of the metal. An important question in nanoplasmonics is when this classical theory breaks down and what new effects, perhaps quantum effects, start to play a role.

For tiny metal nanoparticles, the classical theory predicts that the optical resonances will not depend on the particle size, but only on its shape. But this is not seen when shining light on few-nanometer sized metal particles. Instead, for noble metals such as silver and gold, the resonances of smaller particles move to higher frequencies ("blueshift"), while for so-called simple metals such as sodium the resonances shift instead to lower frequencies ("redshift").

Until now these phenomena could only be reproduced with quantum mechanical ab-initio calculations, which are numerically very costly. Giuseppe Toscano and co-authors from Germany, China, and Denmark have now developed a simpler hydrodynamic theory for light that also predicts the observed frequency shifts. This increases our understanding of the origin of these frequency shifts. And since the new hydrodynamic calculations are less heavy, they can be used to make accurate predictions for more and larger structures than before. The research is published in Nature Communications.

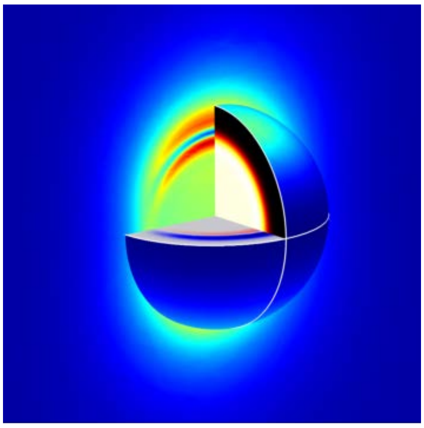

Figure: Electric field and charge densities in a nanosphere, based on the self-consistent hydrodynamic theory by Toscano et al.

So what is the origin of the different frequency shifts? Classical Drude theory assumes that the electrons in a metal are free to move, at least within the "box" defined by the metal geometry. Standard hydrodynamic theory also makes this assumption, and then incorrectly predicts that resonances of smaller particles will always shift to higher frequencies, for whatever kind of metal. Giuseppe Toscano et al. have now "removed the box" from hydrodynamic theory, and describe how electrons will spill out a tiny little bit also outside the box defined by the classical boundary of the metal. (Less than a nanometer, but still.) In noble metals, this spill-out is negligible so that standard hydrodynamic theory is pretty accurate, but in simple metals the spill-out is larger and gives rise to the observed redshifts of optical resonances for smaller particles.

Original publication:

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