

Matter dancing to light's beat: probing optomechanical properties of nanoscale matter with the angular momentum of structured light

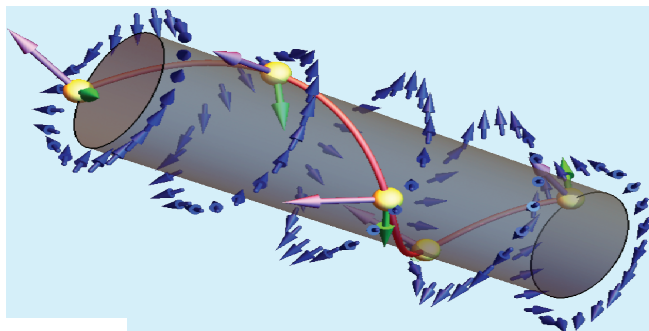


Figure 2: The calculated trajectory (in red) of a glass submicron-sized sphere (yellow), as a result of energy and momentum transfer from the electromagnetic field (blue) generated by a laser. The light also imparts a torque (purple) which varies along the trajectory, causing the sphere's orientation (represented by the green arrow) to continually change along as it propagates along the path.

Sufficiently intense laser light can interact with matter, resulting in the transfer of appreciable amounts of energy, momentum and even angular momentum. In a landmark experiment, Arthur Ashkin and coauthors observed that a single tightly focused laser beam can trap micro and nanoscale dielectric particles. The realization of such a device, dubbed “optical tweezers”, led to the 2018 Nobel Prize in physics (see <https://tinyurl.com/yy38z8zy>).

In their original 1985 experiment, Ashkin et al. achieved the trapping of dielectric particles in all three dimensions, and observed that the particles found a stable equilibrium position wherever the laser's intensity reached a local maximum. Later, Yohai Roichman and coauthors engineered extended regions where intensity of laser light was constant, and found that within these regions particles follow the light's *phase gradient*— that is, the direction where the phase of the light wave is increasing most rapidly (see <https://tinyurl.com/yb7xt3x8>).

These discoveries have opened up the possibility of engineering the structure of light— through its polarization and phase properties—in order to control the trajectory of the nanoscale matter it interacts with. In recent years, theoretical modeling work by Wooster students Carlos Owusu-Ansah '21, John Schmidt '23, Kelsey McEwen '24, and Therrin Baker '28, have led to a new understanding of how structured light impacts the trajectory and orientation on anisotropic nanoparticles of various types. We have found that the polarization structure of the light can cause the particle to spin, which can in turn impact the particle's trajectory in nontrivial ways. In short, nanoscale matter dances to light's beat.

In this project, we will build on these discoveries to probe theoretically how observation of nanoparticle motion under the influence of structured light may act as a tool for measuring the particle's material properties— or conversely, given nanoparticles of known composition, as a tool for measuring the properties of the light itself! For dielectric particles, a fundamental mechanism known as the electromagnetic self force plays a central role in the particle dynamics; while for conducting particles, resonances may occur that are expected to dramatically impact the optical forces and torques experienced by the particle.

Currently, this project is predominantly theoretical in nature, and will involve both pencil-and-paper calculations as well as numerical modeling and analysis through graphical visualization using Mathematica and/or other programming languages. However, the project is now maturing to the point that the design of a related experiment is a possibility.