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Magnetized plasmas that "twist light" can produce high-power microscopes, and more.

A non-twisting laser beam propagating through magnetized plasma can be converted into a rotating "optical vortex" that can trap, rotate and control microscopic particles. This opens a new frontier in high-powered microscopy.

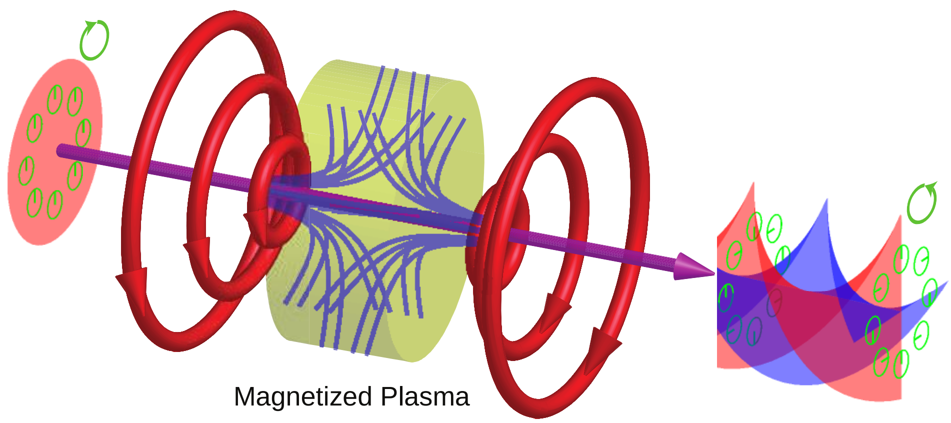

Image courtesy of Kenan Qu
Converting a Gaussian laser beam into an optical vortex in magnetized plasma. An input Gaussian laser beam is sent through a plasma, which is mediated in an axial symmetric magnetic field generated by anti-Helmholtz coils. Traveling through the plasma twists the laser beam wavefront. The light red and blue shades at right show the isosurfaces of the wavefront in which the electric fields are parallel and perpendicular to the azimuthal directions, respectively. The small green circles show the polarization. The green ticks show the instantaneous directions of the electric fields. The green shaded cylinder is the plasma and blue lines illustrate the magnetic field lines.

The Science

Light is a travelling wave of electric and magnetic fields. We all know that when a stone is thrown into a pond, the wavefronts form concentric circles. For a laser beam of light moving uniformly in one direction, the wavefronts form parallel sheets. There exists another special type of light beam, called an "optical vortex," whose wavefronts twist and rotate as it passes through space. This vortex can trap, rotate and "control" microscopic particles or droplets, thereby functioning as an "optical spanner" that enhances the control flexibility of the "optical tweezers" that can trap particles. Development of this method for cooling and trapping particles won the 1997 Nobel Prize in Physics. Super-resolution microscopes, with resolutions smaller even than the diffraction limit of light, can also be built using optical vortices. Showing how led to the 2014 Nobel Prize in Chemistry.

Low intensity optical vortices can be formed using birefringent material media, such as quartz or liquid crystal, which split light into parallel and perpendicular "polarizations." However, using conventional material media for the microscopes has its limitations. As the intensity (power) of the optical vortex increases, the material literally burns up and is destroyed. To produce high-power optical vortices we need a better approach.

The Impact

Dr. Kenan Qu and collaborators at Princeton Plasma Physics Laboratory have introduced a method by which optical vortices with 1000x more power than previous methods can be produced using magnetized plasmas. Plasmas are ionized gases that can be controlled with strong magnetic fields. By creating a nonuniform magnetic field in the plasma, as shown in the figure, the motion of the lightwave parallel to the magnetic field is separated from the perpendicular motion of the wave, and their interference causes the wave to rotate.

An optical vortex has rotating wavefronts and a hollow intensity profile. To create an optical vortex, physicists use a plasma q-plate to combine an infinite number of light waves with slight phase differences, called "superposition." Due to interference effect, the waves annihilate each other in the beam center and concentrate the energy near the beam edge. The superposition also leads to the nontrivial rotating structure, as shown in the figure.

We expect that the *plasma q-plate* will revolutionize sources for generating optical vortices, impacting a broad range of applications. These include: optical communication (increasing the communication bandwidth of both optical fiber communication and millimeter-wave wireless communication); quantum information (leading to the next generation of super-computers based on quantum physics, with *unbreakable* encryption in quantum communication systems); super-resolution microscopy (beating the diffraction limits of spatial resolution, using e.g. the Stimulated Emission Depletion [STED] microscopy that earned the 2014 Nobel in Chemistry); and multi-dimensional manipulation of particles ("optical spanner").

Summary

This paper addresses how an optical vortex beam can be produced at high intensity. Q-plates produced in material media are limited by thermal damage. This limitation may be removed by employing a plasma medium. The task of creating the required structure in plasma is challenging because plasma is inherently unstructured. Here, we circumvent the difficulty of creating structure by introducing anisotropy through a magnetic field.

We show that a non-twisting laser beam, after propagating through magnetized plasma, can be converted into an optical vortex. The magnetized plasmas can manipulate the laser wavefront and directly convert a high-intensity Gaussian beam, say at a terahertz, into a twisted beam with high efficiency.

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Publications

K. Qu, Q. Jia, & N. J. Fisch, “Plasma q-plate for generation and manipulation of intense optical vortices.” Phys. Rev. E 96, 053207 (2017).

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https://journals.aps.org/pre/abstract/10.1103/PhysRevE.96.053207