Three-Dimensional Trapping and Rotation of Dielectric Particles via a Laguerre-Gaussian Beam

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An optical tweezers setup was constructed using a Helium-Neon laser and an inverted microscope, and later modified to produce a Laguerre-Gaussian beam. This Laguerre-Gaussian beam was utilized to transfer orbital angular momentum from the laser to trapped dielectric particles.

1 Introduction

It is well documented that three-dimensional optical tweezers can be made by having a tightly focused laser beam incident on dielectric particles [1]. Optical tweezers utilize the transfer of momentum of light as it travels through a refractive particle to trap the particle in the center of a concentrated light beam. Tweezers are useful in the biological sciences for testing the strength of bonds in biological molecules, as well as in other fields, such as the construction of nanomaterials [5]. When combined with controlled rotation due to either Laguerre-Gaussian mode or circular polarization through a birefringent material, applications such as microrheology and construction of molecular motors also become possible [2][4].

1.1 Optical Tweezers

Optical tweezers function by manipulating the momentum change associated with the transfer of light through a dielectric material. In a Guassian beam profile, the light at the center of the beam has a higher intensity than that of the surrounding light. This requires a larger momentum change to be imparted at the center of the beam for refraction to occur, consequently delivering a stronger pull on the particle towards than center than toward the edges. With the laser light being focused from a microscope objective with a high numerical aperture, this can be done with a standard Helium-Neon laser. The use of a tightly focused laser through an objective also provides the advantage of allowing for light to

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come from the sides as well, providing a pull backwards to compensate for the forward push of the laser's light pressure on the specimen.

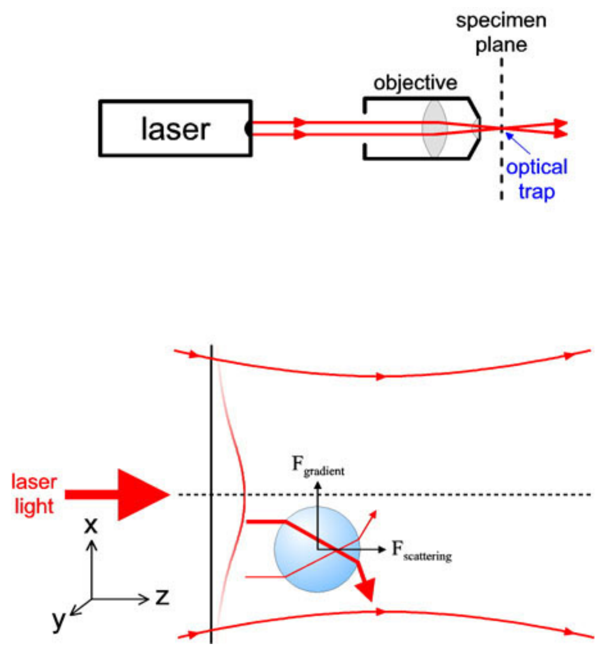

Figure 1: A diagram demonstrating the mechanisms behind optical tweezers. From Block Lab at Stanford University, Stephen Block, `https://blocklab.stanford.edu/optical_tweezers.html`. Copyright 2015 by Stephen Block

1.2 Vortex Tweezers

An optical tweezers setup can be modified using a beam such as a Laguerre-Gaussian, which possesses orbital angular momentum that it is able to transfer to a trapped particle. A Laguerre-Gaussian beam can be created from a TEM_{00} mode using a spiral phase plate, which utilizes the different indices of refraction of the phase plate and the air around it in order to provide an azimuthal phase shift to the wave. The center of the beam destructively interferes with itself due to the phase differences made present, and a ring shaped, or 'doughnut' as it is sometimes called, beam is formed in the far field. In an experiment, this far field beam can be simulated by imaging the focal point of a lens onto the specimen. A Laguerre-Gaussian beam may also be formed using a holographic diffraction pattern, oftentimes generated using a computer and displayed on a spatial light modulator. Laguerre-Gaussian beams are often useful in optical tweezers setups because they allow for controlled rotation of the trapped particles. Light that reflects off of trapped particles or is absorbed transmits orbital angular momentum possessed by the beam to the trapped particles, causing them to orbit around the phase singularity at the center of the beam.

2 Setup

A 30 mW Spectra-Physics Model 127 Helium-Neon laser was used as the light source for the experiment. A Glan-Thompson polarizer was placed at the output of the laser to control attenuation, and the light was then passed through a telescope. The telescope consisted of lenses of F=100 millimeters and F=400 millimeters. The expanded beam, with a beam spot of approximately 6 millimeters, then passed through an RPC Photonics 633 nm variable spiral phase plate. The beam was then focused by an F=150 millimeter lens, in order to both mode match into the non-infinity corrected objective that was used and to provide a far-field substitute for formation of the Laguerre-Gaussian mode.

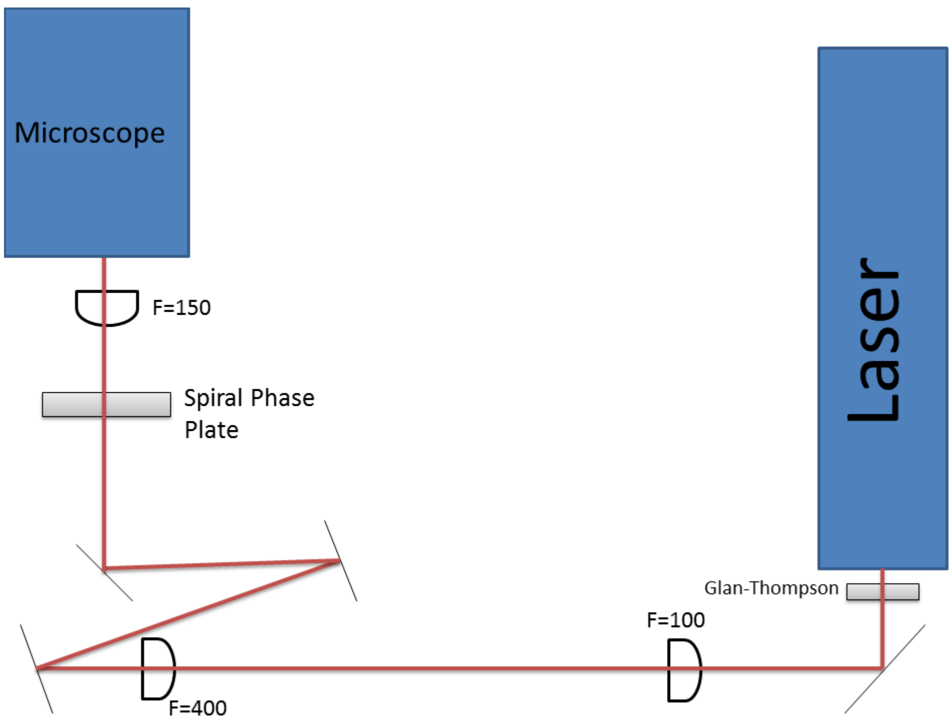

Figure 2: The setup of the optical table

The beam was then passed into a Nikon inverted microscope by way of a dichroic mirror, using a 50x magnification Melles Griot objective with a numerical aperture of 0.85. The objective imaged the sample onto a Thorlabs CMOS camera, which was connected to a nearby desktop computer. A pair of OD 1.5 laser protection goggles were placed between the dichroic mirror and the camera in order to selectively remove the beam from the image without affecting the sample. Samples consisted of silica microspheres of 3, 5, 10, and 15 μm, as well as diluted milk samples.

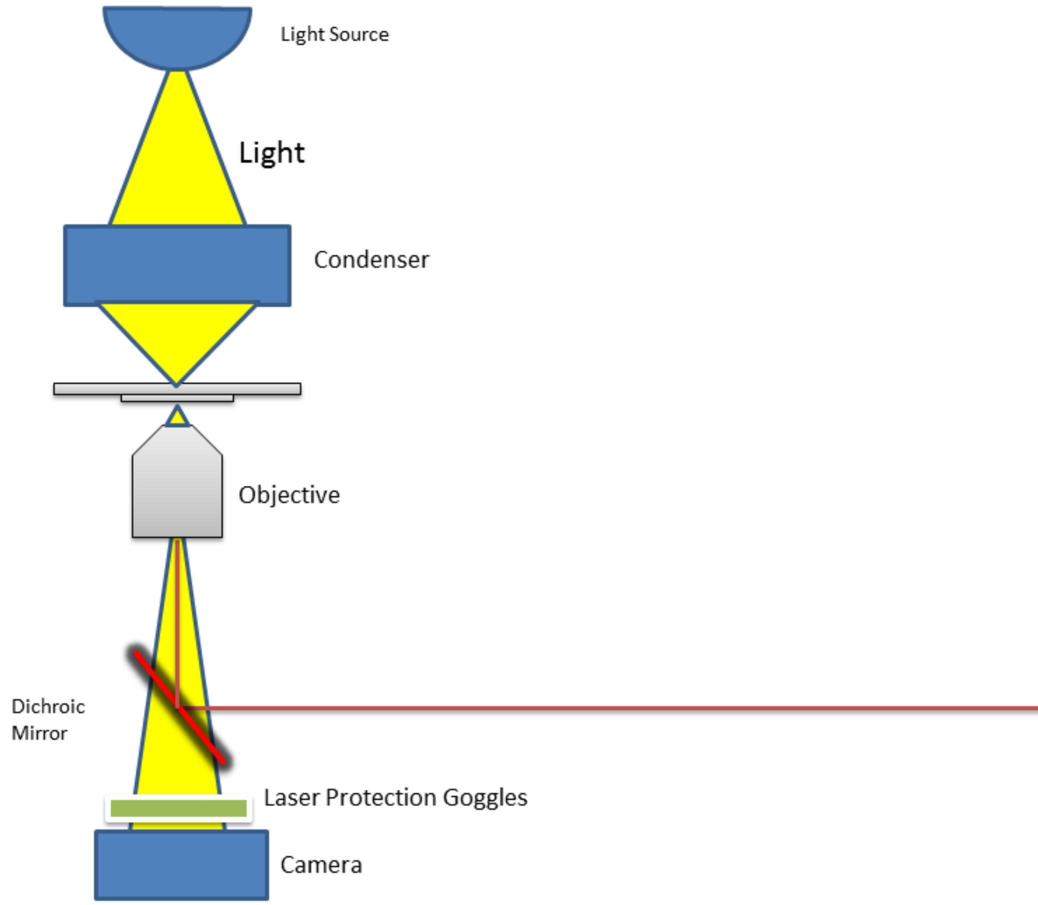

Figure 3: The setup of the inverted microscope

3 Results

The spiral phase plate was successfully able to produce vortex beams in the sample plane, as shown in Figure 4.

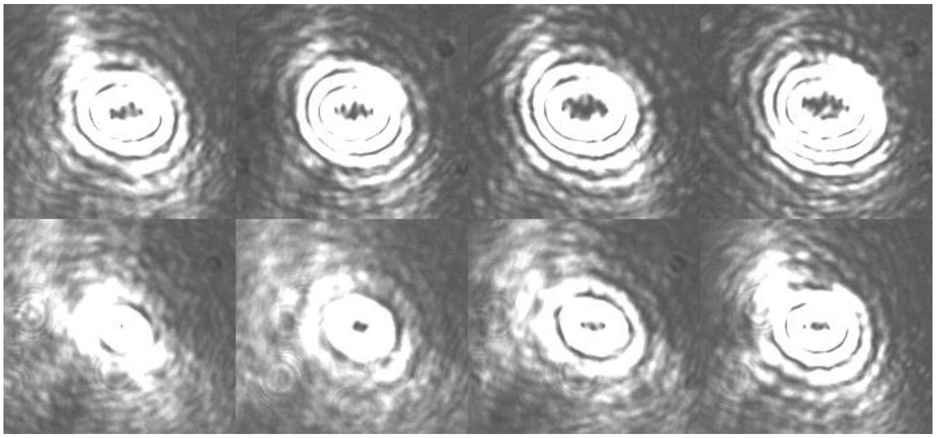

Figure 4: Each charge produced by the spiral phase plate, in increasing topological charge from bottom left to top right

The setup produced highly effective trapping of both several sizes of silica microspheres as well as milk particles. When converted to a Laguerre-Gaussian mode, the trapping was still apparent, as seen in Figure 5, but successful rotation was only achieved with with the silica microspheres with beams containing a high topological charge (this was charges 6-9). Due to time constraints, the alignment was unable to be corrected enough so that higher topological charges could provide enough trapping to hold for long periods of time. Due to this, although both trapping and rotation were achieved, they could not be done concurrently.

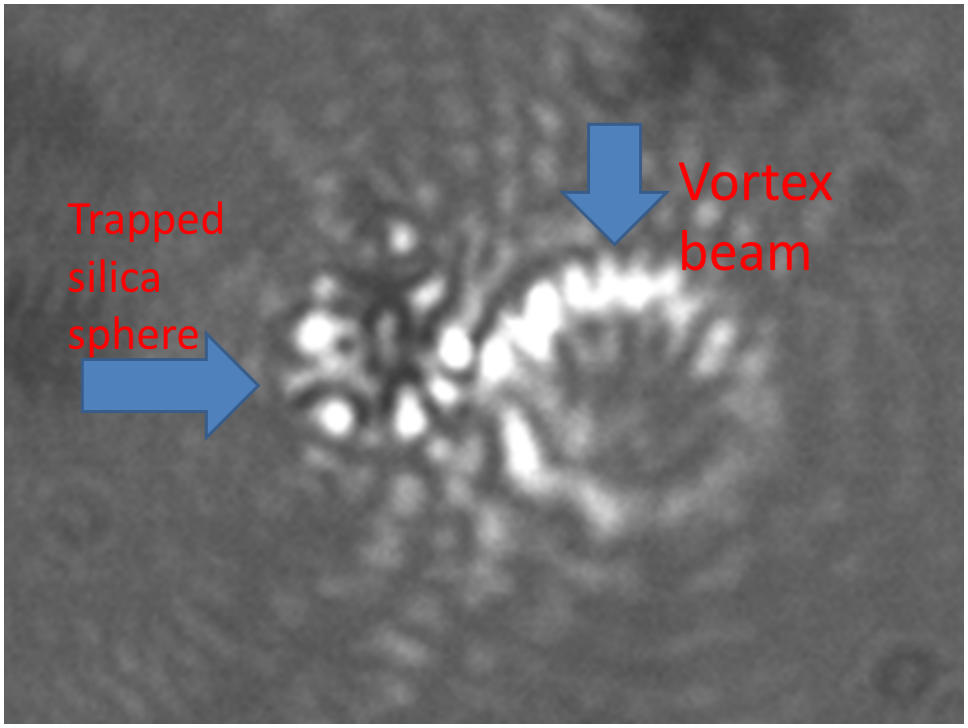

Figure 5: Trapping of a 3 μm microsphere using an LG beam

4 Conclusion

An optical tweezers setup was constructed using a 30 mW Helium-Neon laser and an inverted microscope.The tweezers were then modified to utilize Laguerre-Gaussian beams of various topological charges, and rotate trapped dielectric particles by transferring orbital angular momentum from the beam. The ability to trap and rotate small particles has many potential applications, such as microrheological studies and molecular motor construction. Due to time constraints, the experiment was not able to proceed to satisfactory controlled rotation of trapped particles, but both trapping and rotation were observed.

References

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