Optical Tweezers

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Theory

- Photons carry momentum
- Momentum is conserved in the trap

\[ E^2 = (m_0 c^2)^2 + p^2 c^2 \]
Why use an optical trap?

- Capture and manipulate microscopic objects for testing and observation
- Non-contact and non-invasive

Applications:

- Laser Cooling
- Cell picking
- Protein motor analysis
Experimental Setup
Project Goals

- Measure power-current relationship of laser
- Determine trap strength using Brownian Motion
- Determine trapping force using Stoke’s Drag Force
- Add vortex phase plate to create a Laguerre-Gaussian beam
- Determine trapping force of LG beam
- Estimate the angular velocity exerted on trapped bead
Now we can analyze measurements as a function of power.
Using Brownian Motion to Calculate Trap Strength

- *Brownian Motion*: random motion of particles due to collisions with atoms in a fluid excited by thermal energy
- Trapping force exhibits spring potential
- For low trapping forces:
  \[
  \frac{1}{2}(2)k_B T = \frac{1}{2}kx^2 \\
  k = \frac{(2)k_B T}{x^2}
  \]
  - \(k\): trap strength
  - \(k_B\): Boltzmann constant
  - \(T\): temperature
  - \(x^2\): variance in position of the bead
Brownian Motion Trap Strength Calculations

- Accurate for low laser powers
- Above ~13 mW, software cannot track bead
Stoke’s Drag Force

- Motion of surrounding fluid causes drag known as Stoke’s Drag Force
- Added piezoelectric component to translation stage driven by sine curve
- Measure frequency at which $F_{\text{trap}} = F_{\text{Stoke’s}}$

$$F_{\text{trap}} = 12\pi^2 \mu RA f_{\text{escape}}$$

- $\mu$: viscosity of water ($8.9E-4 \text{ Pa*s}$)
- $R$: radius of trapped bead ($1.28 \mu m$)
- $A$: amplitude of distance ($12.9 \mu m$)
- $f_{\text{escape}}$: frequency at which bead escapes the trap
The trapping force increases linearly with laser power output.
Vortex Half-Wave Retarder

- Gradient of densities causes light to emerge with some angular momentum - Laguerre-Gaussian “donut” beam ($m=1$)
- Spot size: $\sim 4.7 \, \mu m$
Trapping force increased by a factor of 2.2
Angular Momentum Estimate

- Trapped a rod-like bead (shown right)
- Using bead images, estimated that:
  
  1 Rotation = ~650 Frames

- At 409.5 frames per second:
  
  \[ \omega_{OBJ} = 3.59 \text{ rad/s} \]

- Same order as theoretical calculations for a 1 μm radius spherical glass bead \((\omega_{OBJ} = 3.14 \text{ rad/s})\)
- Decreasing power led to slower rotations
Conclusion

By adding a vortex phase plate to optical tweezers system, we:

- Increased trapping force by factor of 2.2
- Spun rod-like glass bead at 3.59 radians per second
- Angular velocity increases as a function of power

Further Research:

- Beam manipulation with Spatial Light Modulator
  - Effect of pixel resolution error on trap strength
  - Hermite-Gaussian trapping beam
- Biological Research
  - Protein motor analysis
  - Cell picking