Measuring the Transverse Trapping Field Strength of Optical Tweezers

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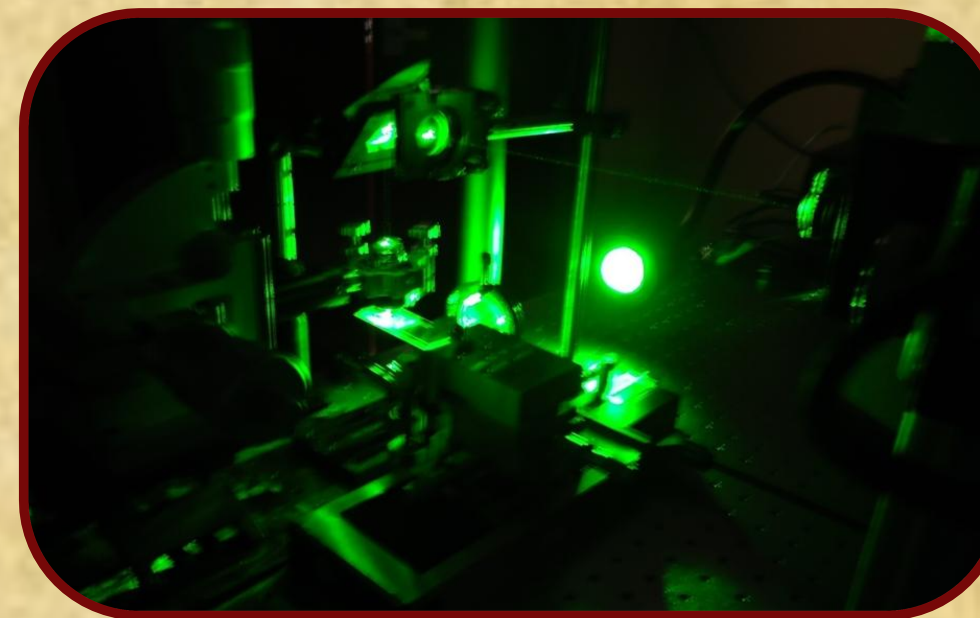
Abstract

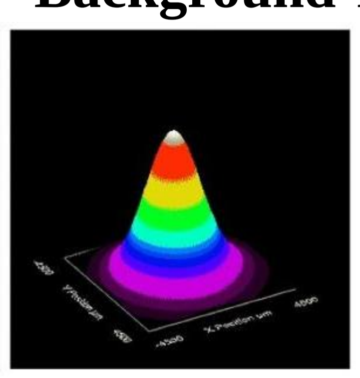
Single beam gradient-force optical traps, or laser tweezers, are useful for manipulating small particles, molecules, and biological specimens like cells or bacteria. In this Advanced Lab project, students designed and constructed an optical trap using a 532 nm laser with a measured power output of 34 mW, a 40x microscope objective, and various optical components. They also designed a method to control the sample using a linear motorized stage and implemented a system for imaging the trapped particle using a digital microscope camera. An optical trapping strength on the order of 0.1 pN was measured using 3 micron polystyrene spheres in a distilled water solution. In making the trap strength measurements, two unexpected anomalies were encountered and subsequently studied -- asymmetric trapping strengths on opposite sides of the trap and the presence of multiple traps. This project demonstrates the design, experimentation, and analysis process expected of students conducting a capstone laboratory project (i.e. the Advanced Lab "major project"); and it allows the students to reinforce and apply material learned in other courses, Optics in this case, in their Advanced Lab experience.



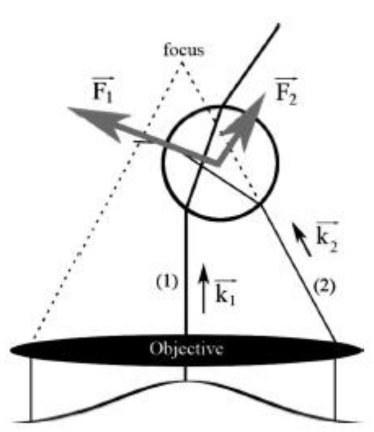
Introduction

An optical tweezer, uses a laser beam to trap and manipulate microscopic particles. For this "major project," students designed and built an operational optical trap based on equipment readily available in the department. As part of the project, the students also developed an experiment to examine the trapping strength and employed data analysis techniques learned previously in the course.

Background Theory



Gaussian Distribution



Trapping Forces[3]

The optical tweezers use the Gaussian distribution of a laser beam to create a negative radiation pressure. This pressure is similar to Bernoulli's Principle, in that areas of increasing fluid velocity (higher intensity light) have a correspondingly lower pressure. Therefore, the particle experiences a force toward the center of the beam, similar to a spring restoring force.[1,2,3]

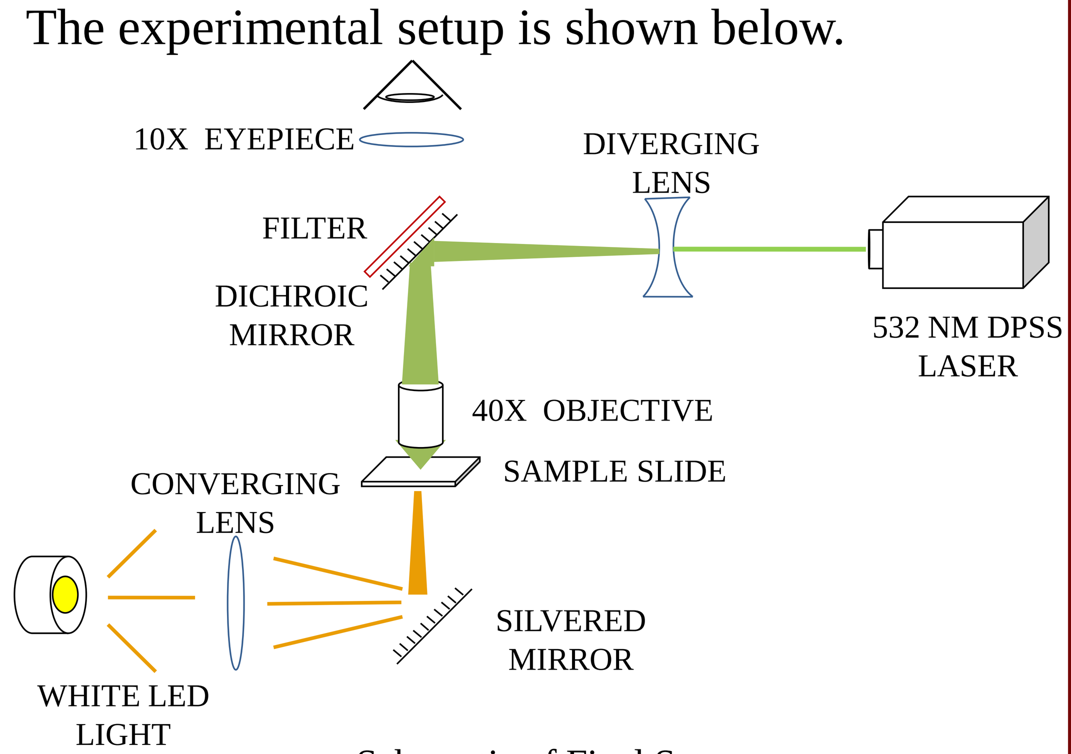
Basic Tweezing Elements

- Trapping Optics: 532 nm diode laser and 40x standard microscope objective
- Staging System: standard microscope slide on 3D translation stage attached to a Newport linear motorized stage
- Imaging System: Optix Digital Microscope Camera read out to a computer
- Sample: 50 L of 3.0 m polystyrene spheres diluted in 25 mL of water

Experimental Methods

Setup

The experimental setup is shown below.



Schematic of Final Setup

Data Acquisition

Using the 3D translation stage, a single sphere was moved into the optical trap. The Newport stage was used to control the sample velocity with a precision of 0.1 μm/s. This velocity was slowly incremented until the sphere escaped from the trap. This procedure was then repeated with a new sphere.

Qualitative Results

Qualitative evidence of trapping can be seen below, with pictures take prior to and 10 minutes after the laser beam was turned on. While doing preliminary testing, it was discovered that there was a "strong" and "weak" side to the trap.

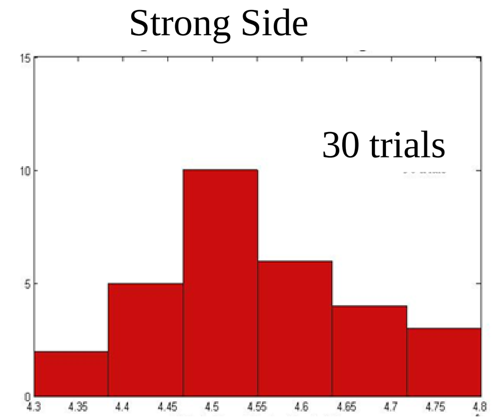
Beam OFF

Beam ON

Results

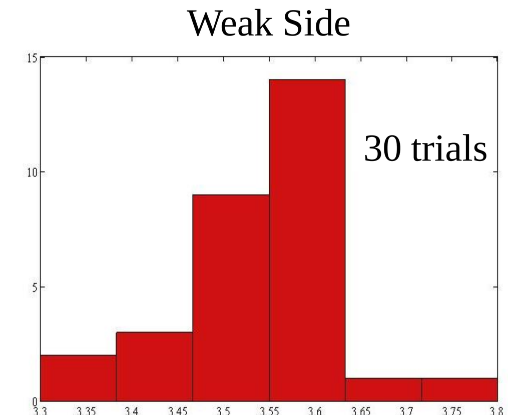
Data and Calculations

Strong Side



Escape Velocity (m/s)

Weak Side

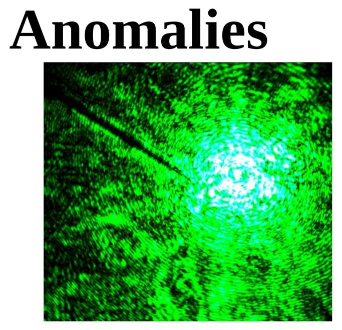


Escape Velocity (m/s)

Thirty trials were conducted for the strong and weak side of the trap. The trapping strength was then calculated using the equation[2] $F_d = 6 \quad rv_e$ where is the viscosity of the solution, r the radius of the sphere, and v_e the escape velocity.

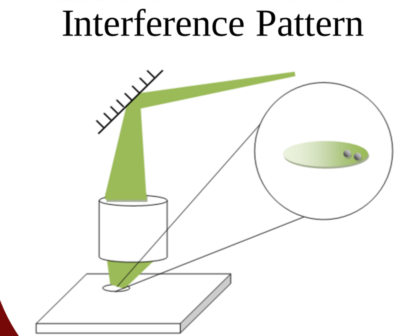
	Escape Velocity (μm/s)	Trapping Strength (pN)
Weak Side	3.54±0.11	0.091±0.003
Strong Side	4.55±0.14	0.117±0.004
Average	4.05±0.13	0.104 ± 0.004
Difference	1.0±0.3	0.026 ± 0.007

Anomalies



Interference Pattern

This interference pattern results in multiple traps, but the exact cause requires further examination.



Misalignment

Misalignment can result in the beam coming to a focus somewhere besides the trapping plane and therefore a directionally dependent trapping strength.

Conclusions

This optical trapping project provided students with the opportunity to experience the entire scientific process from conception through dissemination. The students learned basic trapping theory and applied experimental techniques acquired in their Optics Lab. Future advanced lab projects such as modifying the design of the trap and further studying trap characteristics can stem from this project.

References

[1]M.S. Rocha, Am. J. Phys., **77** (8), 704 (2009)

[2]S.P. Smith, et al., Am. J. Phys., **67** (1), 26 (1999)

[3]R. Pastel, et al., Am. J. Phys., **68** (11), 993 (2000)

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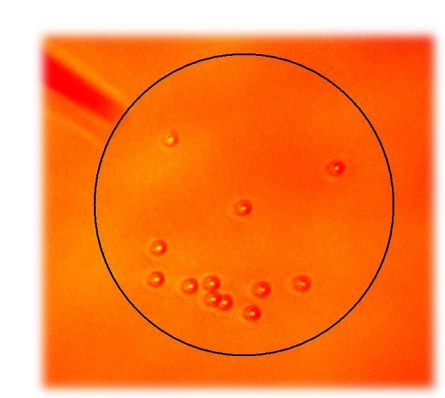

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