Wolkite University

College of Natural and Computational Science

Department of physics

Trapping dielectric particle using laser trapping Techniques

A Final research proposal Submitted to the department of physics in partial fulfillment for the degree of Bachelor of Science in physics

By Zara Mustefa

Advisor Mr. Darese Ahmed

Submission date 25/03/2019

Wolkite, Ethiopia

Table of content

Contents

1. Introduction

Optical trapping began as a proposed method for atomic trapping and laser-cooling, but evolved into a tremendously powerful tool in biological physics. Applications for optical traps range from manipulating single bacterial cells, to measuring the forces generated by singular motor proteins. Most experiments involving optical traps will require the determination of trap stiffness, which is the effective spring constant experienced by a trapped bead displaced from equilibrium. Since the factors involved in determining the stiffness of optical traps are often complicated and theories for calculation are not entirely accurate, the stiffness should be measured empirically each time a parameter is altered. The goal of this lab is to measure the stiffness of the optical trap through multiple methods.

1.1. Background of study

This paper gives a detailed description of the trapping of micron-sized dielectric spheres by a so-called single- beam gradient optical trap. Such dielectric spheres can serve as first simple models of living cells in biological trapping experiments and also as basic particles in physical trapping experiments. Optical trapping of small particles by the forces of laser radiation pressure has been used for about 20 years in the physical sciences for the manipulation and study of micron and submicron dielectric particles and even individual atoms These techniques have also been extended more recently to biological particles .The basic forces of radiation pressure acting on dielectric particles and atoms are known For dielectric spheres large compared with the wave- length, one is in the geometric optics regime and can thus use simple ray optics in the derivation of the radiation pressure force from the scattering of incident light momentum. This approach was used to calculate the forces for the original trapping experiments on micron-sized dielectric spheres. These early traps were either all optical two-beam traps or single beam levitation traps which required gravity or electrostatic forces for their stability. For particles in the Rayleigh regime where the size is much less than the wavelength the particle acts as a simple dipole. The force on a dipole divides itself naturally into two components: a so-called scattering force component pointing in the direction of the incident light and a gradient component pointing in the direction of the intensity gradient of the light.

The single-beam gradient trap, sometimes referred to as "optical tweezers," was originally designed for Rayleigh particles. It consists of a single strongly focused laser beam. Conceptually and practically it is one of the simplest laser traps. Its stability in the Rayleigh regime is the result of the dominance of the gradient force pulling particles toward the high focus of the beam over the scattering force trying to push particles away from the focus in the direction of the incident light. Subsequently it was found experimentally that single-beam gradient traps could also trap and manipulate micron-sized and a variety of biological particles, including living cells and organelles within living cells. Best results were obtained using infrared trapping beams to reduced optical damage. The trap in these biological applications was built into a standard high resolution microscope in which one uses the same high numerical aperture (NA) microscope objective for both trapping and viewing. The micro manipulative abilities of single-beam gradient traps are finding use in a variety of experiments in the biological sciences. Experiments have been performed in the trapping of viruses and bacteria; the manipulation of yeast cells, blood cells, protozoa, and various algae and plant cells; the measurement of the compliance of bacterial flagella; internal cell surgery; manipulation of chromosomes ; trapping and force measurement on sperm cells; and recently, observations on the force of motor molecules driving mitochondrion and latex spheres along microtubules . Optical techniques have also been used for cell sorting Qualitative descriptions of the operation of the single beam gradient trap in the ray optics regime have already been given the action of the trap on a dielectric sphere is described in terms of the total force due to a typical pair of rays a and b of the converging beam, under the simplifying assumption of zero surface reflection. In this approximation the forces Fa and Fb are entirely due to refraction and are shown pointing in the direction of the momentum change. One sees that for arbitrary displacements of the sphere origin **0** from the focus of that the vector sum of Fa and Fb gives a net restoring force F directed back to the focus, and the trap is stable. In this paper I tried to quantify the above qualitative picture of the trap. I show how to define the gradient and scttering force on a sphere in a natural way for beams of arbitrary shape. One can then describe trapping in the ray optics regime in the same terms as in the Rayleigh regime.

1.2. Objective of study

- ✓ Demonstrate How can we trap dielectric particles using radiation pressures?
- ✓ Demonstrating Basic principles of optical trapping
- ✓ Identify Physics behind trapping of particles using radiation pressure
- ✓ Interdependence of How can we trap particle base on the size of the particles and wave length the laser beam?

1.3. Significance of study

laser trapping techniques of Dielectric trapping is especially important because optical laser beam is primarily used in biological applications, and low power beams cause less damage to biological organisms and also used in trapping impurities. Infrared lasers are generally used due to the low absorption coefficient of infrared light for living organisms.

laser trapping techniques of Dielectric trapping have been used to study molecular motor mechanisms such as kinesin and myosin, as well studying the properties of DNA by winding. Properties of cells and their internal structures have also been studied by isolating or moving separate cell parts, including organelles, chromosomes, cell membranes, and micronuclei.

Lastly, Optical laser beam have been used to manipulate cells themselves; for example, they were to bring together killer cells and target cells to investigate the immune response

1.4. Scope of study

I arrived laser trapping techniques of Dielectric trapping by realizing that making a setup. In this research, I choose an inverted optical, single laser beam and investigated the Basic principles of optical trapping and its effects of light intensity entering the microscope objective on trapping dielectric particles using radiation pressures & Physics behind it. finally analyzing trapping particle base on the size of the particles and wave length the laser beam the paper cannot discuss analyze the effects on trapping efficiency

2. Literature review

Most of the early work in optical trapping is attributed to Arthur Ashkin. He built the first optical traps in the 1970's at AT&T Bell Laboratories. The first optical traps was built in 1970 and, like all optical traps, this so-called 'levitation traps' was based on the radiation pressure a particle experiences when in a laser beam[i]. Ashkin used the radiation pressure of a laser beam pointing upwards to balance the gravitational force pulling the particle downwards. When in balance, the particle would 'float' in mid-air due to the upward pointing optical force, somewhat similar to a tennis ball 'floating' on a vertical fountain. Somewhat later, in 1978, Ashkin had developed 'two-beam traps', which were based on the radiation pressure of two counter propagating laser beams. Levitation and two-beam traps were precursors of the optical trap Ashkin and his colleagues would develop in 1986, the optical tweezers. This optical trap used only a single, strongly focused laser beam to trap a particle in three dimensions (3D). In this set-up, a Gaussian intensity profile laser beam is tightly focused using a high numerical aperture (N.A.) microscope objective, which can also be used for imaging the trapped particle.

2.1. Trapping Theory

There are two distinct models to quantify the forces of optical tweezers: the ray-optics model and the dipole model. Which model is used depends on the size of the trapped particle and the wavelength of trapping light. For particles significantly smaller than the wavelength of light ($d >> \lambda$) the dipole approach is used, while for particles significantly larger than the wavelength of light ($d << \lambda$) the ray-optics model is used. When particle size is comparable to the wavelength of light, as they are in most practical tweezers applications, the much more complex Lorenz-Mie theory must be applied.

In the dipole model, particles are in the Rayleigh regime, usually atoms or sized in the nanometers. Trapping occurs when neutral dielectric particles act as induced dipoles in the trapping beam's electric field. The Lorentz force $F=qE$ (in the absence of a magnetic field) causes 'like' charges to attract, and as this force is directly proportional to the light's electric field E, the particle with an induced charge q will be attracted most to the regions of highest light intensity. Due to the structure of a focused Gaussian beam, this region of highest intensity is located at the center of the beam waist.

In the ray-optics model, particles are in the geometric regime, which means that their diameter is at least ten times greater than the wavelength of light. Transparent particles are trapped due to the absorption, reflection, and refraction of light rays that come into contact with the particle. When the light rays change direction due to one of these three interactions with the particle, the particle is actually exerting a force on the light that induces a change in momentum. The conservation of momentum means that the particle must then in turn experience an equal and opposite change in momentum.

For a trap to be stable in three dimensions there must be both axial and lateral trapping. Axial trapping, which occurs in the direction of beam propagation, is generally weaker than lateral trapping because reflected light rays incur a forward's change in momentum on the particle. This forwards component of the force on the particle is called the 'scattering force'. Refracted rays similarly contribute to this forwards scattering force, since most are bent away from the beam axis. However, when the particle is past the waist of the focused beam, the rays coming in at steep angles are refracted towards the beam axis, thus causing a 'backwards gradient force' that is used to counter the forwards scattering force. If $F_{gradient} > F_{scattering}$ then the axial trapping is stable.

Trapping in the lateral direction results from the 'gradient force' of the uneven intensity distribution of trapping light (usually Gaussian). The changes in momentum of refracted and reflected light rays produce forces on the particle in the opposite direction; regions of higher intensity and light density will have a larger change in momentum and therefore cause the net change in momentum of the particle to be towards these regions of highest intensity.

3. Methodology

3.1. Preparing Set up

The optical tweezers setup was assembled. Detail set up shown in figure below

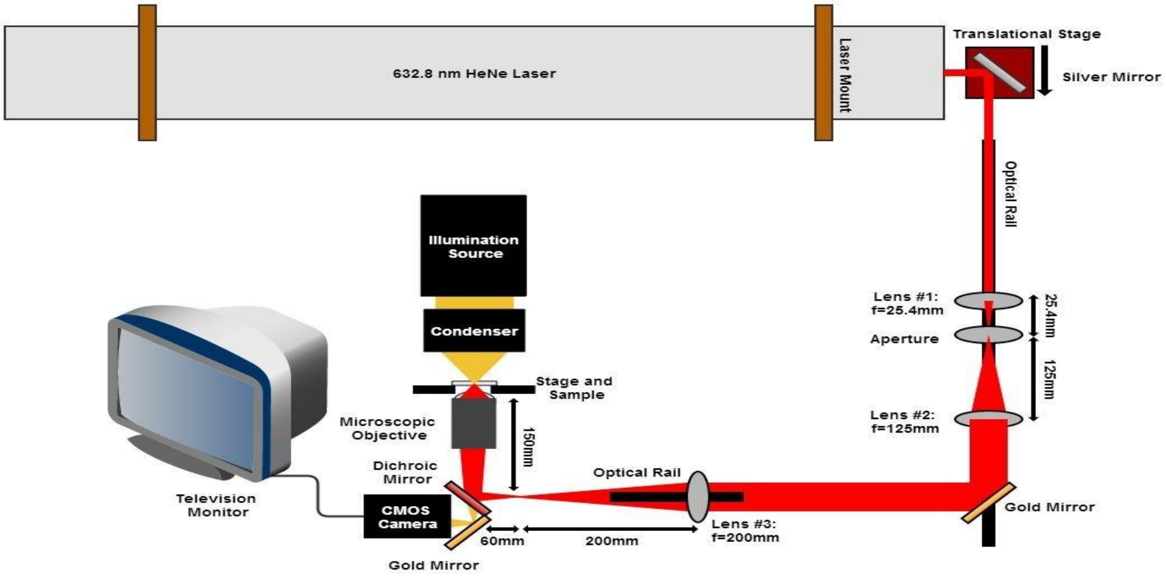

Figure 4: setup design.

.

3.2. Sample Preparation

Particle trapping was achieved in a large droplet of tap water that was replaced every few hours due to evaporation. To prevent evaporation chamber Trapped particles included dirt, yeast, and others. trapping particle turn by turn were dirt particles next moved on to trapping yeast cells then others.

3.3. investigation of Imaging System

The trapped particle was viewed with a high-resolution monochrome CMOS camera The light was focused directly onto the CMOS element without a lens. The camera was used with a laptop computer in order to view and record particle motion. In order to find the trapping beam location, it is possible to see the ‘laser spot’ where the light reflects off of the air-coverslip and coverslip-water interfaces

3.4. **Demonstrate How can we trap dielectric particles using radiation pressures**

incoming light originates from a focused laser beam through a microscope objective and focuses on a spot in the sample. The spot creates a trap able to hold a small dielectric object at place. The total forces experienced by the object, or bead in most experimental settings, consist of a scattering force and a gradient force. The scattering force arises when an incident light beam is scattered by the surface of the bead. This scattering produces a net momentum transfers from the light photons to the object and causes the bead to be pushed towards the beam propagation. The gradient force is a result of the intensity profile of the laser beam which acts as an attractive force drawing the bead towards the region of greater light intensity. In the case of a highly focused laser beam with a Gaussian intensity profile, the latter force operates like a restoring force that pulls the object into the center of the focal plane.

3.5. **Analyzing interdependence of trap particle on their size and wave length**

The interdependence of wave lenghth and particle size affect region of interaction of laser beamthis means When the particle size is very large compared to the wavelength of the incident light ($z = d/\lambda >> 1$) Mie regime and the particle-light interaction can be described by simple ray optics. In the opposite limit, where the particle is very small compared to λ ($z = d/\lambda << 1$), wave optics are used to describe the interaction.

4. **Time Schedule for Activities of planning during study**

Table 1: Time Schedule

s.no.	Activities	Time (in months)		
		April	May	June
1	Checking available laboratory equipment	@@@@@@@@@@@@		
2	Proposal writing	@@@@@@@@@@@@		
3	Collecting literature documents		@@@@@@@@@@@@@@	
4	Demonstrating in Laboratory		@@@@@@@@@@@@@@	
5	Finalizing my research report			@@@@@@@@@@@@

5. Budget Breakdown

Budget Summary

Proposal title: *Trapping dielectric particle using laser trapping Techniques*

Duration of project: three month

Table 2: List of Material and their costs

S/NO	Material type or description	Quantity	Price (ETB)
1	Pen	10	50
2	Pencil	2	10
3	Note book	2	50
Direct cost			
4.	Food Expenses		100
5.	Laboratory investigation, perdium for project staff/lab assistant Role		500
6.	Other direct project cost		20
Total budget	730 ETB		

References

A. Ashkin, “Acceleration and trapping of particles by Radiation Pressure,” *Phys. Rev. Lett.*, vol. 24, p. 156, 1970

A. Ashkin and J. M. Dziedzic, “Optical Levitation by Radiation Pressure,” *Appl. Phys. Lett.*, vol. 19, p. 283, 1971

A. Ashkin, J. Dziedzic, J. Bjorkholm, and S. Chu, "Observation of a single-beam gradient force optical trap for dielectric particles," Opt. Lett. **11**, 288-290 (1986).

M. Mahamdeh, C. Pérez Campos, and E. Schäffer, "Under-filling trapping objectives optimizes the use of the available laser power in optical tweezers," Opt. Express 19, 11759-11768 (2011).

A. Ashkin, "Forces Of a Single-beam Gradient Laser Trap On A Dielectric Sphere In The Ray Optics Regime." *Biophysical Journal* 61.2 (1992): 569-582.

K. Svoboda and S M Block, "Biological Applications Of Optical Forces," *Annual Review of Biophysics and Biomolecular Structure* 23.1 (1994): 247-285.

A. O'Neil and M. Padgett, "Axial and lateral trapping efficiency of Laguerre–Gaussian modes in inverted optical tweezers," *Optics Communications*193.1-6 (2001): 45-50. *ScienceDirect*.
