Polarimetry using optical forces

1 Introduction

Highly precise and accurate measurements and control of light polarization are crucial for experiments in atomic physics [1] or quantum information processing [2]. In astrophysics, polarimetry of extraterrestrial light sources has led to significant advances [3]. While versatile polarimeters that can measure any polarization state of light with modest precision and accuracy can be bought off the shelf (e.g. PAX1000IR2/M from Thorlabs), highly sensitive and polarization specific polarimeters are an active research area [4].

The aim of this project is to theoretically evaluate the potential of an optically levitated nanoparticle system [5] as a highly sensitive Stokes polarimeter [6, 7]. The levitated nanoparticle is trapped in an optical potential that is formed by a tightly focused laser beam of certain polarization. The three-dimensional motion of this particle can be measured with high sensitivity. As this motion sensitively depends on the form of the optical potential, which itself depends on the trapping light polarization, the particle motion could be utilized for polarimetry of the trapping light.

2 Research questions

(a) Following Ref. [8], numerically calculate the three-dimensional focal electric field distribution of a purely linearly polarized Gaussian laser beam (wavelength 1550 nm, power 100 mW) that is focused by a lens with numerical aperture 0.8.

(b) Calculate the optical potential that a spherical fused silica particle of 100 nm diameter would experience in the focal field calculated in (a). Assume that the particle is a dipolar scatterer and neglect radiation pressure (scattering force).

(c) Harmonically approximate the optical potential around its minimum and calculate the particle oscillation frequencies. Does your result show qualitative agreement with Figure 3(b) from Ref. [5]?

(d) Generalize (a)–(c) to the case of fully polarized trapping light of arbitrary polarization. Use the Jones or the Stokes formalism to describe the Gaussian laser beam before the focusing lens (i.e., the input beam).

(e) Assume a harmonically oscillating particle in a potential formed by a perfectly circularly polarized input beam. Now slightly change the input polarization state. Could this polarization change be detected by monitoring the particle motion? On which system parameters does the sensitivity of this particle polarimeter depend?

(f) Could the particle polarimeter be generalized to measure arbitrary polarization states of light? How does the performance of the polarimeter depend on the polarization of the input state? Is it possible that different input polarizations lead to the same output of the polarimeter?
(g) Compare the performance of the particle polarimeter to other state-of-the-art polarimeters.

3 General instructions

For your work and your report, keep the following points in mind:

- Write a report demonstrating your understanding of polarization measurements using optical forces. Your report must not exceed five A4 pages.
- Make use of all accessible literature and cite correctly.
- Focus on presenting your ideas for realizing a state-of-the-art polarimeter based on optical forces.
- Use the research questions above to inspire your thinking and answer them throughout your report. However, keep your report in the form of a research paper presenting your ideas, instead of a lab report answering predefined questions. Put yourself in the situation of a scientist or an engineer trying to convey a new idea to his/her peers.

References


