Lab 3: Optical Trapping of Dielectric Particles in Liquid

October 11, 2021

1 Introduction

1.1 Background Reading

1. A. Ashkin, J. M. Dziedzic, J. E. Bjorkholm, S. Chu. "Observation of a single-beam gradient force optical trap for dielectric particles", Opt. Lett. 11, No. 5 (1986).

2. S. P. Smith, S. R. Bhalotra, A. L. Brody, B. L. Brown, E. K. Boyda, and M. Prentiss, "Inexpensive optical tweezers for undergraduate laboratories", Am. J. Phys. 67, No. 1 (1999).

1.2 Motivation

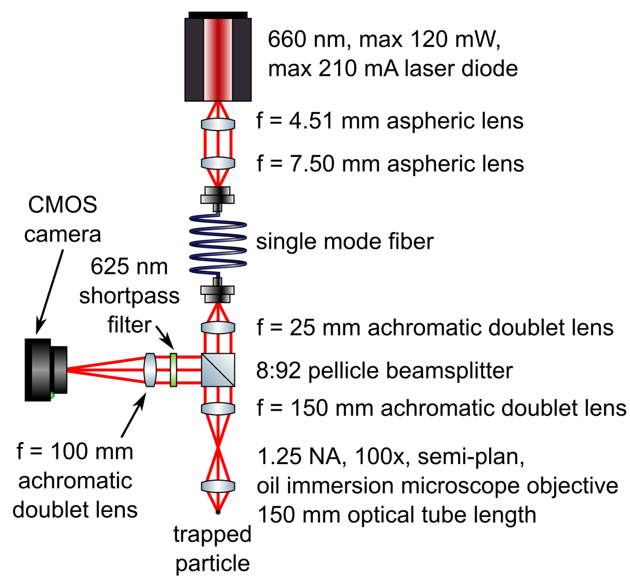
Trapping dielectric particles in the focus of a laser was developed by Arthur Ashkin and others at Bell Labs in the 1970's and 1980's, which ultimately earned Ashkin the Nobel Prize in physics in 2018.

This experiment will demonstrate the operating principle of optical traps in liquid.

1.3 Techniques

In this lab, data will be acquired by analyzing images of the particle taken with a high-speed camera. You will use a pre-written C++ program to acquire images from a Basler acA1920-40um high-speed camera with a high numerical aperture microscope objective lens. The images can be analyzed with trackpy or an algorithm of your own to track the center of the particle from frame to frame.

The optical setup is shown schematically in the figure at right. The illumination and trapping light comes from a red diode laser and is spatially filtered by a single-mode optical fiber. The light is focused down to trap a particle, and the light scattered off the particle is collected and imaged onto the camera. The particles to be trapped are e.g. polystyrene microspheres with 1.72 μm diameter.



2 Objectives

These objectives are intended to guide your experiments. They are not a step-by-step procedure.

1. Setup:
   Couple the trapping light through the single mode fiber and adjust all optics to collimate and focus the light as needed. Since the objective lens is an oil immersion lens, coupling oil must be placed

between the objective and object to be imaged. Oil can be placed directly on the calibration slide. To avoid mixing the coupling oil with the water that suspends the microspheres, place a coverslip over the microspheres and put a drop of oil on the coverslip.

2. Calibration:
   Measure the camera and lens calibration in both horizontal and vertical directions by taking images of the calibration target in two orientations. Check the size of the microspheres against your calibration. You should use this calibration for all remaining parts of this lab (convert all data from pixels to meters or μm). Compare your results to the expected calibration based on the specified pixel size of the camera and magnification of the optics.

3. Trap a single polystyrene microsphere with an appropriate dilution of the microspheres under a microscope coverslip. Record and plot the thermally-driven motion of the particle in the time and Fourier domains in both transverse directions. Make sure you choose a frame rate which captures all important features of the motion. The more images you acquire, the lower the noise in your final analysis will be.

4. Measure the transverse strength of the trap by moving the sample stage with a single particle in the trap. Record images while moving the stage quickly enough to drag the particle out of the trap. You can then calculate the escape velocity by finding the first image where the particle escapes the trap and getting the velocity from the movement of other (untrapped) particles from one image to the next combined with the camera frame rate. The procedure is also given in section VI. D. ("Trap Calibration") of reference 2 (S. P. Smith et al).

3 Questions

These questions should be specifically answered in your lab notebook, and can also serve as a guide for discussion in your lab report analysis.

1. If you assume that the mass of a microsphere is given by the density of polystyrene times the volume (based on the diameter specified by the manufacturer) and that the temperature of the thermal motion is given by room temperature, make a histogram of the particle displacements from equilibrium (or is displacement squared better?) and use it to calculate the "spring constant" of the optical trap.

2. Calculate the apparent particle mass by making a histogram of the velocity (or is velocity squared better?) and fitting a room-temperature thermal distribution to it with mass as a fit parameter. Compare this mass to that from the density of polystyrene times the volume (based on the diameter specified by the manufacturer).

3. Compare the strength of the trap calculated from the direct measurement (Objective 4) with that you calculate from multiplying the spring constant in Question 1 by the calculated diffraction-limited radius of the optical trap. Do they agree? If not, discuss possible sources of disagreement.

4 Hints

1. Alignment steps:
   (a) Couple light into the fiber with the laser controller set at 65 mA. You should get $\sim$ 1 to 2 mW out of the other end of the fiber. This might take a while.
   (b) Adjust the focus at the output of the fiber by moving the fiber mount up or down. Adjust it to collimate the laser light reflected off the 8:92 beamsplitter.
   (c) Adjust the 100 mm lens which images the light on the camera to focus light that is transmitted through the beamsplitter from a far-away object on the camera.
   (d) Adjust the distance between the objective lens and the 150 mm lens to be 30 cm with a ruler. Measure from the shoulder of one lens to the shoulder of the other.
   (e) If everything is aligned well, you should be able to get a focused image with white light while also seeing a focused laser spot through the objective. The calibration slide is a good choice of test object to image.
2. The fiber ends are keyed and only insert fully in one orientation. Make sure you have them fully inserted.
3. Try not to crash the objective into the slide! You can check for contact as you approach the slide by making sure the slide can be moved around easily. A gentle touch won't damage anything, but a hard crash may break the slide or optics.
4. The calibration slide is great for getting an initial focus. If you adjusted everything right, you will see the slide come into focus at the same time that the laser light reflected off the slide focuses to a spot on the camera.
5. Don't use too many spheres! They tend to clump if you have too many, making it difficult to keep only one trapped.
6. The spheres will tend to dry out in a hour or so. You can try to add more water if you don't have too much oil on your slide.
7. Decrease the optical power to the minimum needed for trapping. Lower power will result in larger Brownian motion, which will give better data. The laser spot will also cause trouble with data analysis if it is too bright.
8. Camera adjustment:
   (a) Choose the exposure time to adjust the brightness.
   (b) For Objective 3, make your camera image small enough to capture only the one sphere you have trapped. Extra spheres will interfere with image analysis.
   (c) For Objective 4, make your camera image large enough to capture multiple spheres, since you have to use untrapped spheres as a reference for determining the escape velocity.
9. We have two options for analyzing the images and tracking the spheres:
   (a) Cross-correlation: This works for single trapped objects only, but can give the most accurate sub-pixel displacements.
   (b) trackpy `http://soft-matter.github.io/trackpy/v0.4.2/`: It has lots of options! It is possible that the settings left in the tracking script don't work for your images, and you may have to vary them to get robust tracking.