Effect of small forces on microsphere under optical trap

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Abstract. In this era of technological development, greater impact of nanotechnology now can be seen in many fields due to better properties and precise control. Many functions are being executed by bio nano-materials or biomolecules in living systems in a very efficient manner. The functional behaviour and their properties need to be examined to use them for various nano-device applications. The mechanical properties of the biomolecules can be studied by attaching them with microspheres and measuring forces on these microspheres through optical trap. Microspheres of three-micrometer diameter were trapped at the focus of infrared laser and viscous drag forces were applied to measure the effect of these forces on the trapped microsphere. It was observed that with 28mW intensity Laser, the trapped microsphere was displaced by 0.19 µm at 2.1 pN force and trap stiffness was determined as 0.011pN/nm. The findings can be useful while attaching these microspheres as cargos along the bionanomotors for nanorobotics and drug delivery applications.

1. Introduction

Lots of advancements have taken place in the field of engineering and technology, and still we are understanding and learning from nature for better and useful healthcare devices particularly. The biomolecules like bionano motors are an important component of nanotechnology that will allow us to learn these wonderful structures and to produce challenging engineering systems. Therefore, behavioural properties of these systems are going to play a crucial role in the nano-device developments [1]. To measure the mechanical properties and to understand the forces being executed at nanolevels, microspheres can be attached with biomolecules, which can be used as handles under optical trap. Now, by measuring the position of the microsphere in the trap, various mechanical and other properties of the biomolecules can be determined [5].

Optical tweezer uses the laser beam to provide an attractive force to physically move the objects having sizes in microns or even below that. For the object to be trapped, it is necessary that the refractive index of the object should be higher than that of its surrounding medium [2]. Therefore, it is possible to catch and manipulate dielectric objects and biological materials. A microsphere can be chemically attached to a desired molecule to measure very small forces acting on it.

The basic idea of optical trap comes from the fact that light interacts with matter. Light consists of photons and each photon is having the momentum. Therefore, it must exert a force on an object that absorbs, reflects or refracts it. In most situations, this force is of course negligible like the rays from the sun falls on us. However, for the micron-sized object, these forces can be significant. Therefore,
during the interactions of photons with object will produce some mechanical force on the object. The resultant force of the light on object is in the direction towards focus of the light. Thus, the object is pulled towards the most intense region of light i.e. focal point of the laser in the absence of other forces. Therefore, in these conditions, when using intense light and microscopic objects, these forces can pull or push the object. If in addition, the intensity and direction of the light are controlled, then these forces can become useful. The optical trap behaves like mechanical springs and generates a restoring force. This force displaces the object from the trap centre. This displacement of the object depends on the force applied and strength of trap. Therefore, the behavior of the trap force and displacement need to be examined to precisely control and manipulate the objects [3].

The technique of optical trapping has helped to revolutionize the mechanical analysis of biomolecules. It was Arthur Ashkin, who first noted optical forces on microscopic object and established that a laser beam can push particles by exerting axial forces [2-3]. Since then, the application of trapping the particles has allowed the multi discipline researchers to work under one roof in the broad field of nanotechnology [4]. Many authors have given some good review publications to understand the optical trap process and discussed about the progress made in various fields [5-8]. With the introduction of optical tweezers, it is possible to measure forces in the range of 0.01 – 200 pN [9]. The trapped bead or microsphere can be moved with constant velocity relative to suspended media with respect to the position of the trap. The bead or microsphere may be pulled out of the trap along with the bead motion due to the viscous or Stokes’ drag of the fluid on the bead [10]. Polystyrene micron-sized spheres were attached with a live cell and trapping forces and drag forces were measured in optical tweezer by moving the mixture [11]. To Calibrate the forces acting on polystyrene bead under optical trap, viscous drag force acting on the bead as well as Brownian motion has to be studied [12-14]. Many authors have used Matlab to find the trap stiffness [15]. Many techniques including power spectrum has been used to find the trap stiffness and Brownian dynamics simulations also have been used [16-17]. Optical trap system was used with microfluidic chip technologies for single cell manipulation tool [18]. Moreover, the static and dynamic mechanical properties of single-cell has been examined with optical trap system [19]. The Brownian motion exerted by micron-sized spheres suspended in water was also measured at limited noise and high bandwidth [20]. The authors measured the restoring force for polystyrene microspheres of diameters ranging from 0.36 to 3 µm in an optical trap [21].

Therefore optical trap system has been used widely in many field like engineering, physics, material science, biology etc due to its ability of apply and measure small forces [22]. Very recently, it has been demonstrated that the 160 nm diameter polystyrene spheres can be trapped in optical tweezer for speeds up to 0.17 mm/s with 0.1 to 1 mm distance [23]. Therefore, it is very important to understand and calibrate the forces in optical trap. A very simple approach has been discussed in this paper to measure the small forces on microsphere under optical trap using viscous drag force.

2. Experimental Work

All the materials used were from the standard Lab grade sources. The polystyrene microspheres were obtained from M/s Polyscience, Inc. The hydrodynamic drag forces were applied on micro spheres by moving the surrounding media (water, 20°C) at pre-adjusted flow rate with the help of the microscopic robustage of optical tweezer (PALM, Germany).

The polystyrene microspheres of 3 µm diameter were diluted in such a way that about 1-4 microspheres were visible in the field of view. A microsphere was trapped in the water using optical tweezer system. The robustage of the optical tweezer system was moved to verify the trapping of the microsphere. As it can be seen in the consecutive figures 1(a-d), movement of robustage from t=0.3s onwards displaced the mean position of the microsphere. It can be seen from the figure 1(b-d) that the displaced microsphere is now at the same position while the marker line and surrounding particles are disappearing from the screen. Therefore, it was evident that the microsphere has been trapped. As
shown in the figure 1, the relative motion of the stage w.r.t. trapped microsphere produced the drag force on the microsphere that shifted the centroid position of the microsphere.

![Figure 1](image/url)

**Figure 1.** Evidence of trapping as microsphere is fixed while marker line is changing its position with time (b-d). Surrounded objects also may be seen moving with time.

The microspheres were observed to be executing Brownian movement in the fluid due to collision with water molecules. The Brownian movement of the particle at equilibrium position and at displaced position where viscous force acting is recorded and then the recorded data were processed using custom developed Matlab software [14-15].

### 3. Results and Discussions

The polystyrene micro spheres of 3µm diameter were used for the measurement of forces under optical trap. The density of the micro spheres was controlled in such a way that there was good dispersion so that many microspheres are not trapped at the same time. The microspheres were trapped using IR laser power and the robo stage at the preadjusted speed was moved. The relative motion between the trapped microsphere and surrounding water produced drag force on the microsphere. The viscous drag force was calculated using stokes’s law [9]. The trapped centroid position of the microsphere changed due to drag force developed on the microsphere as shown in the figure 2.
The pattern of the Brownian motion of the trapped microsphere was observed with and without drag force. When viscous drag force was applied on the microsphere, a shift in the mean position of the microsphere was observed and at the same time, more scattered behaviour of the microsphere’s motion at mean position was found as is evident from figure 3.

The relative speed between trapped microsphere and surrounded water exerted drag force on the microsphere and therefore a shift in initial mean position of the microsphere was observed. The flow rate of the surrounding media was 74.38 µm/s.
As shown in figure 4, it was observed that the centroid of the microsphere got shifted by 0.19 µm distance when a force of 2.1 pN was applied due to relative movement between trapped microsphere and surrounding medium.

Therefore, by measuring the shifted centroid position of the trapped microsphere due to drag force at different relative speeds between microsphere and surrounding media, the trap stiffness was determined by plotting the data between drag force and displacement as shown in figure 5. The trap stiffness corresponding to 28 mW laser intensity power was found to be 0.011 pN/nm.
4. Conclusion

Following important conclusions are drawn:

a) Microspheres of three-micrometer diameter were trapped at the focus of 28mW intensity laser power in optical tweezer and viscous drag forces were applied by providing relative motion between microsphere and surrounding medium at various speeds of robostage.

b) The microspheres were found to be executing Brownian motion at their mean position when no drag force was present and the mean position shifted with the application of viscous force.

c) It was observed that trapped microsphere was displaced by 0.19 µm at 2.1 pN force and trap stiffness was determined as 0.011pN/nm.

d) The trap stiffness can be used to apply and measure small forces on biomolecules to understand their functioning behavior and further it can be used in the designing and development of nanodevices.

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