Optical Tweezers：Motion of Particle Affected by Restoring Force

Wei-Chih Huang (黃偉智), Yi-Syuan Chen (陳逸軒)
Professor : Yung-Fu Chen (陳永富); T.A.: Yu-Ting Lin (林侑鋌)

Department of physics, National Central University

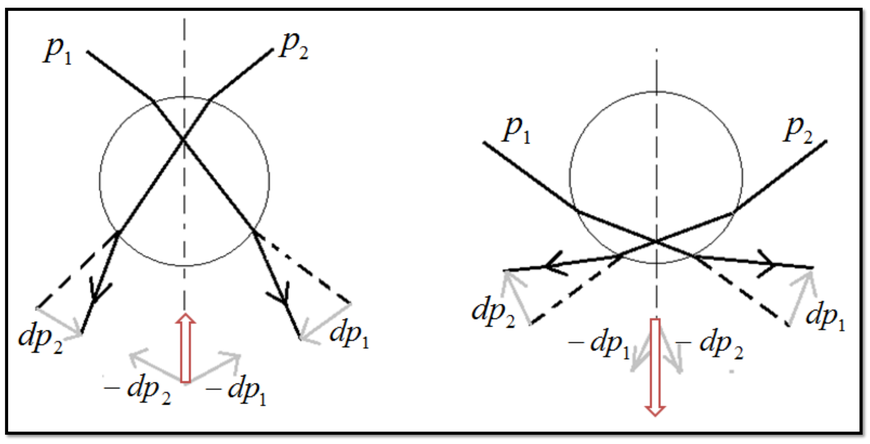
Introduction

➢Optical tweezers - an appropriate method to move or fix tiny particle(s)
in a micro-scale system.
➢This concept was suggested by Arthur Ashkin in the 1970s in Bell laboratory .
➢Tiny particle(s) will be trapped at the focus of light which has a potential
well.
➢This technology can be applied to many fields, such as medical, biological and chemical science.

Motivation

➢Understand the physical mechanism of optical tweezers.
➢Learn and practice how to use the optical components.
➢Learn how to set up optical tweezers.
➢Try to trap and shift particle by laser beam (tweezers).
➢Study the objects′ behavior which are affected by optical tweezers.

Theory



➢From refraction of photon, there is a force which particle exerts on it.
➢From Newton′ s 3rd law, the photon also exerts a force on particle, which is a trapping force.
➢Therefore, the total forces act on particle is

$$\Sigma\vec{F} = \frac{d\vec{p}}{dt} = m\frac{d\vec{v}}{dt} = m\frac{d^2\vec{x}}{dt^2} = \vec{F}_{tweezer} + \vec{F}_{viscosity} + \vec{F}_{Brownian}$$

➢The force of tweezers on particle is a restoring force.

$$F_{tweezer} = -ks$$

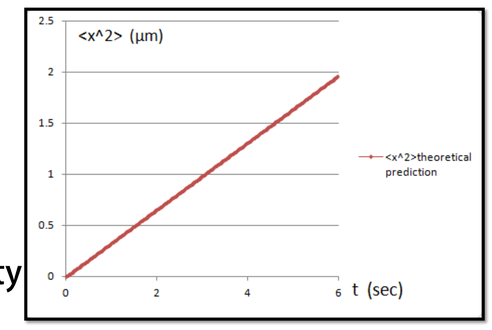
➢The viscous force is related to the coefficient of viscosity of solution, radius and velocity of particle.

$$F_{viscosity} = -6\pi\eta a v$$

➢Brownian motion

☆ From the result of the diffusion equation

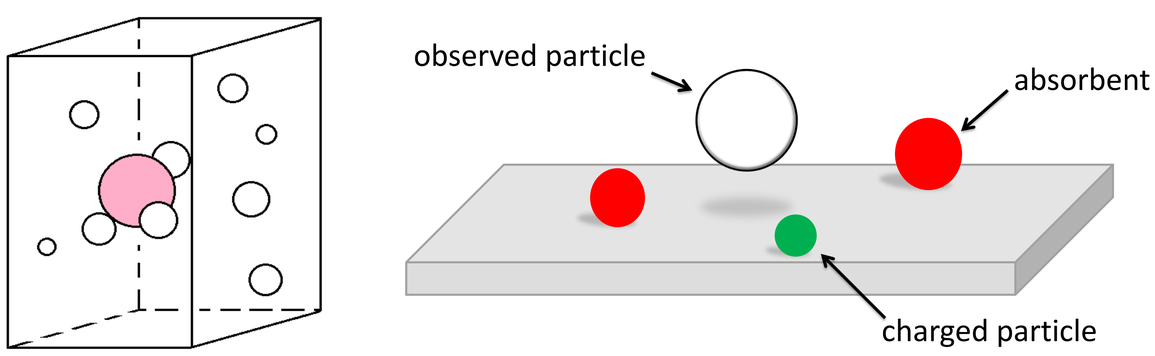
$$< x^2 >= 2Dt \text{ ， } D = \frac{KT}{6\pi\eta a}$$



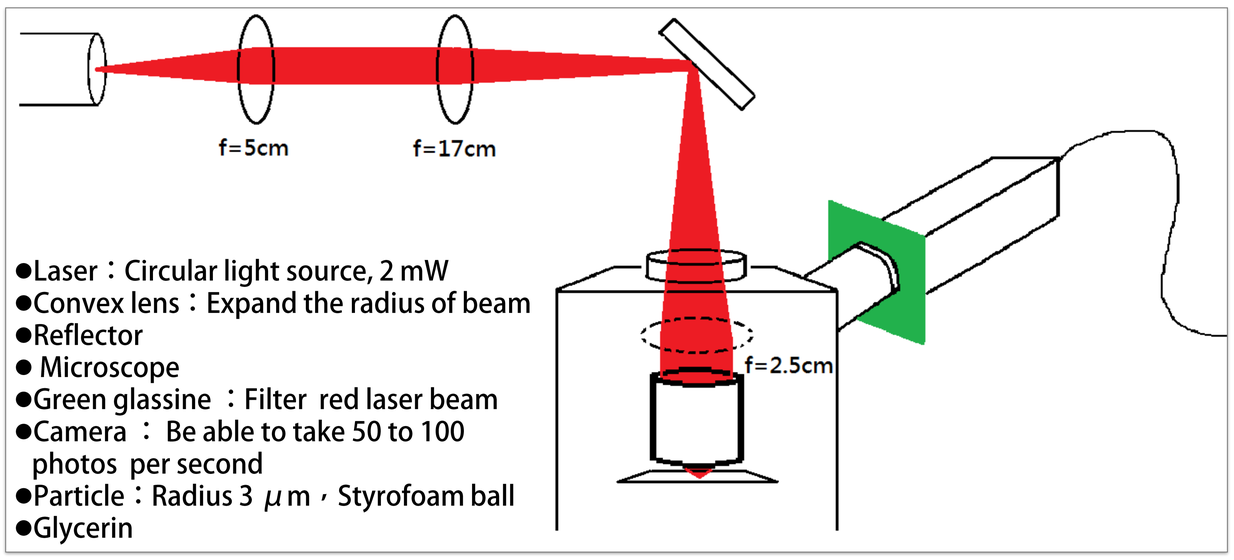
K ：1.38×10^{-23} J/K Boltzmann constant
T ：27 ℃, 300 K Temperature
η ：8.94×10^{-4} Pa・s Coefficient of viscosity
a ：1.5 μm Radius of particle

➢The formula of estimated-mean square displacement is
$< x^2 >\cong (3.28\times10^{13}t)m^2 = (0.328t)\mu m^2$
and is shown below.

Schematic Diagram of Brownian Motion



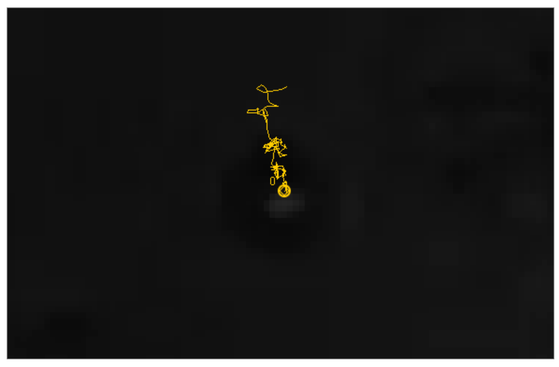
Experimental setup

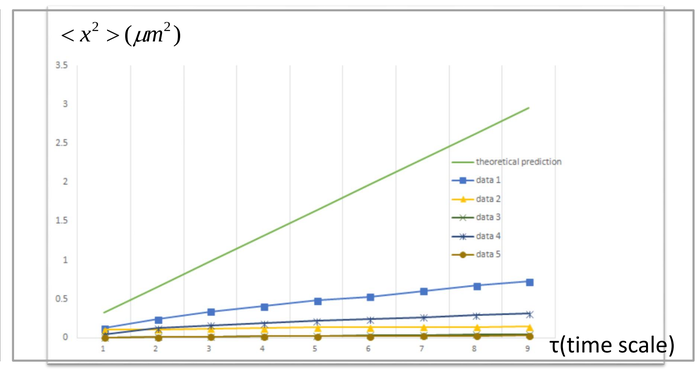


●Laser：Circular light source, 2 mW
●Convex lens：Expand the radius of beam
●Reflector
● Microscope
●Green glassine ：Filter red laser beam
●Camera ： Be able to take 50 to 100 photos per second
●Particle：Radius 3 μm，Styrofoam ball
●Glycerin

Results and Discussion

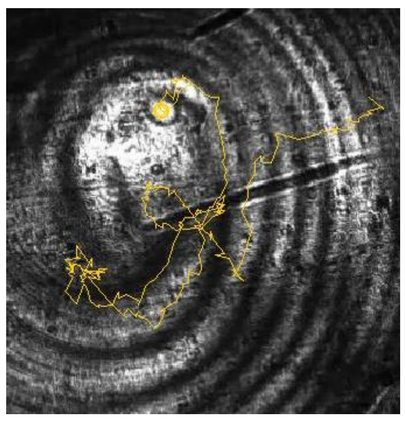
(1) Particles without Laser Beam Affecting

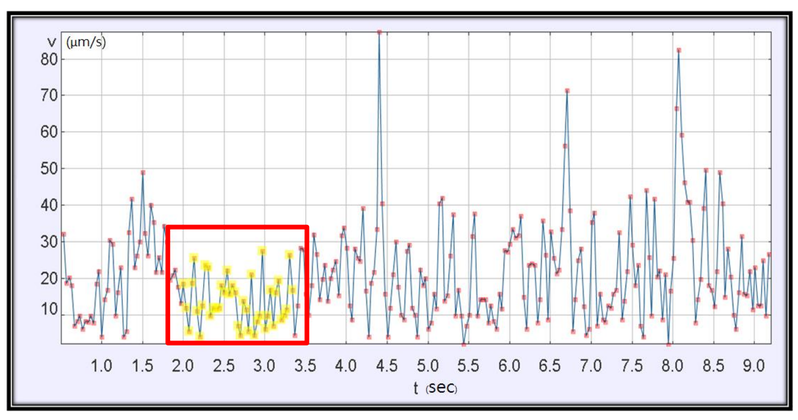




➢Comparing with estimated value, the behavior of particles are not Brownian motion obviously.
➢There is resistance exerting on the particle.
➢Some absorbents or defects of the glass slides affect the motion of the particles.

(2) Particle Affected by Obvious Flow Field





➢The particle under an obvious flow field and flows through the area of laser beam.
➢When the particle goes through the area of laser beam, its velocity changes obviously.
➢Indirectly prove that tweezers work by observing the change of velocity
of particle.
➢The standard deviation of velocity of particle, which is affected by laser
beam, is 6.52; without being affected by laser beam, the standard deviation is 13.75.
➢This demonstrates the particle is affected by optical tweezers.

Summary

➢Realize tweezers how to work and the factors which affect the motion of
particles.
➢Understand how to set up optical tweezers.
➢Optical tweezers affects the motion of particles.
➢Besides the trapping force of optical tweezers, some absorbents or defects of the glass slides also affect the motion of the particle.

Reference

➢【歷史回顧】光鑷與朱棣文：1997諾貝爾物理桂冠.
➢Journey of Quantitative Spectroscopy and Radiative Transfer 146 (2014) 59-80.
➢從布朗運動到液體微觀動力 物理雙月刊（廿七卷三期）2005 年6 月
文/溫偉源、伊林.