Optical Tweezers and Their Application to Biological Systems

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From 2018 Physics Nobel Prize Lecture – Arthur Ashkin

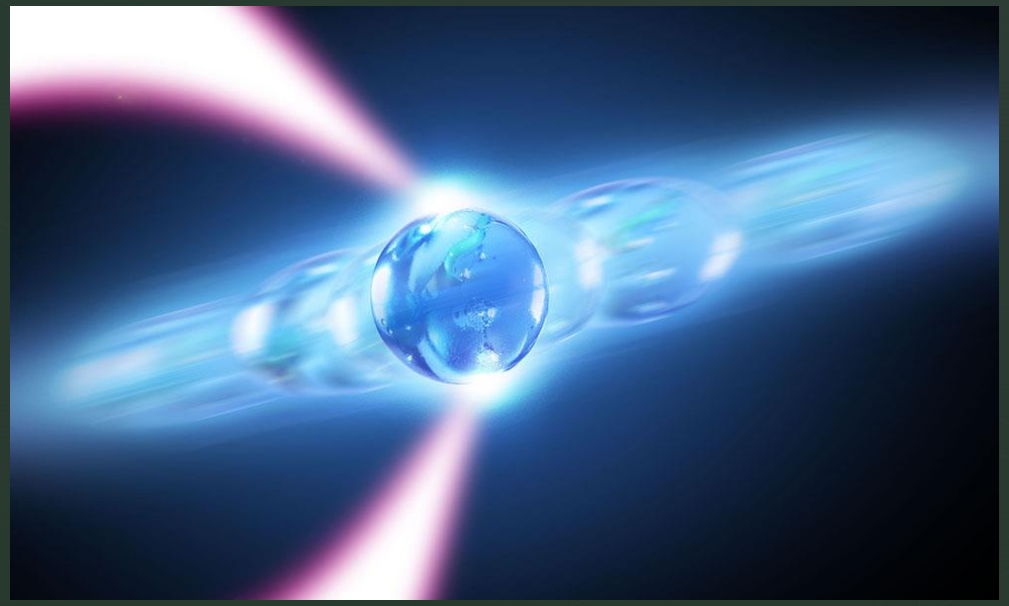
University of South Carolina Fall 2021 – Physics 730

Overview

- Light and its Properties
- Optical Tweezers
- How Optical Tweezers are Used

Importance of Optical Tweezers

- Optical Tweezer: laser beams used to trap and manipulate molecules and even living cells
- Measurements:
  - Subatomic forces
    - Piconewton (10^{-12} N)
  - Torque
  - Diffusion Dynamics



'Optical tweezer' takes Nobel concept in a new direction : NewsCenter (rochester.edu)

Light Amplification by Stimulated Emission of Radiation

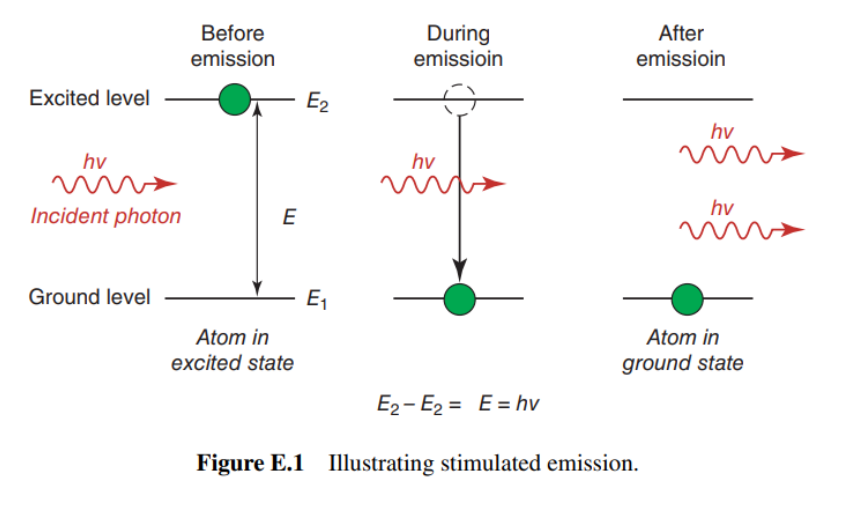
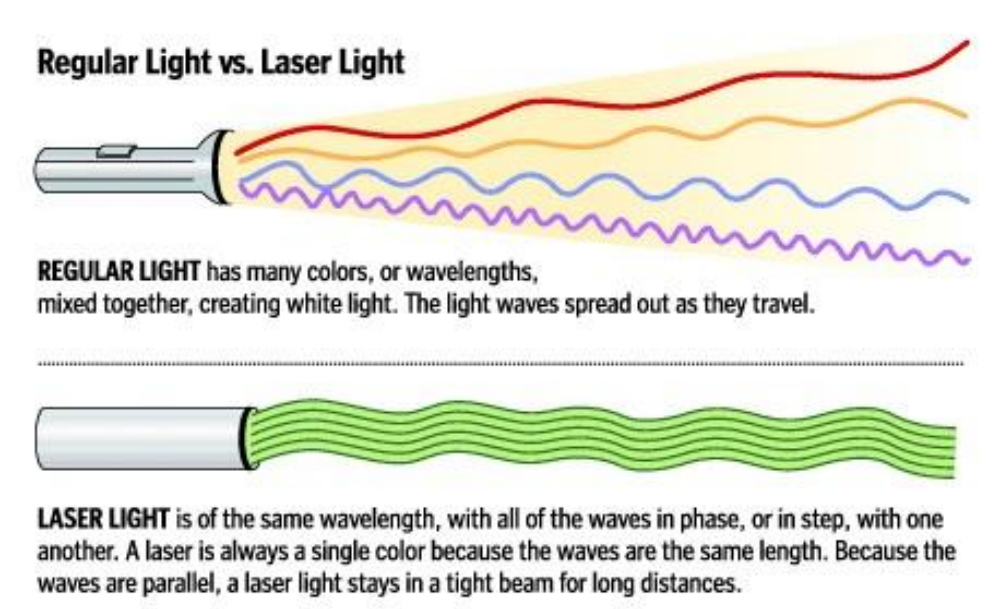


Figure E.1 Illustrating stimulated emission.

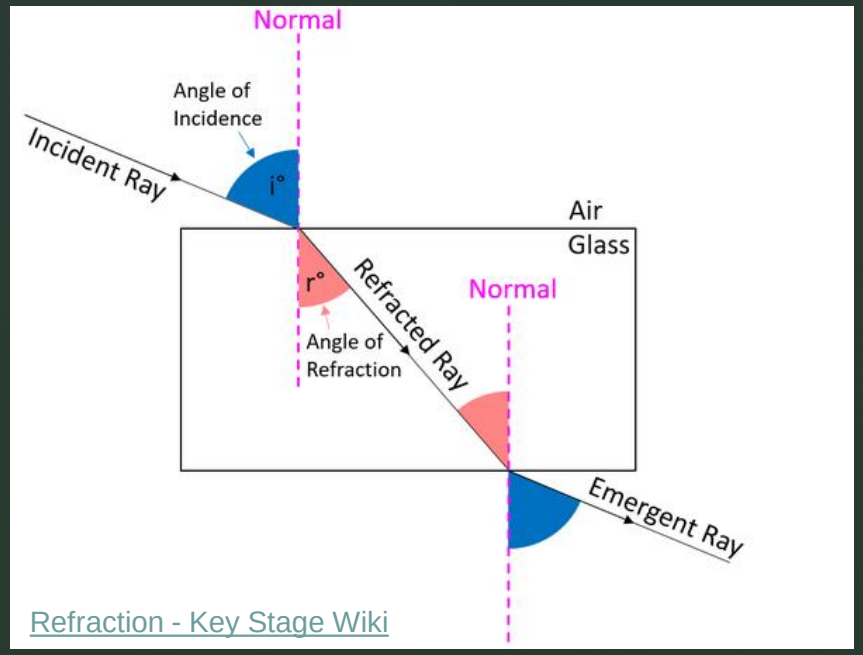
Light Amplification in Lasers - Colour Reproduction in Electronic Imaging Systems - Wiley Online Library



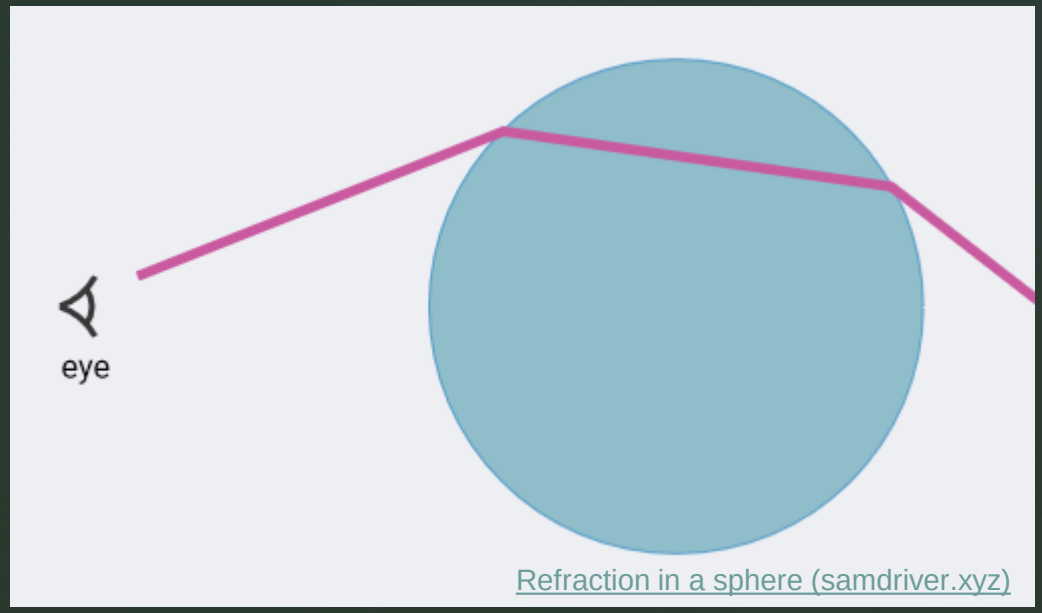
Lasers: lasers | Glogster EDU - Interactive multimedia posters

Refraction

- Bending of light through a transparent object
- Beam changes direction



Refraction - Key Stage Wiki



Refraction in a sphere (samdriver.xyz)

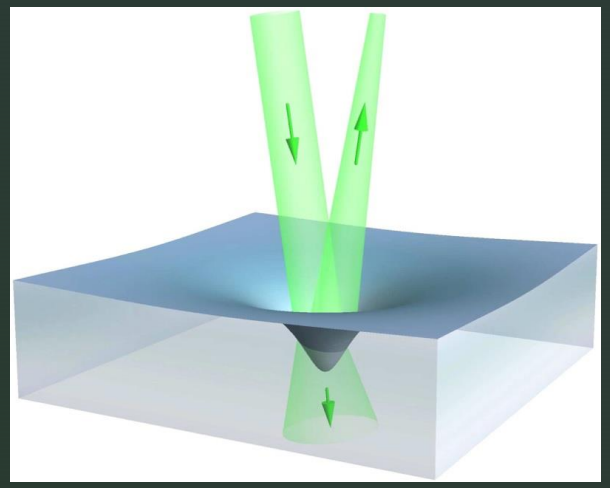
Thermal Effects

Radiometer | Dusty Loft (wordpress.com)

- Light shined on radiometer
- Black side absorbs more light -> hotter
- Heat transferred to air molecules that hit vanes
- Molecules on black side gain more energy -> recoil -> motion

Solar Energy -> Thermal Energy -> Kinetic Energy

Light Pressure

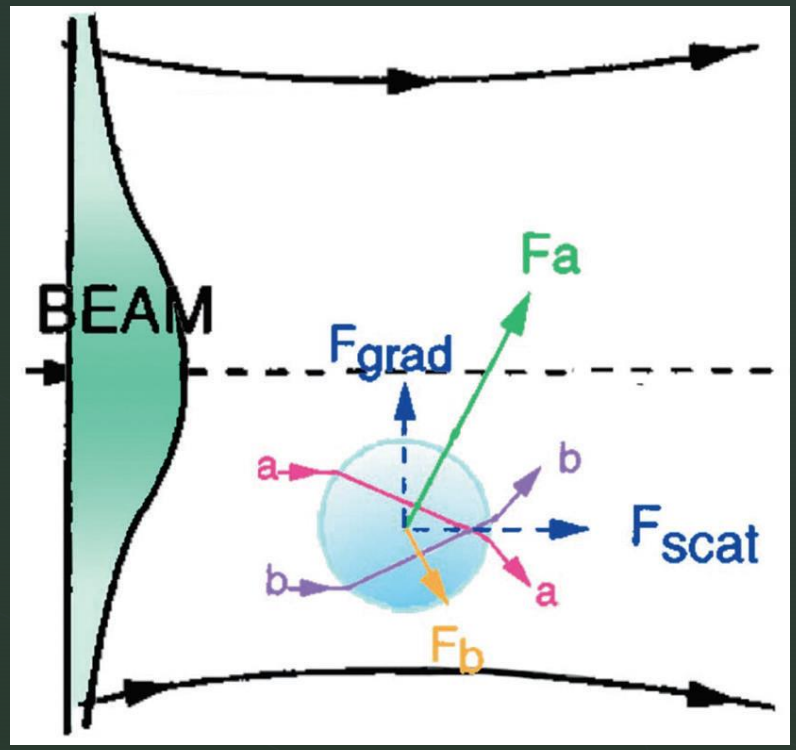


Physicists make first observation of the pushing pressure of light

- Light hits on object
- Counteractive force leads to motion
- Photons have momentum

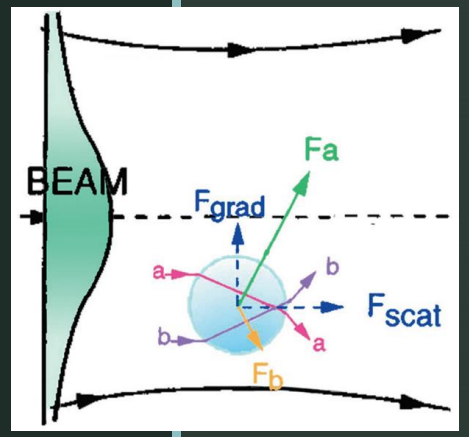
Forces on Bead

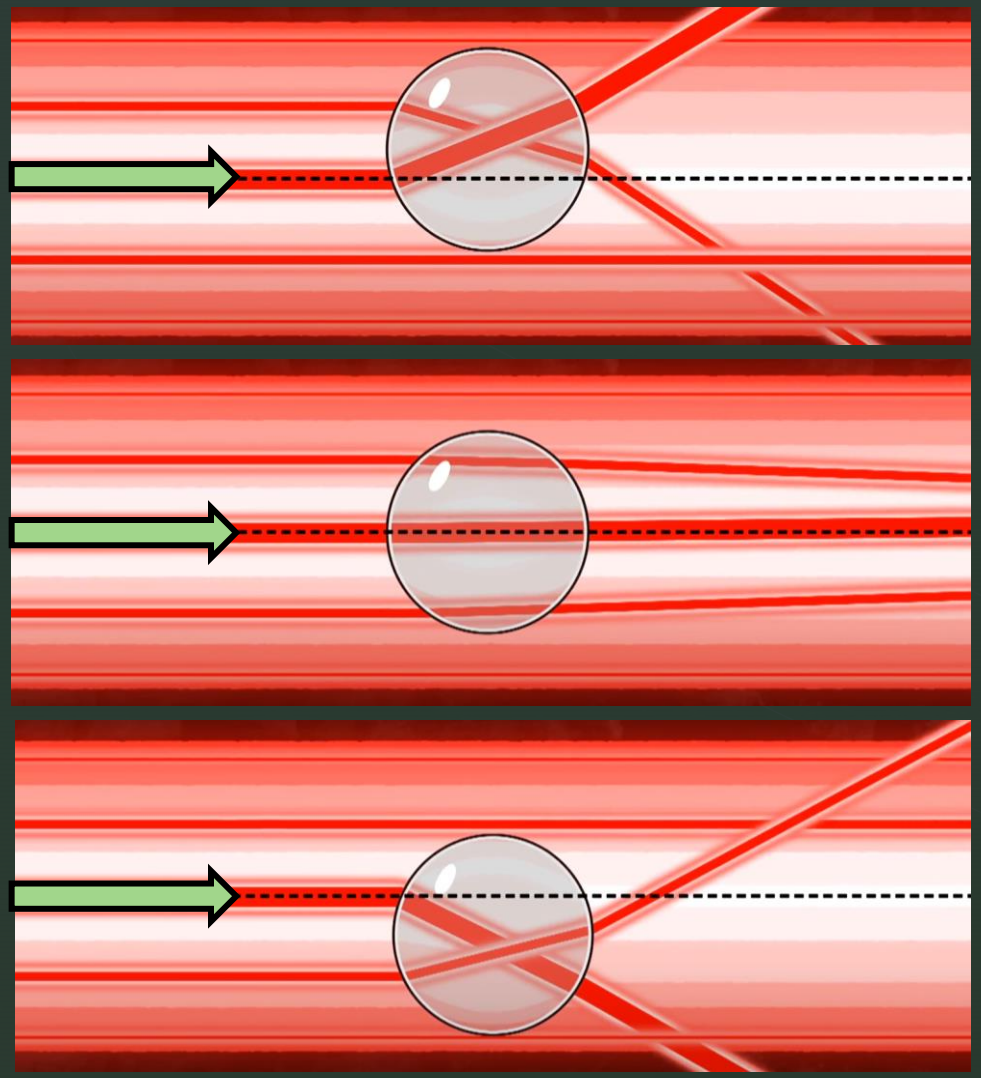
- Light has momentum
- Intensity of Beam
- Scattering Force



Nobel Lecture: Optical Tweezers and their Application to Biological Systems (nobelprize.org)

Optical Trapping





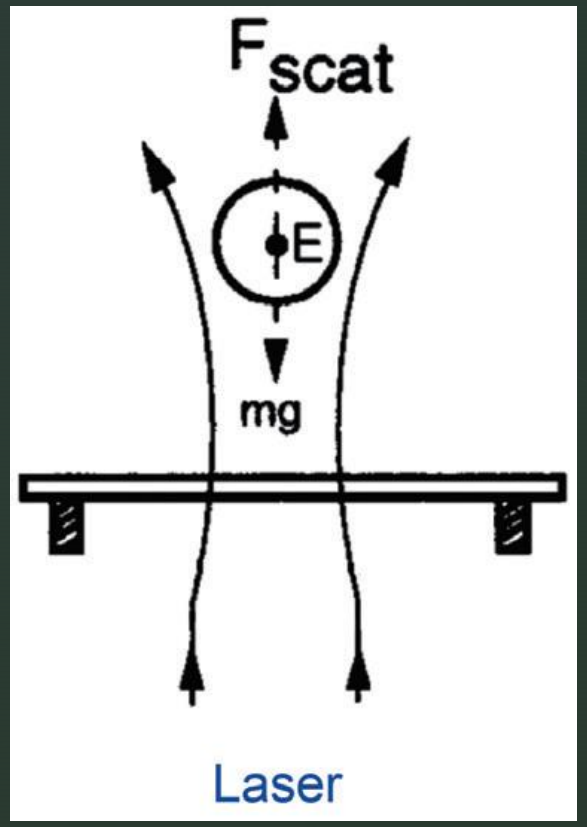
- Brightest in middle
- Sphere is off center
- More photons passing through bottom of sphere

- Momentum
- Newton's Third Law
- Sphere gets pushed back towards middle of laser beam

- Brightest in middle
- Sphere is off center
- More photons passing through top of sphere

Optical Tweezers and the 2018 Nobel Prize in Physics - Sixty Symbols - YouTube

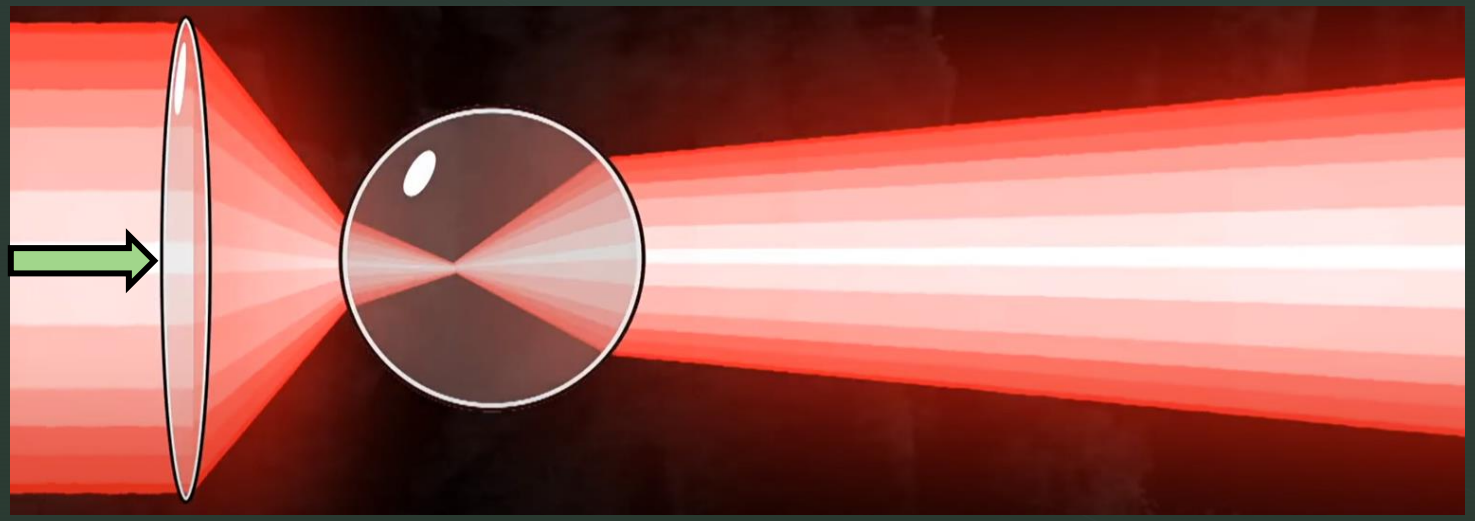
Optical Levitation



- Some light gets absorbed by the sphere
- Sphere gets pushed
- Light pushes sphere up, and gravity pushes down
- Instability

Nobel Lecture: Optical Tweezers and their Application to Biological Systems (nobelprize.org)

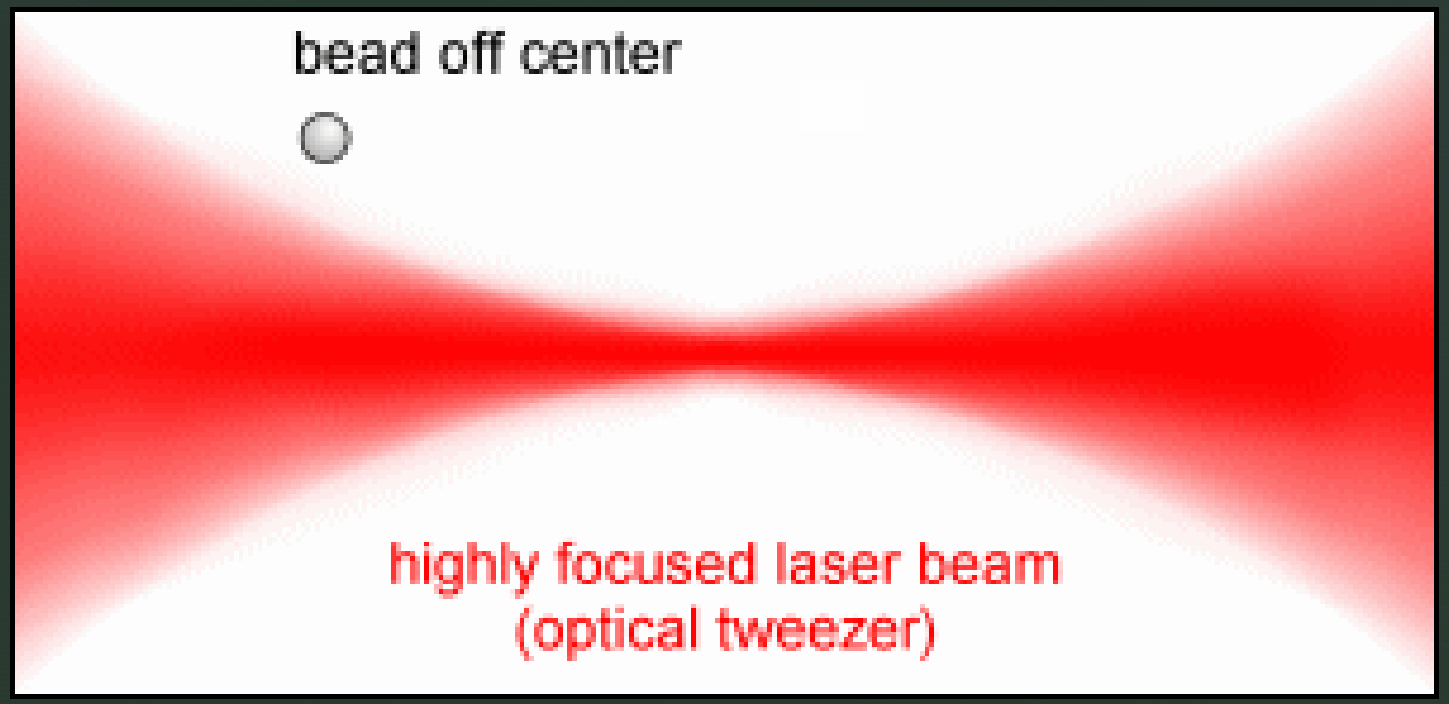
Laser Through Lens



Optical Tweezers and the 2018 Nobel Prize in Physics - Sixty Symbols - YouTube

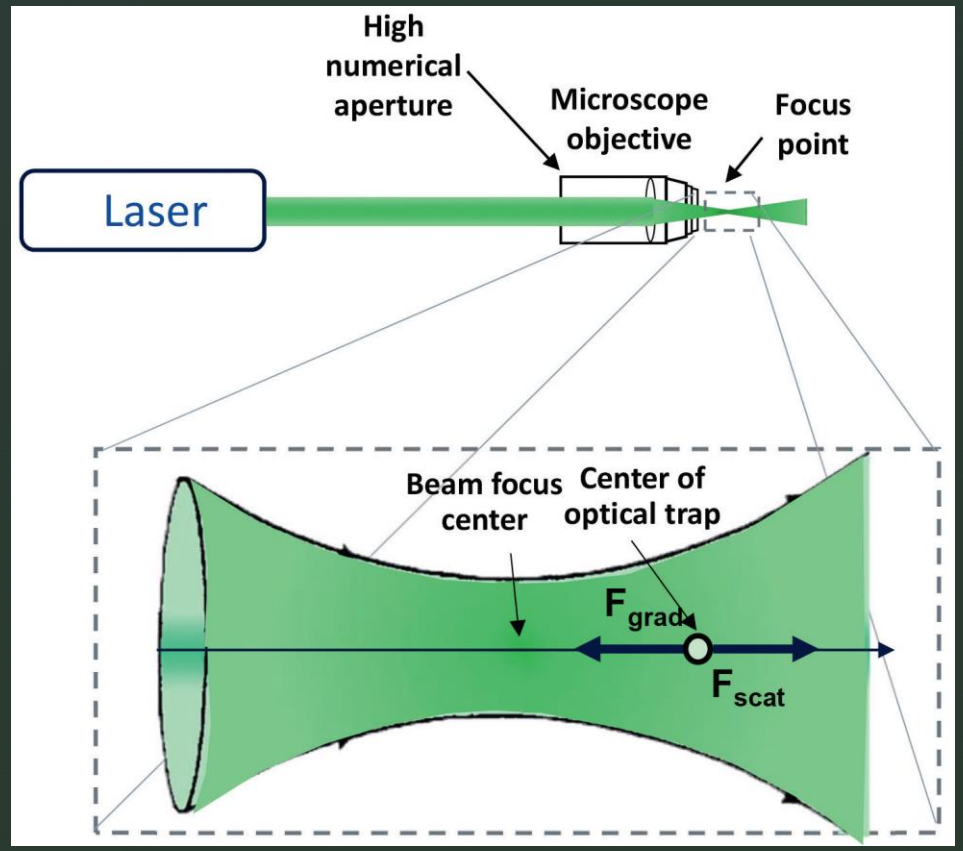
- Putting a lens
- Focal point
- Traps the sphere

Focused Beam



Introduction: Optical Traps - Soft Matter Physics Division - University of Leipzig (uni-leipzig.de)

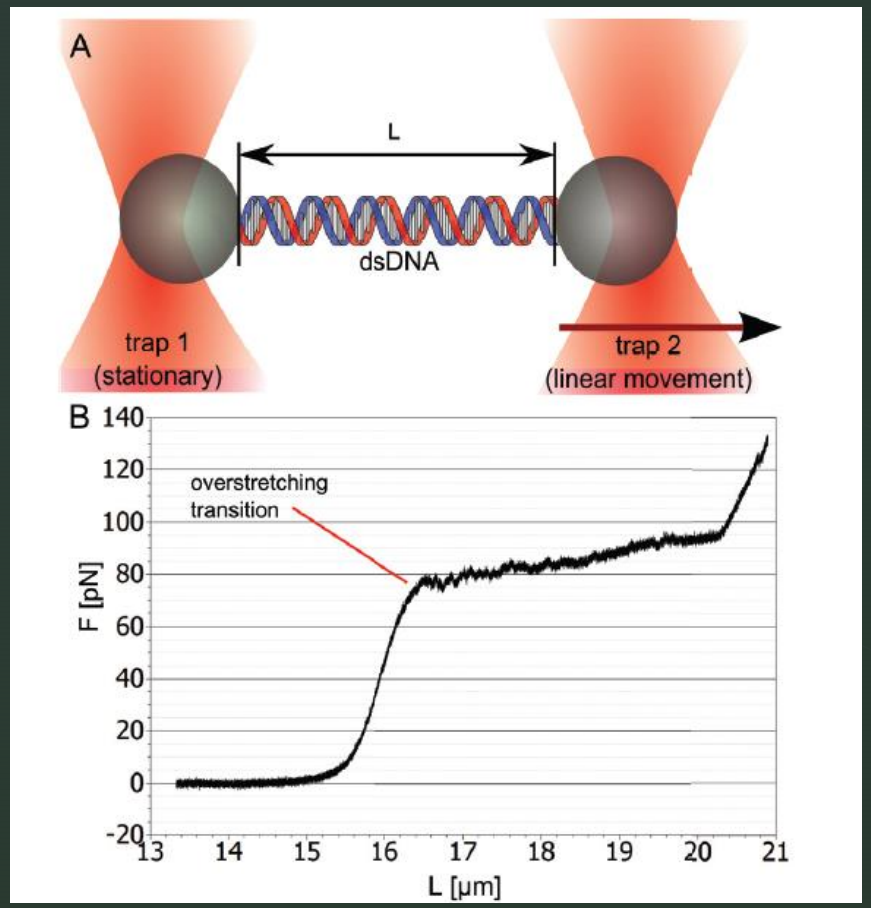
Single-Beam Optical Tweezer



- One laser beam
- Focus point
- Equilibrium point
- Bead is trapped

Nobel Lecture: Optical Tweezers and their Application to Biological Systems (nobelprize.org)

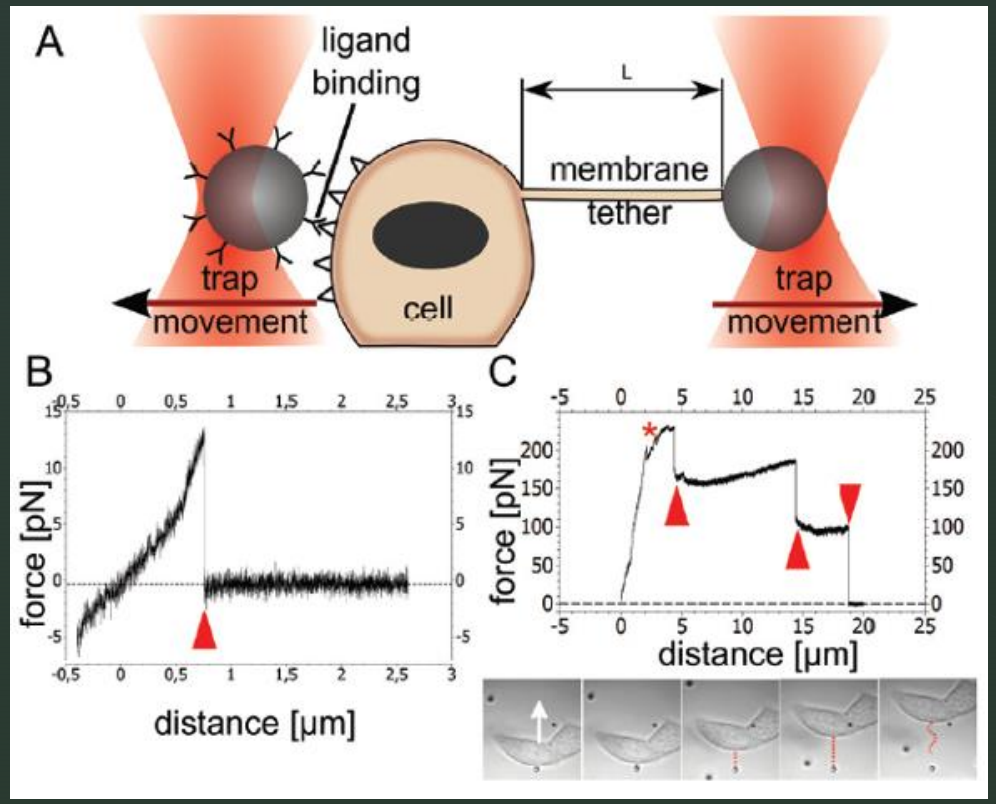
Dual-Beam Optical Tweezer



- Bead attached to DNA
- Bead attached to RNA
- DNA stretching
- DNA transcription
  - Protein moves along DNA
  - Unzips DNA double helix
  - Copies DNA sequence

Optical Tweezers for Single-Cell, Multicellular Investigations in the Life Sciences | American Laboratory

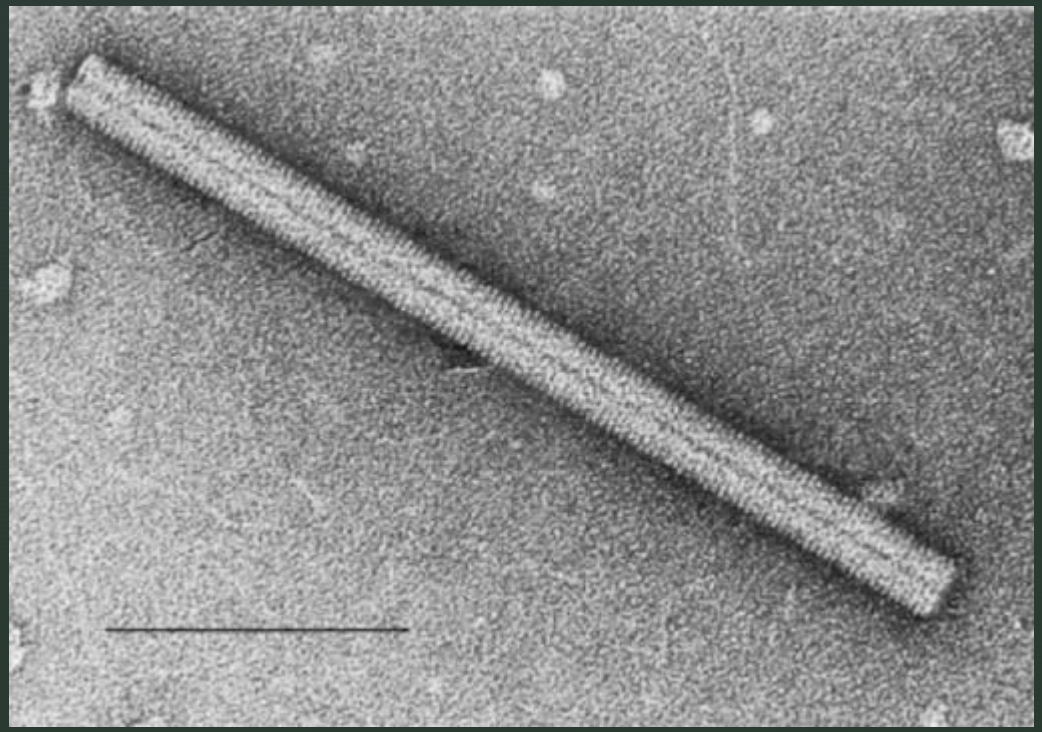
Connecting to Live Cell



- Particle decorated with antibodies
  - Connects to cell membrane
- Optical trap pulls particle away from cell until the chemical bond breaks
- Elongated membrane tether
- Understand mechanical properties of cell membrane

Optical Tweezers for Single-Cell, Multicellular Investigations in the Life Sciences | American Laboratory

Without Attaching Sphere to Microorganism

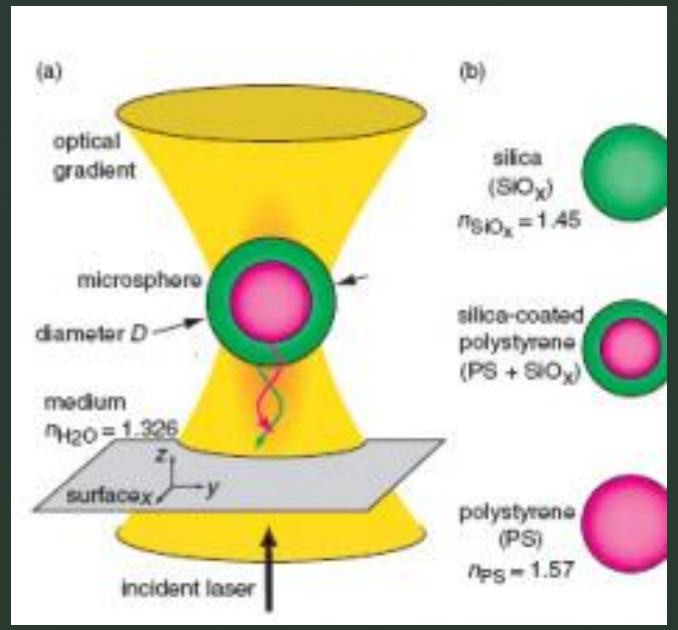


Tobacco mosaic virus - PRG Wiki (crg.eu)

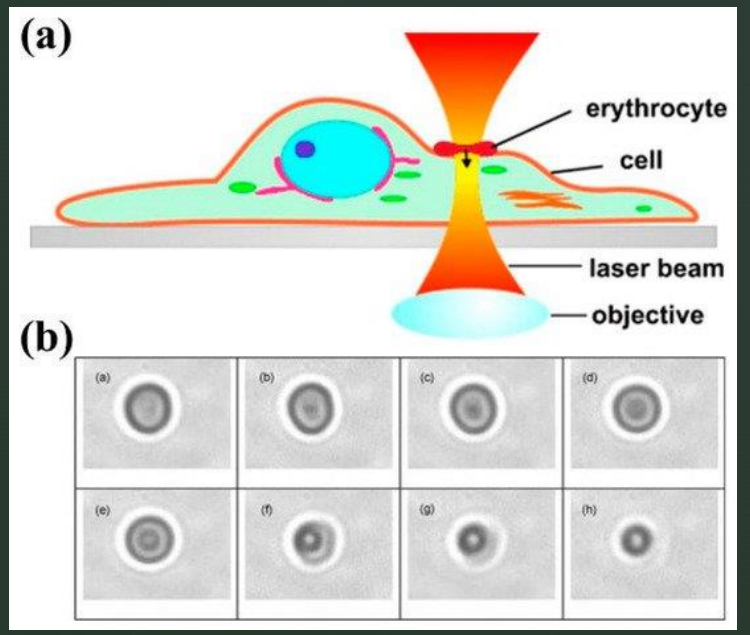
- Tobacco mosaic virus
- Refracting end
- Can be trapped by optical tweezer
- Doesn’t only trap spheres

Uses of Optical Tweezers

- Force to optically trap particle depends directly on refractive index as compared to surrounding medium
- Most used particles: silica and polystyrene microspheres
  - Refractive index higher than that of water
  - Coating of microspheres
- Can increase numerical aperture of the laser beam to increase intensity
- Can trap and attach particle to another particle



Optical trapping of coated microspheres (osapublishing.org)



Micromachines | Free Full-Text | Optical Tweezers: Phototoxicity and Thermal Stress in Cells and Biomolecules | HTML (mdpi.com)

Future of Optical Tweezers

- Direct manipulation of a single molecule (such as a protein)
- Measuring forces of microscopic objects inside cells
- Aim to advance into the nanoscale level

Sources

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