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

Light

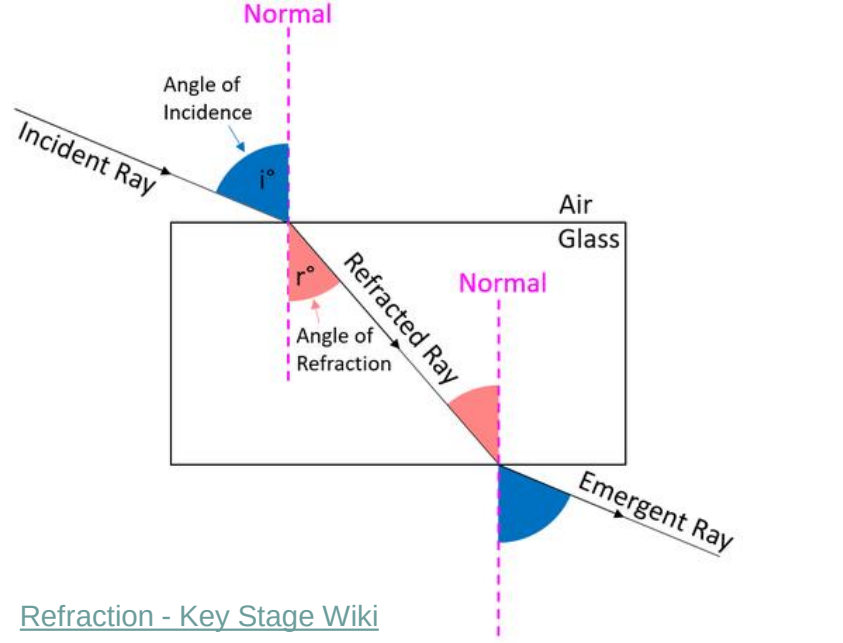
More specifically: Lasers

Lasers

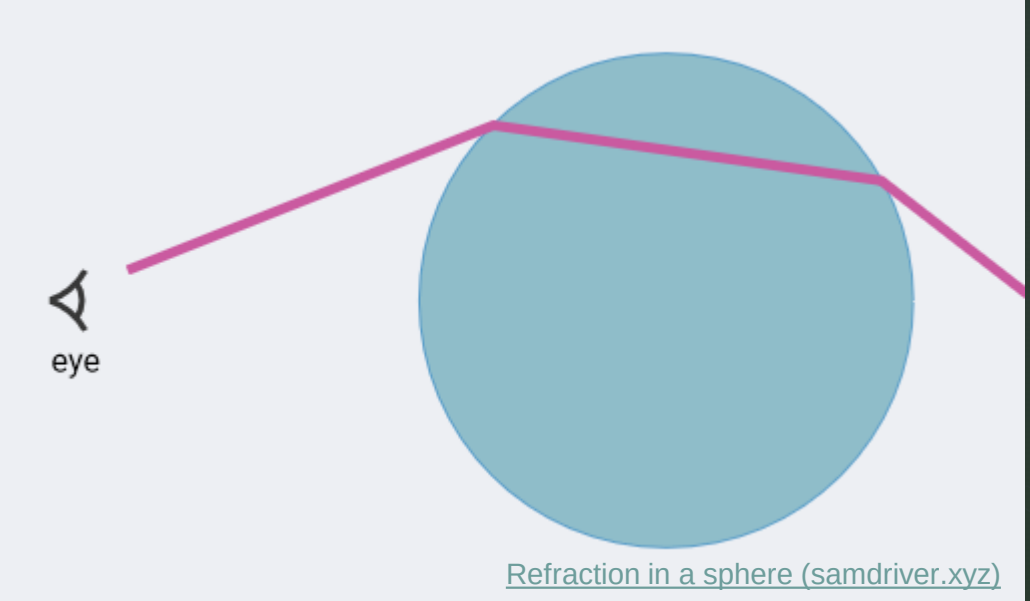
- Monochromatic: made up of a single wavelength
- Directional: low divergence
- Coherent: waves in phase with each other

Refraction

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

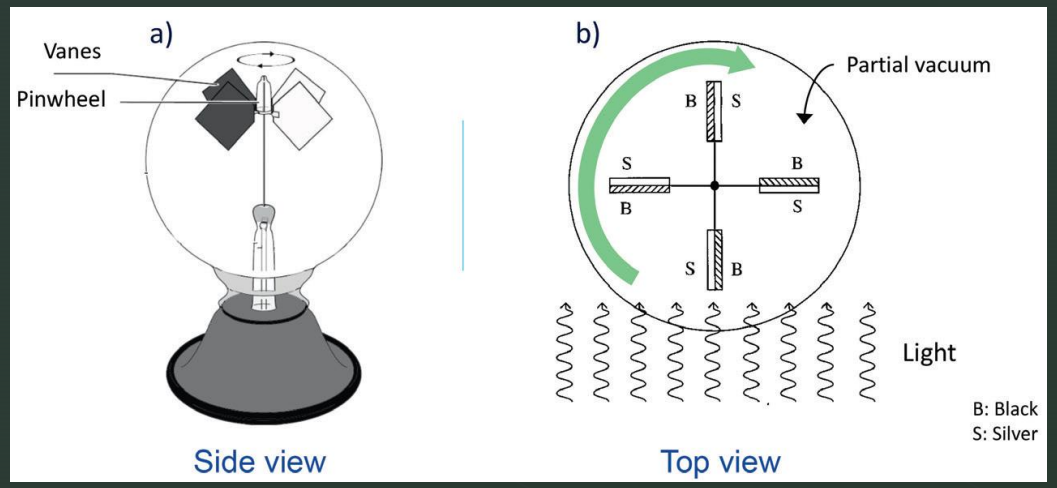


Refraction - Key Stage Wiki



Refraction in a sphere (samdriver.xyz)

Thermal Effects



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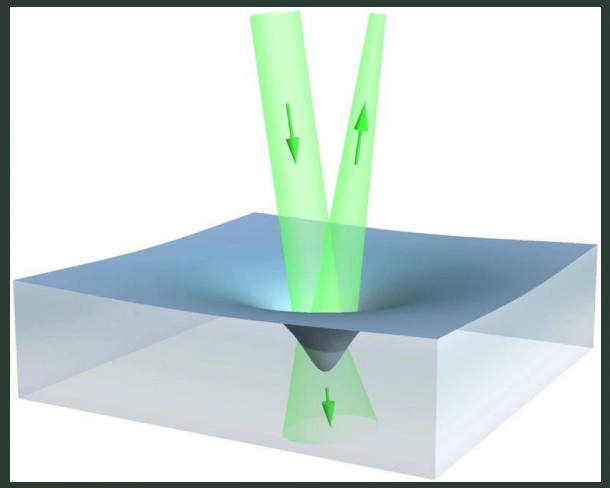
- Light hits onto the radiometer
- Black side of vanes heats up
- Thermal effects lead to motion

Light Pressure

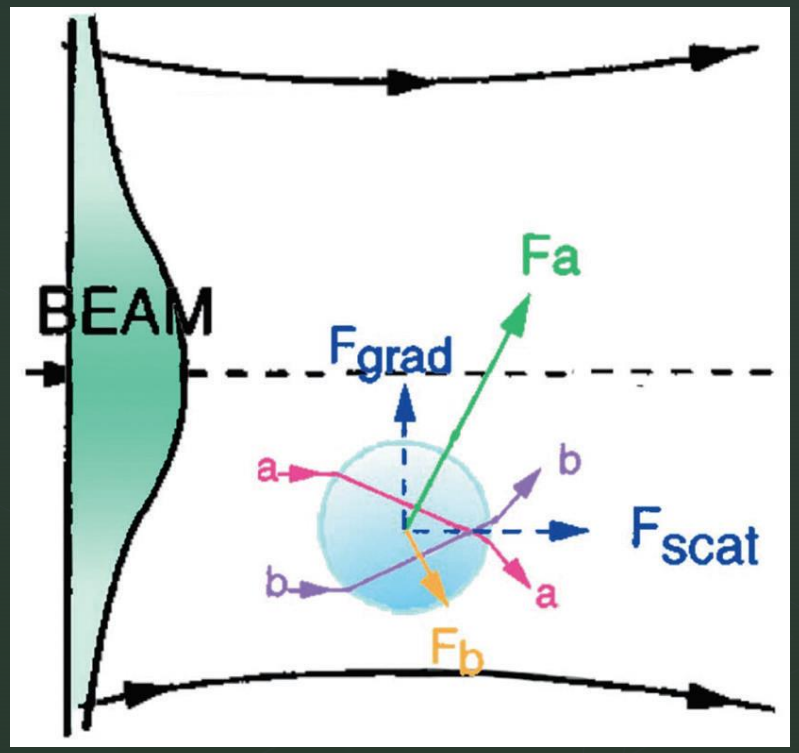


Physicists make first observation of the pushing pressure of light

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

Momentum

- Light has momentum
- $E^2 = p^2c^2 + m^2c^4$
- $E = pc$



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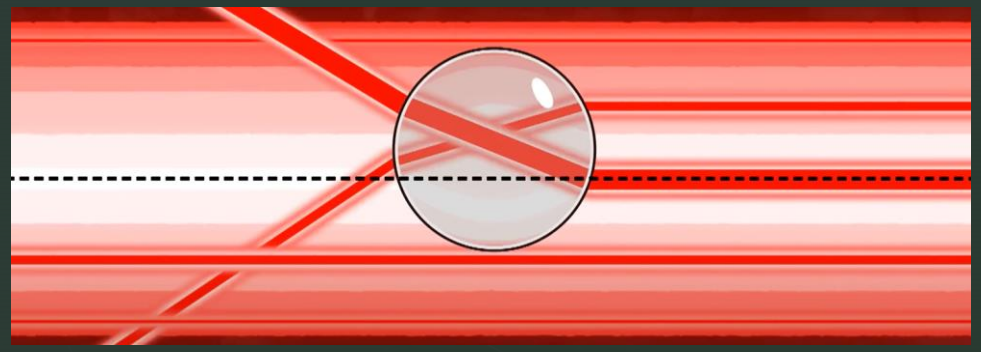
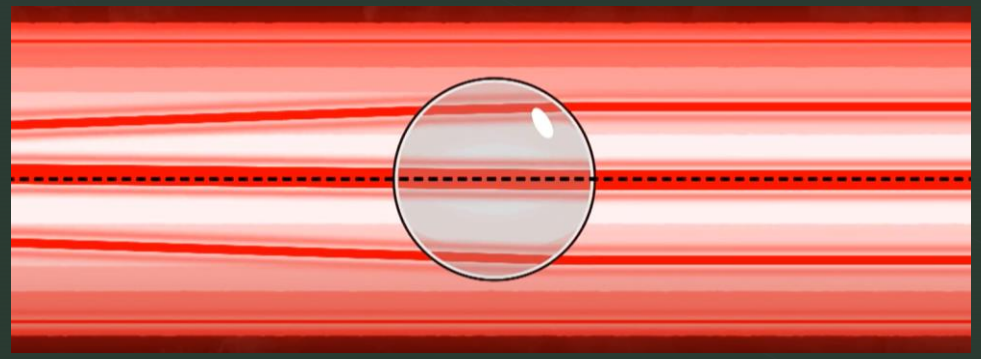
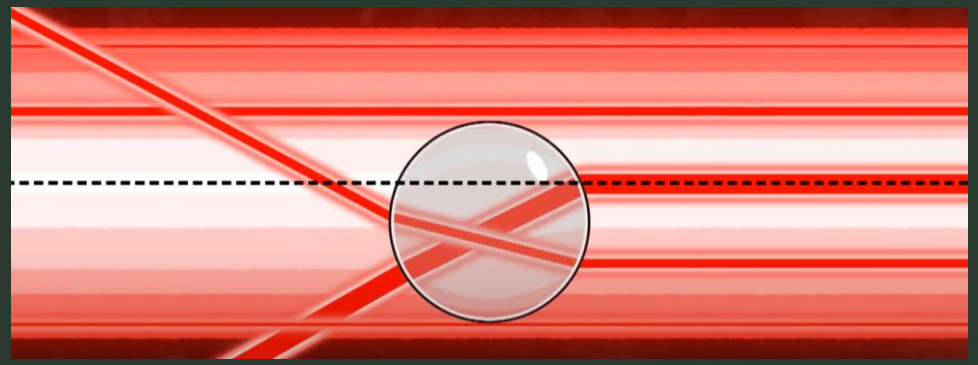
Optical Trapping



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



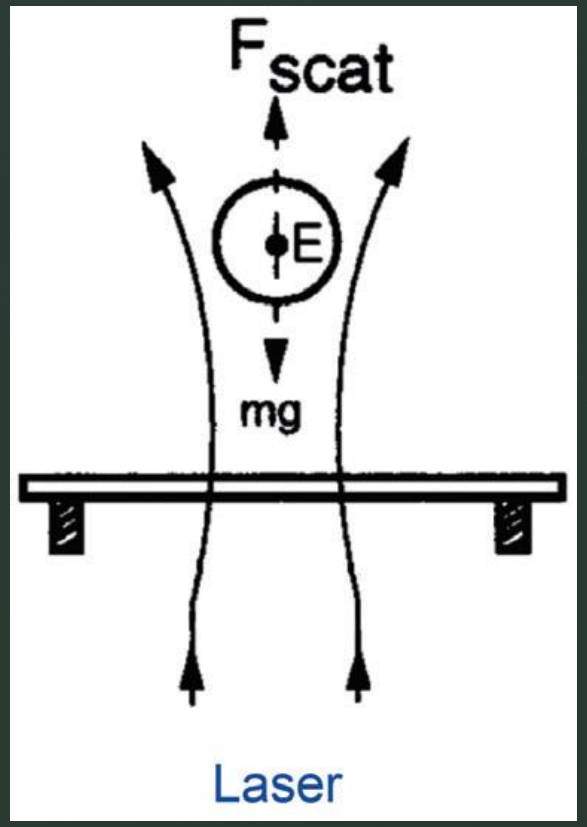
- Momentum
- Newton's Third Law
- Sphere gets pushed back towards middle of laser beam



- 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

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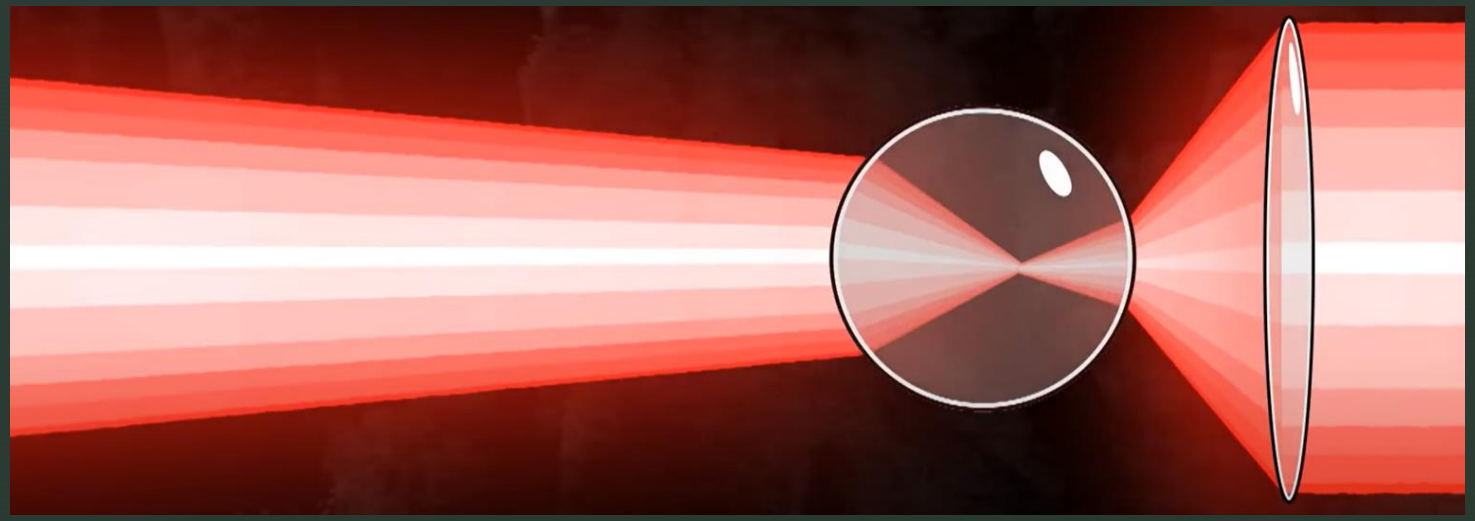
Laser Through Lens



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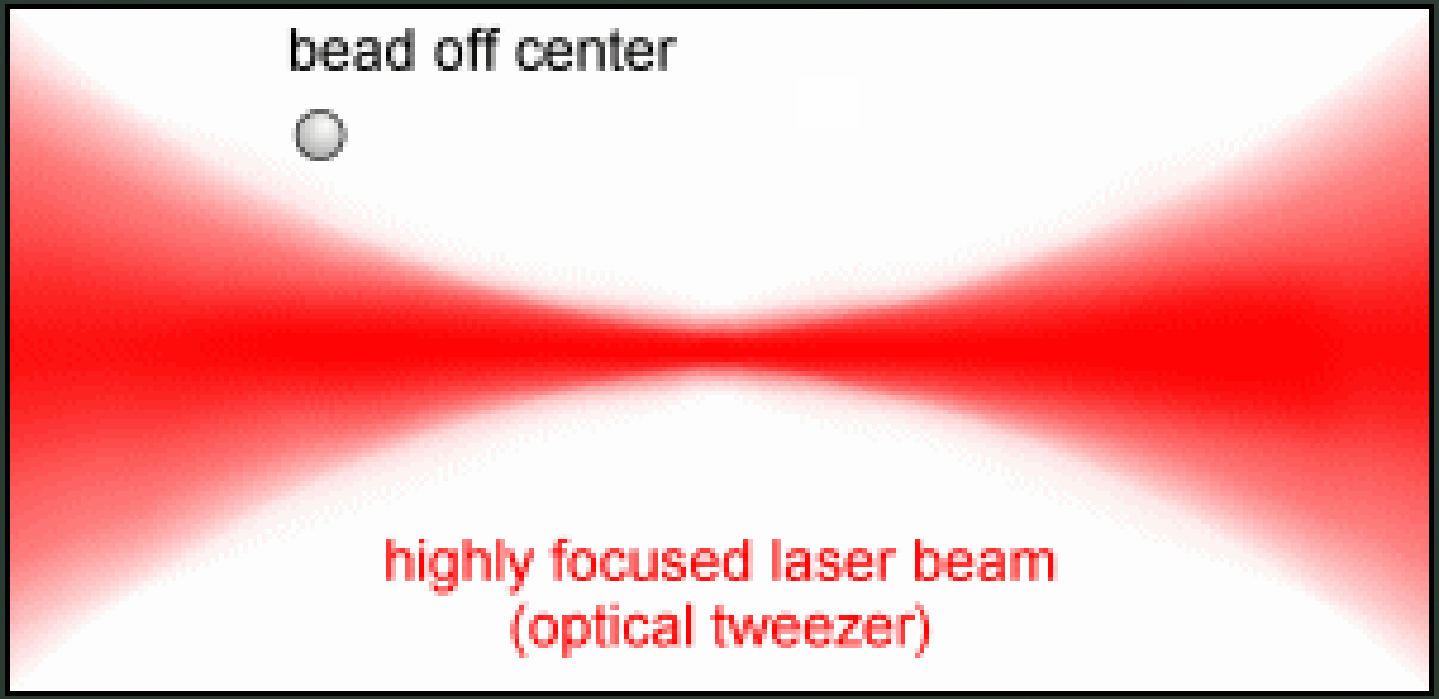
- Putting a lens
- Focal point
- Traps the sphere

Focused Beam

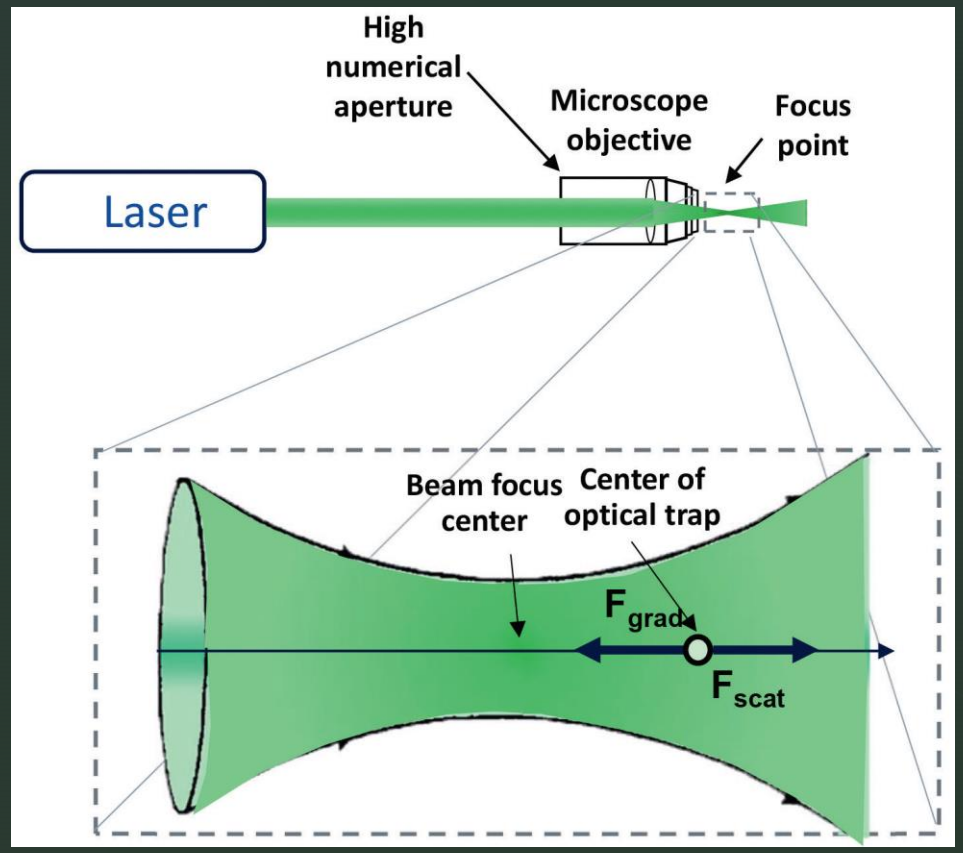


Introduction: Optical Traps - Soft Matter Physics Division - University of Leipzig (uni-leipzig.de)

Optical Tweezers

moving laser, moves the trapped particle

Single-Beam Optical Tweezer



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

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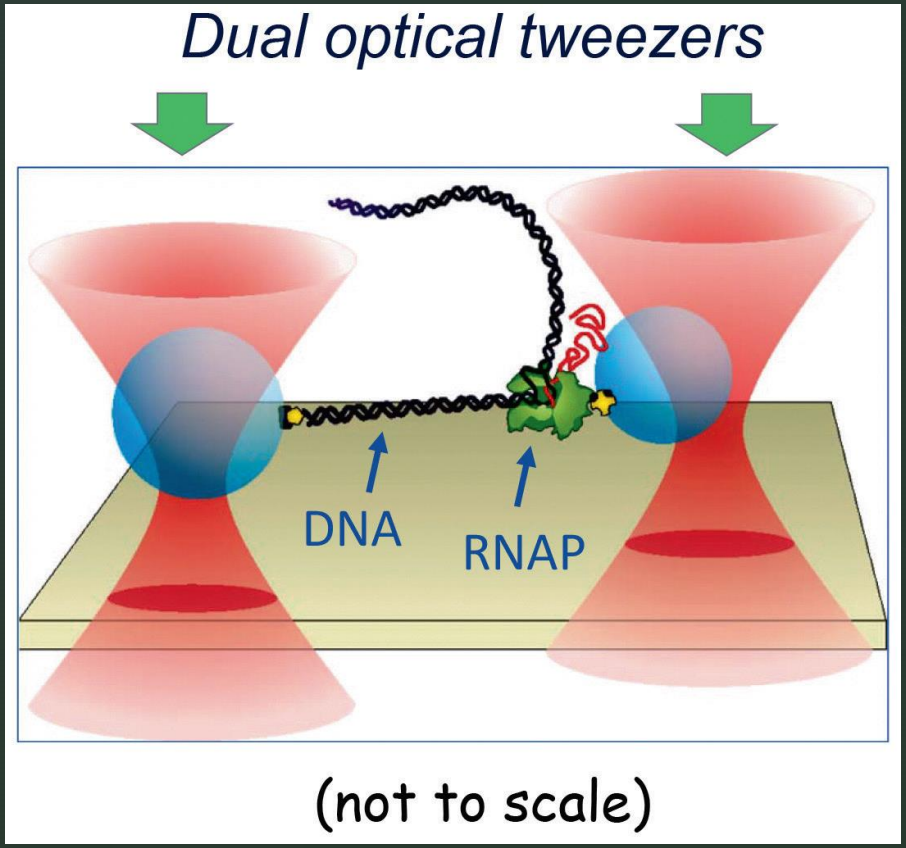
Dual-Beam Optical Tweezer



- Bead attached to DNA
- Bead attached to RNA
- One bead more strongly trapped than other
- RNA moves along DNA by transcription

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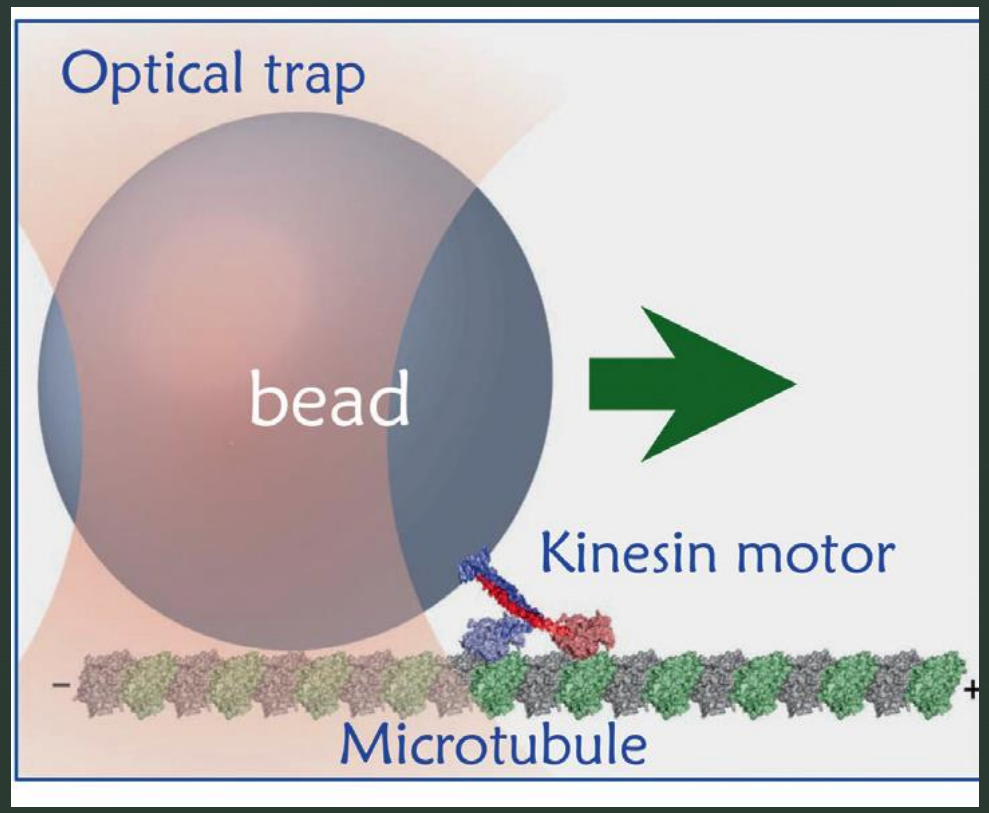
Use of Optical Tweezers

More specifically: Biology

Attaching Sphere to Microorganism



- “Soft” trapping
- Bead attaches to kinesin motor
- Kinesin attaches to microtubule
- Kinesin moves along microtubule

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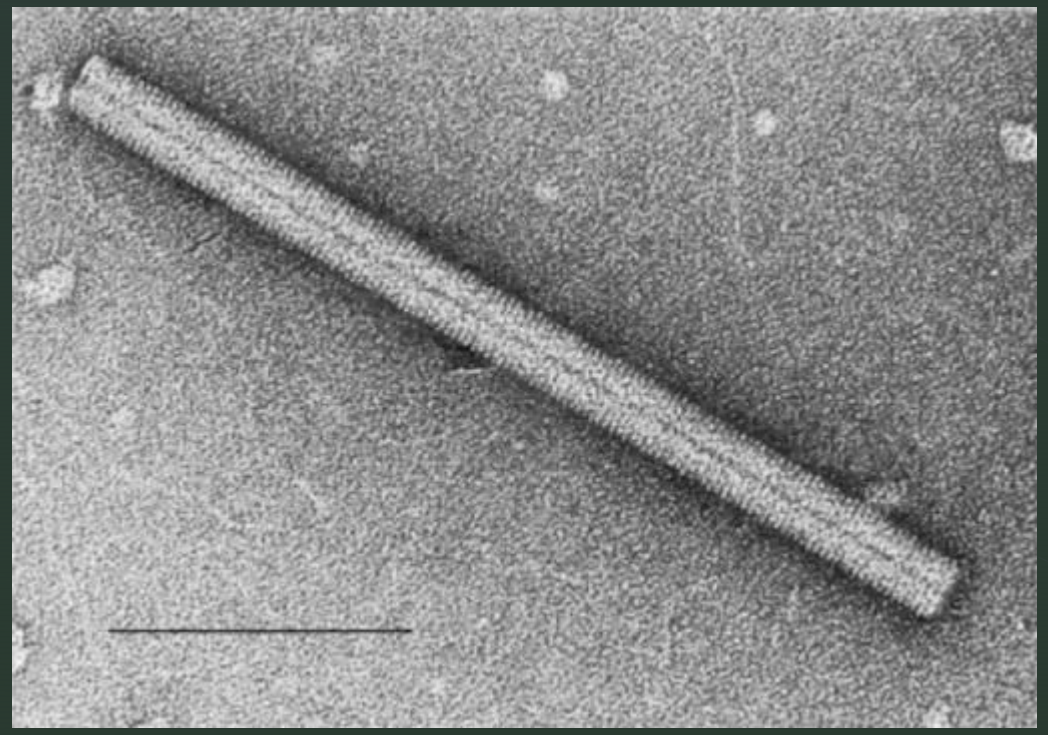
Without Attaching Sphere to Microorganism



Tobacco mosaic virus - PRG Wiki (crg.eu)

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

Other Uses of Optical Tweezers

- Protein binding
- Moving cells
- Measuring properties of biopolymers
- Manipulating cells and organelles
- Studying binding of biomolecular components

Sources

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