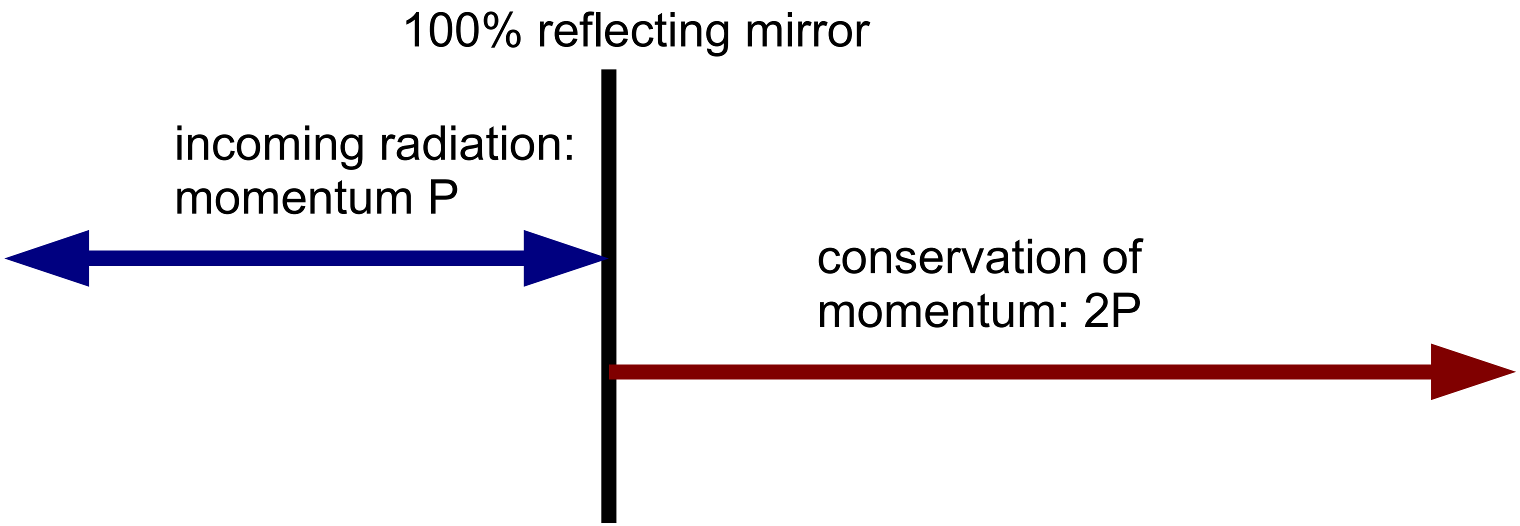
Optical traps: general applications

- **hold and move**
  - **macroscopic dielectric objects (particles up to ~10µm diameter)**
  - microscopic dielectric objects (trapping molecules, lasercooling of atoms)

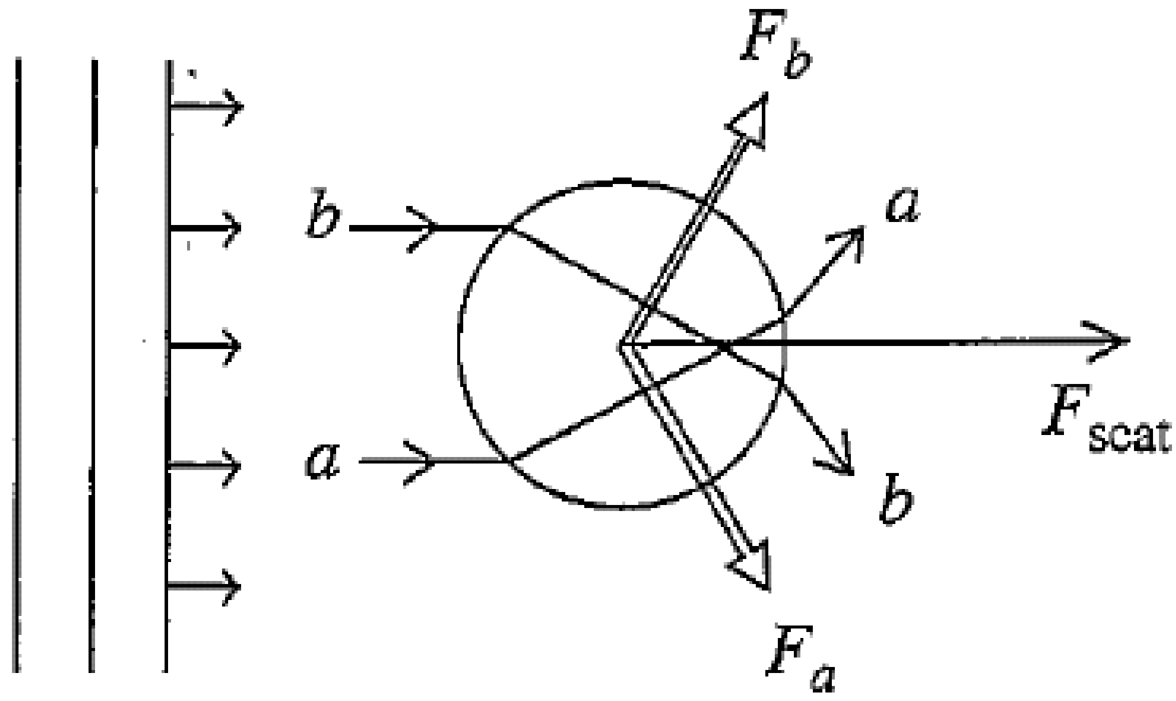
- **measure forces on trapped particles**
  - **learn something about molecule - molecule interaction (e.g. molecular motors)**

The idea: radiation pressure

- first developed by A. Ashkin in 1970
- force on every object reflecting/scattering or refracting light
- negligible for ordinary objects (e.g. 60W light on optimal mirror: F ~10^-7 N)
- significant for particles < 1µg

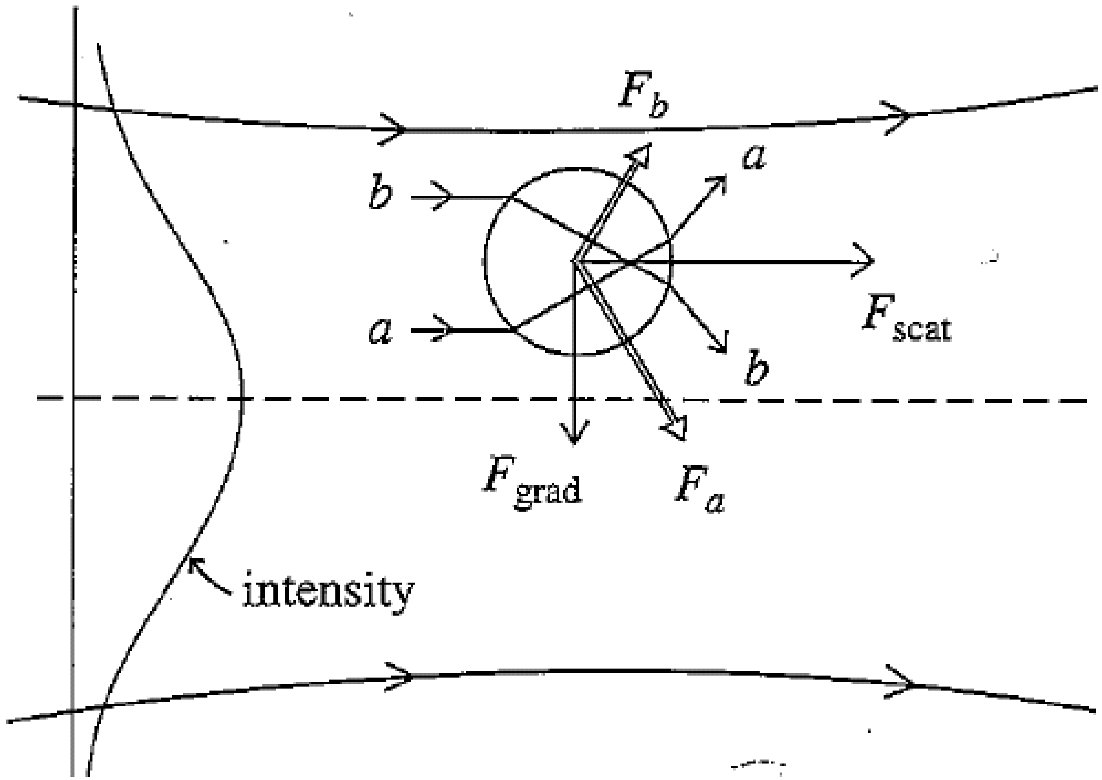


Force on polysterene bead (homogenous intensity)



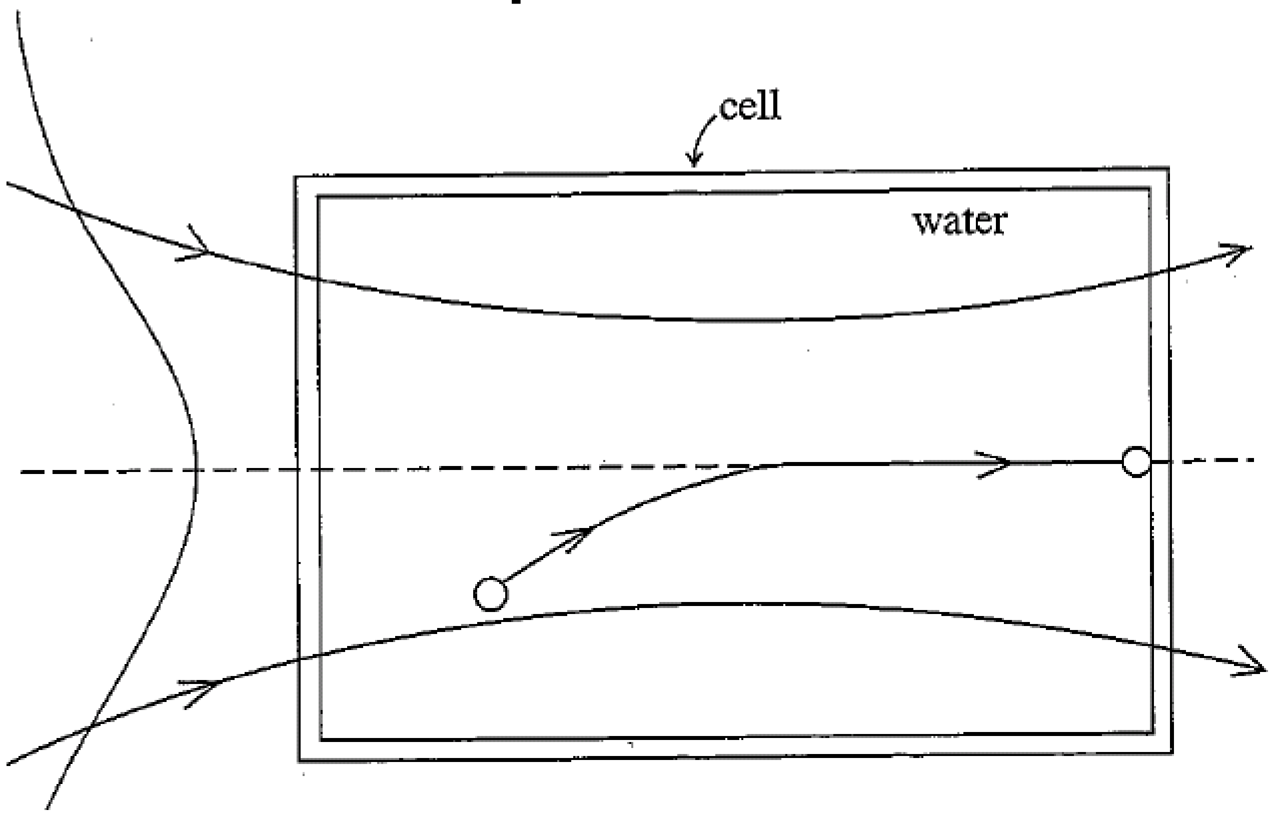
- particle diameter > wavelength: ray optics picture sufficient to calculate forces
- ray **a** equal to ray **b** → $|F_a| = |F_b|$
- resultant force $\mathbf{F}_{scat}$ along optical axis due to scattering effects on surface

Force on polysterene bead (gaussian intensity profile)



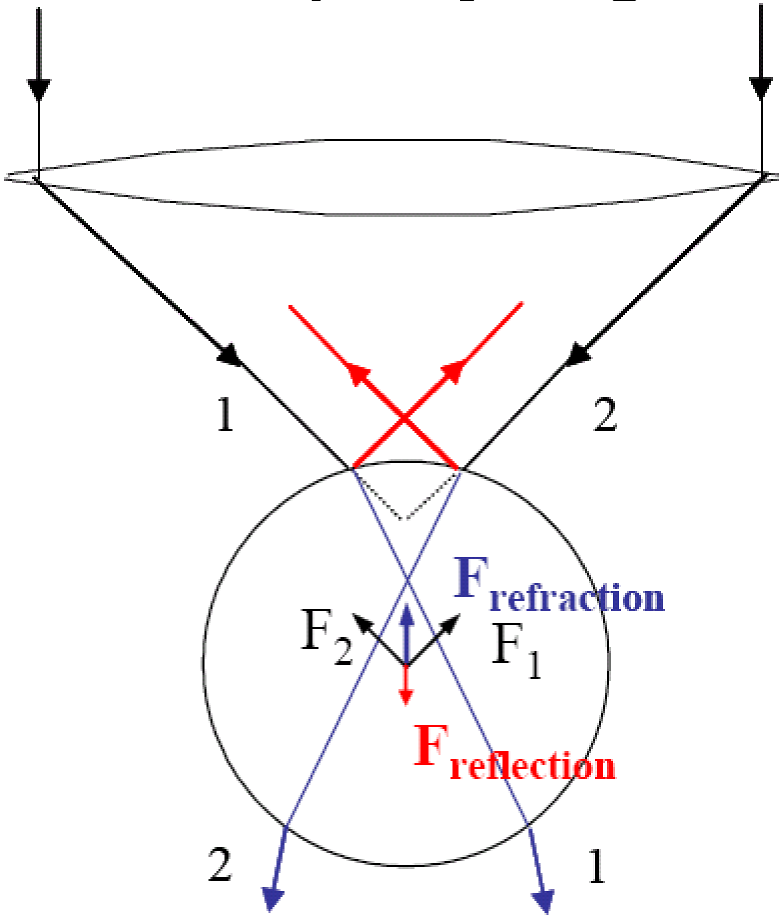
- $\mathbf{n_{bead}} > \mathbf{n_{medium}}$, bead's lighttransmission < 100%
- ray **a**: higher intensity than ray **b** ⟶ $|F_a| > |F_b|$
- resultant transversal force $\mathbf{F_{grad}}$ to beamcenter (maximum of intensity)
- but $\mathbf{F_{scat}}$ still along optical axis due to scattering effects on surface

One of Ashkin's first experiments



- bead is pulled to intensity maximum and pushed forward
- verification of theoretical predictions

Focused laserbeam: specify longitudinal force



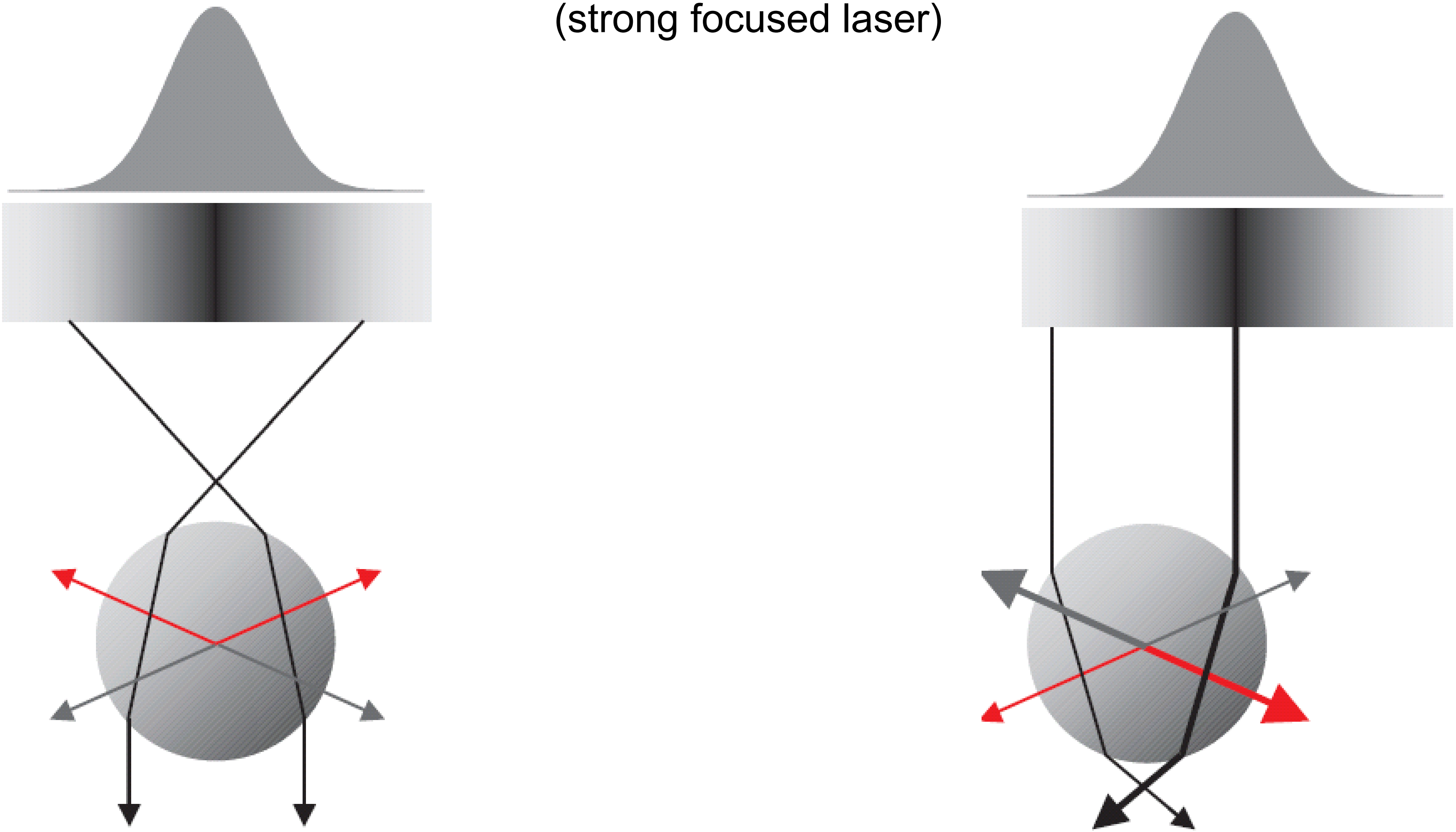
- bead not in focus: resultant refractionforce **to** focus
- light coming from edges of objective contributes **most** to this force
- high numerical aperture (NA) needed for high longitudinal refractionforce.

DUAL-BEAM OPTICAL TWEEZERS (TRAPS)

Single-beam Tweezer

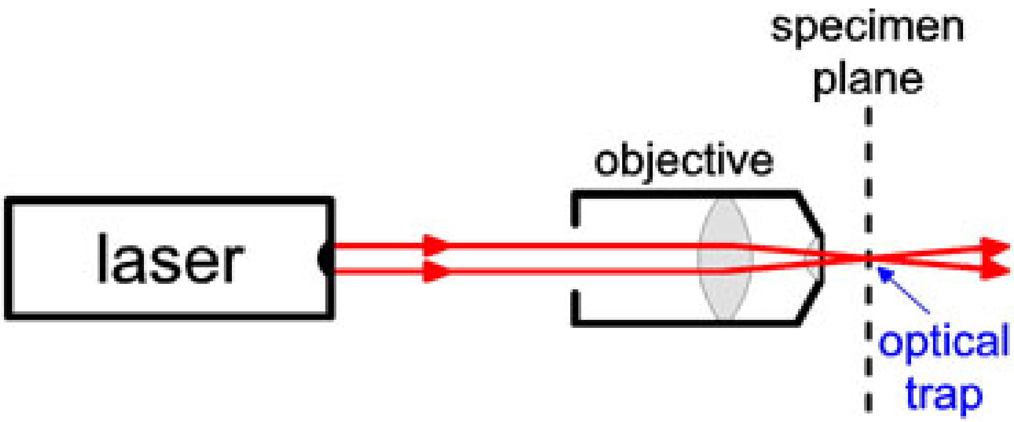
transversal stabilisation due to intensity gradient (gaussian profile)

longitudinal stabilisation due to intensity gradient (strong focused laser)



balance out longitudinal refraction- and scatteringforce: trapped particle

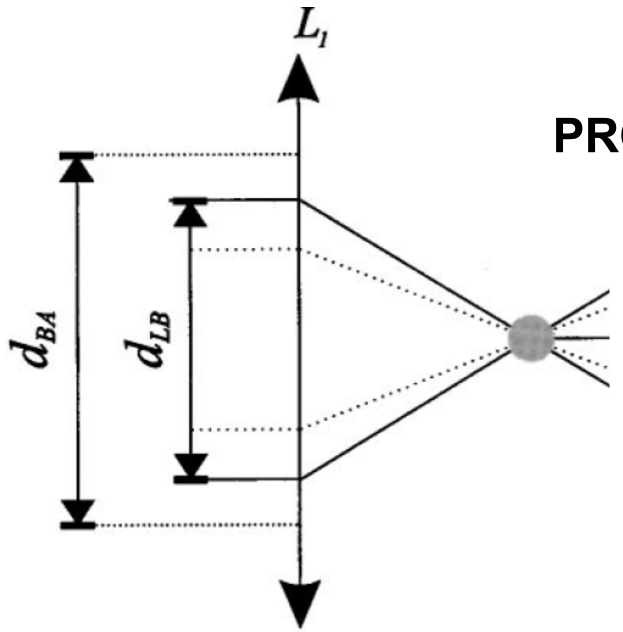
Single-beam OT: trapping force



- When does the bead leave the trap?
- for single-beam OTs: $\mathbf{F}_{trap}$ ~60 pN

Single-beam OT: measuring forces on trapped particles

- theoretically simple technique to measure forces
- conservation of momentum: Force **F** exerted by the laser is the difference between entering momentum flux and outgoing momentum flux
- momentum flux $\mathbf{Q} = \mathbf{nW} / \mathbf{c}$ (**W**: power of light, **n**: refraction index of outer medium)
- to measure $\mathbf{Q}_{out}$ all the outgoing rays have to be collected and detected
- therefore the back aperture of objective lens has to be underfilled

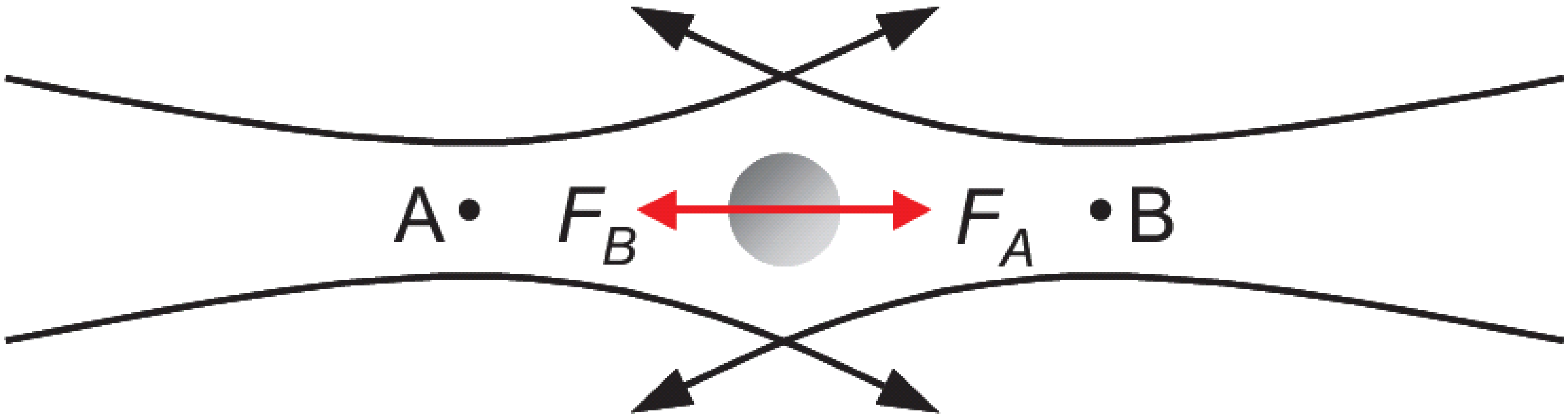


PROBLEM: very high NA needed for functionality of single-beam trap

Single-beam OT: trapping force problems

- small trapping force
- decreasing back aperture filling to enable force measurement also means decreasing the trapping force or even to disable the trap
- observation of intermolecular processes with forces higher than $\mathbf{F_{trap}}$ is not possible

Solution: dual-beam optical trap



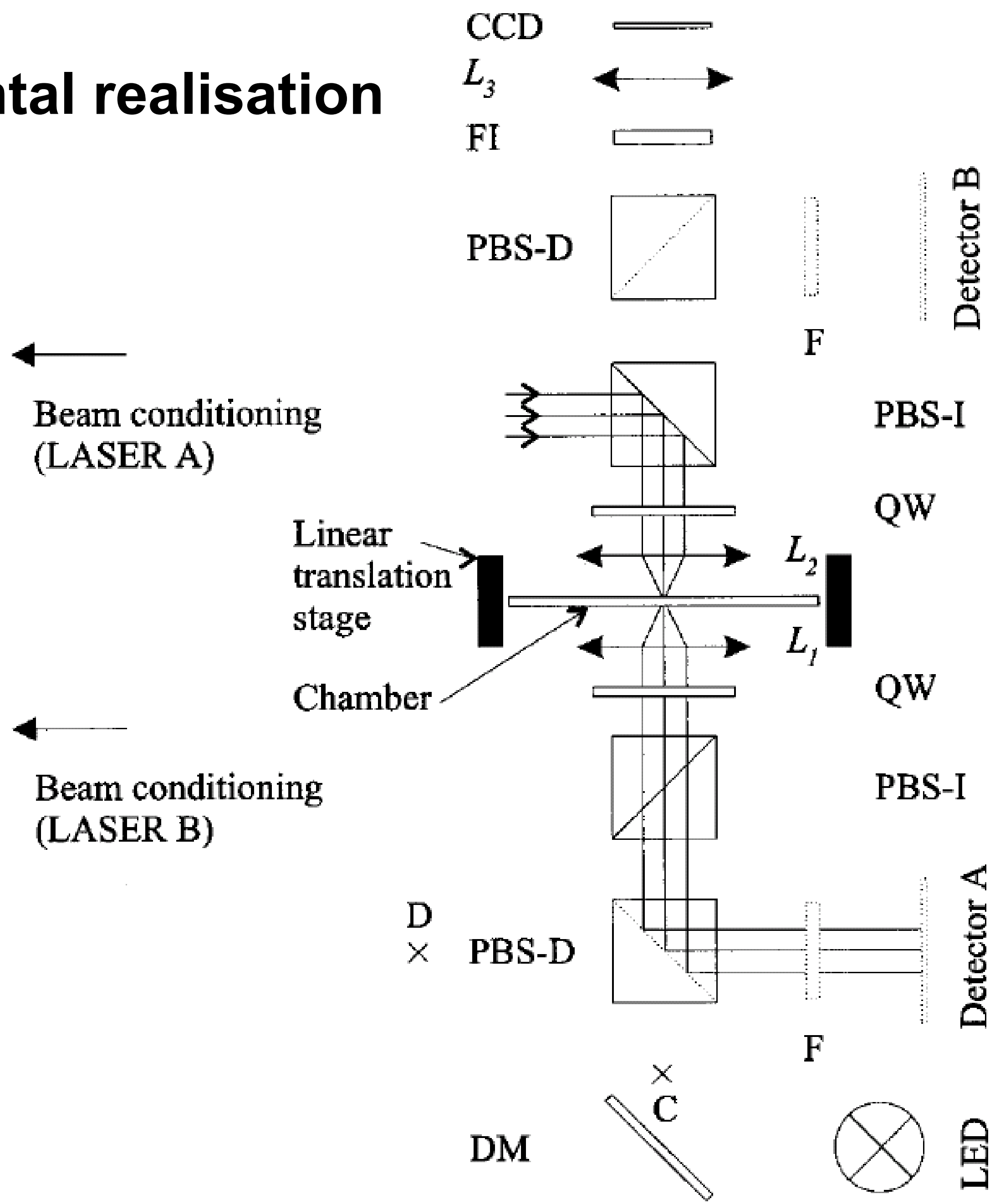
- two equal laser beams face each other and are focused in the same spot
- scattering forces cancel up
- after underfilling back apertures: resultant trapping force is still up to 200 pN and force measurements are possible (extreme precisely; with technique described before)
- trap is very stable (important vor biological investigations)

Dual-beam optical trap: difficulties

- complexity (has to be constructed precisely from many single parts)
- alignment of optical paths (lasers exactly have to face each other)
- standard implementations of these instruments did not exist after 6 years of usage (2002)

→ **if possible, a 'standard' single-beam tweezer is used**

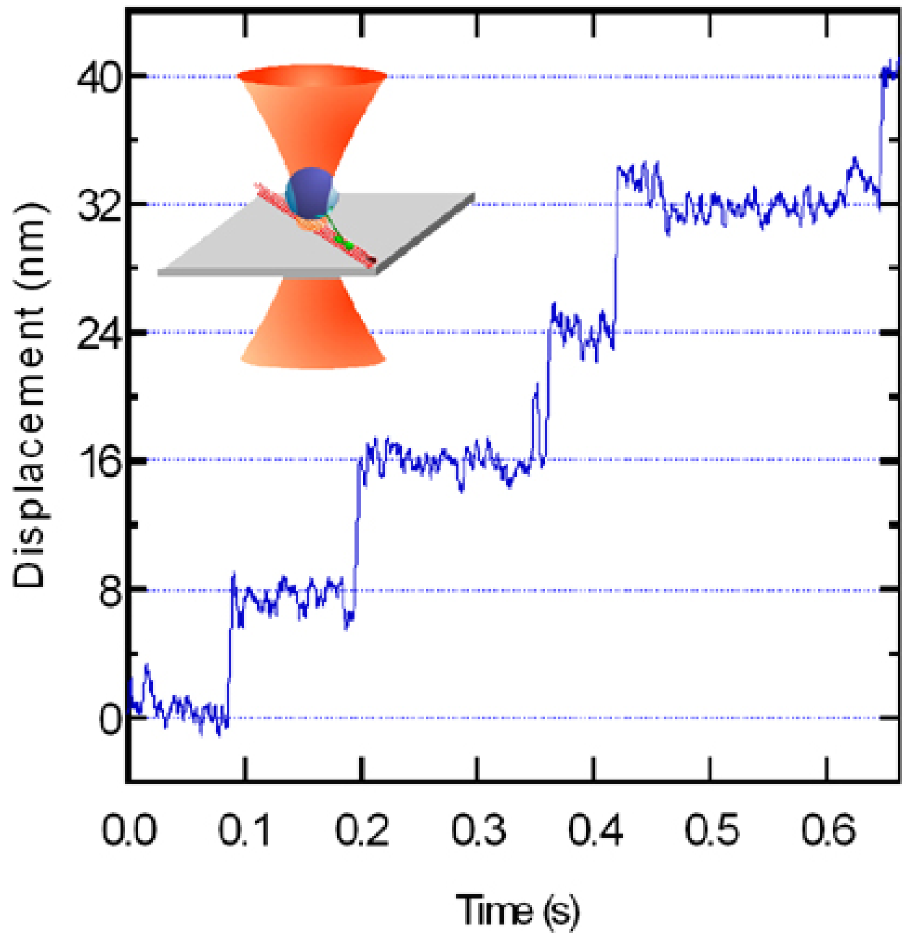
Experimental realisation



Applications in biophysics: examples

Applications in biophysics: molecular motors

movement obvervation kinesin protein

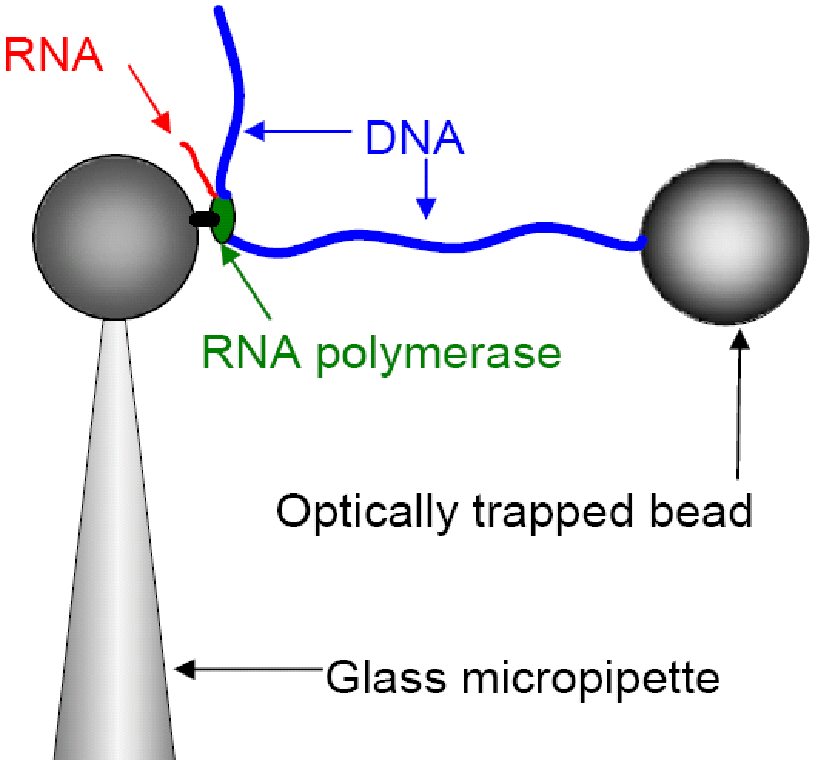


measurement of 8 nm steps of kinesin against 5 pN force

Applications in biophysics: molecular motors

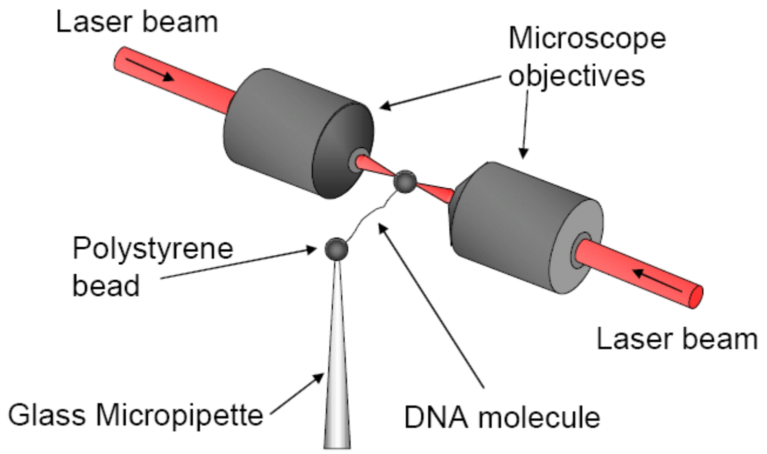
movement obvervation of RNA polymerase enzym along DNA molecule

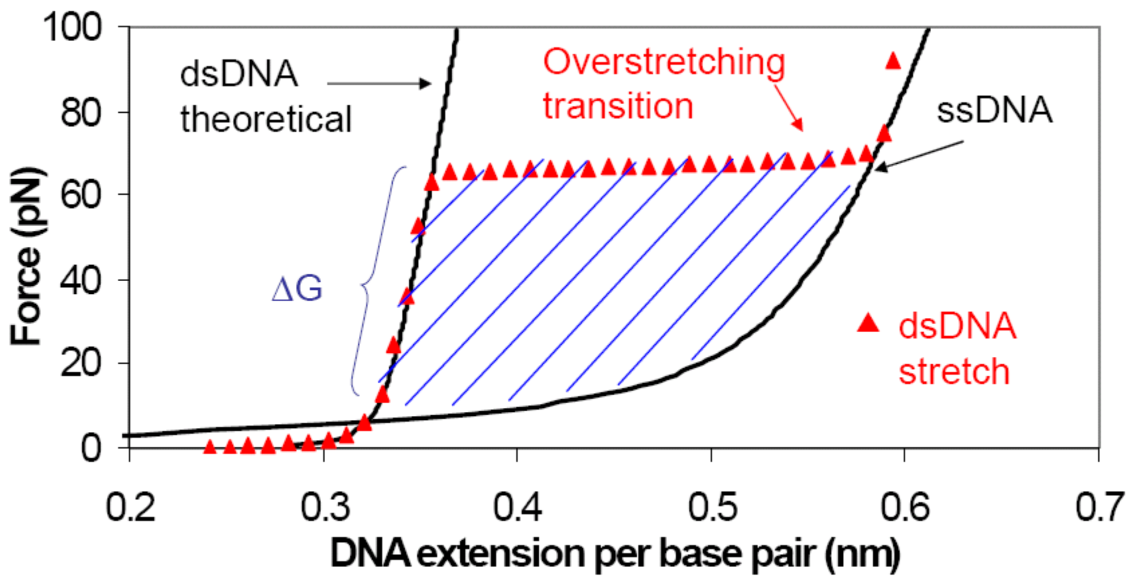
1998 Wang et al. found out, that RNA is a powerfull motor with a stall force of 21 -27 pN in comparison to kinesin (a motor protein with a stall force of 5 - 7 pN) and (1995, Yin et al.) a speed > 10 nucleotids per second.



Applications in biophysics: micromechanical properties

Measurement of the stretching of double- and singlestranded DNA





- graph: transformation of dsDNA to ss DNA at ~ 70 pN
- 1997 Wang et al. could determine persistence length and elastic modulus of DNA. They observed a significant effect on DNA stiffness by ionic strength

Literature

- Grange et al. (2002) Rev. Sci. Instr. 73, 2308 - 2316
- Marc C. Williams: *Optical Tweezers: Measuring Piconewton Forces*
- Arthur Ashkin: *Optical Trapping and Manipulation of Neutral Particles Using Lasers: A Reprint Volume with Commentaries,* World Scientific Publishing, 2007
- Kai Urig, Heike Böhm: *Praktikum Biophysikalische Chemie: Optische Pinzetten, 2005*
- *http://www.stanford.edu/group/blocklab/Optical Tweezers Introduction.htm (called 28th of June, 2007)*