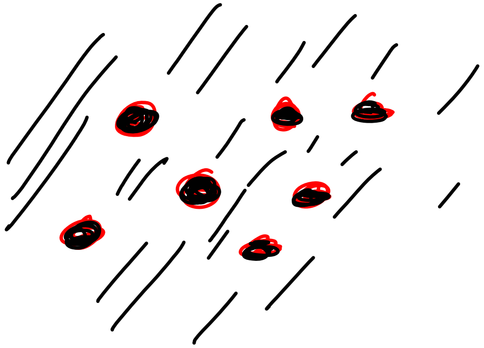
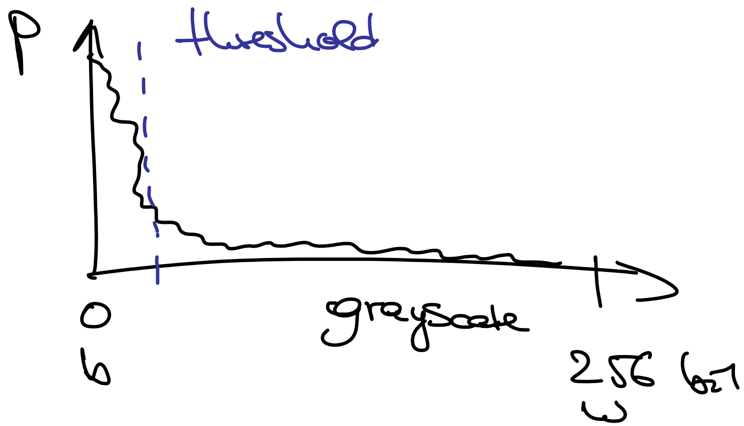
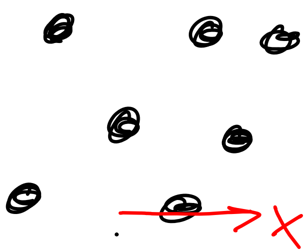
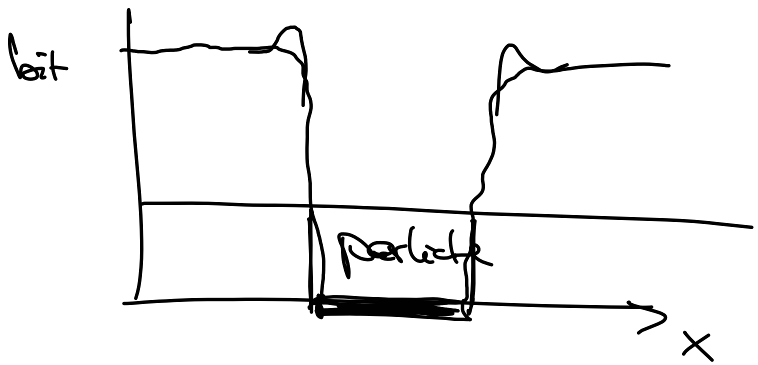
Particle tracking by video microscopy

1) identification of particles

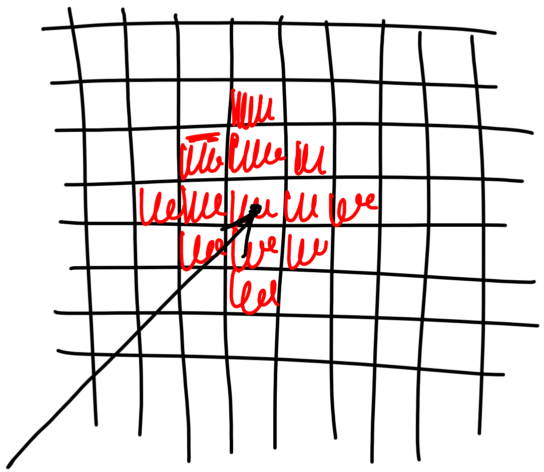




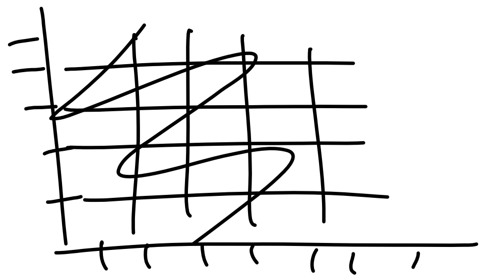


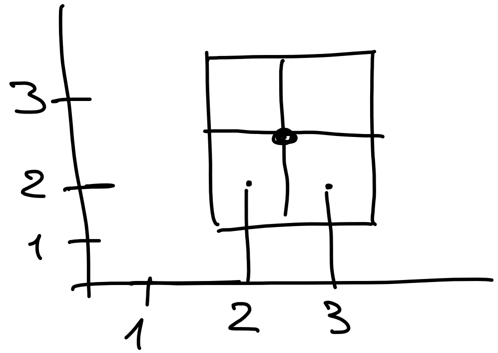


3. Particle coordinates



center of particle
≙ center of mass of intensity distribution





$$\frac{1}{4}\left((2,2)+(3,2)+(2,3)+(3,3)\right)$$
$$=(2.5;\,2.5)$$

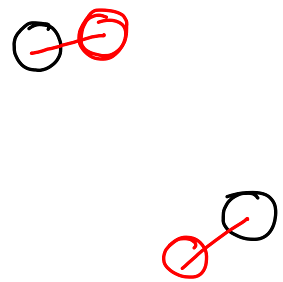
subpixel resolution

typ ~ ± 50 nm

4. From single images → trajectories

$t = t_1$

$t = t_2$



Sampling rate must be large enough to uniquely identify particles

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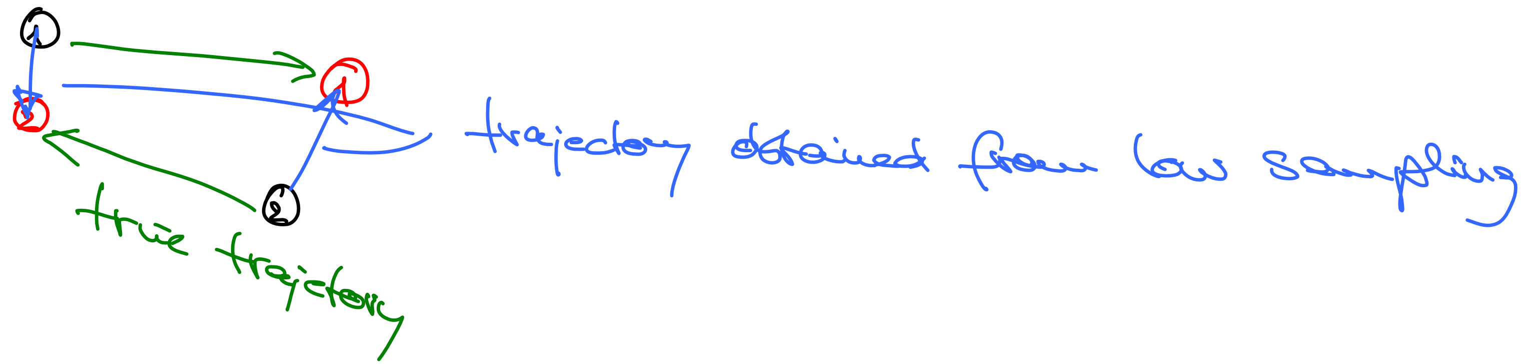
example for a to small sampling rate

$t = t_1$

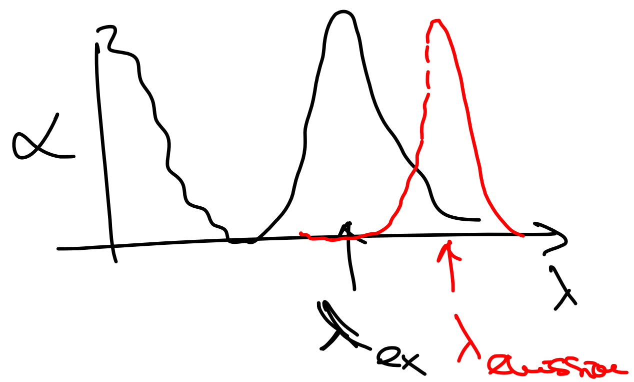
$t = t_2$



normal video microscopy : $r \geq 500nm$

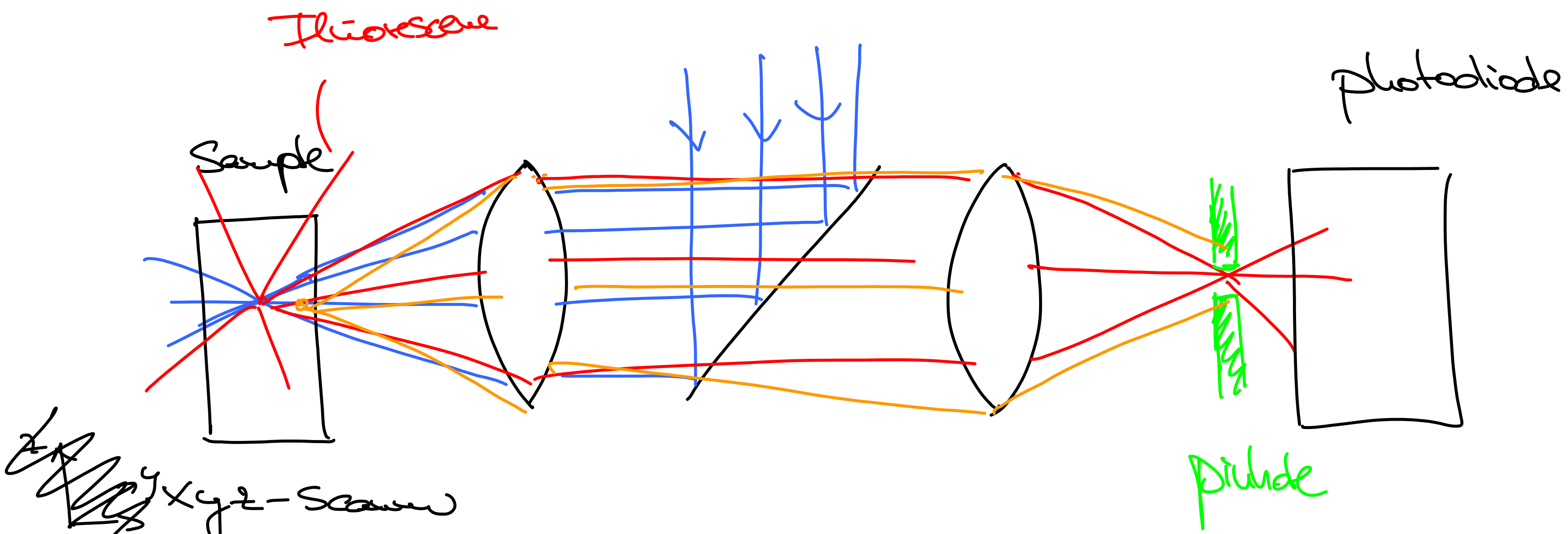
Fluorescence microscopy

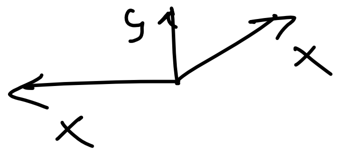
labelling of particles with fluorescent dye



Confocal microscopy

- high resolution (>> diffraction limit)
- three-dim. image of sample





important: density matching of colloidal particles to solvent

→ core-shell particles

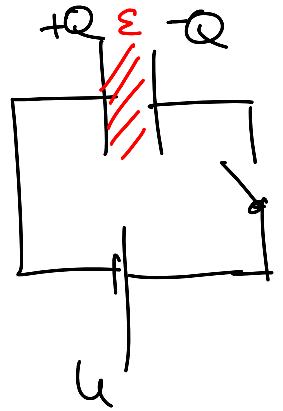
$\Delta x\ \Delta y$: ± 10 nm

Δz : ~ 50 nm

Interaction of colloids with external fields

a) Optical tweezers

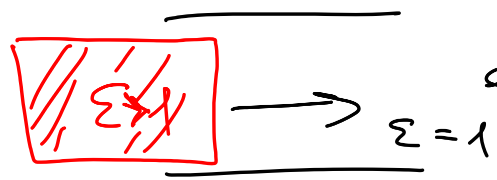
qualitative argument



$Q = \text{const.}$

$C = \varepsilon_0 \varepsilon \cdot \frac{A}{d}$

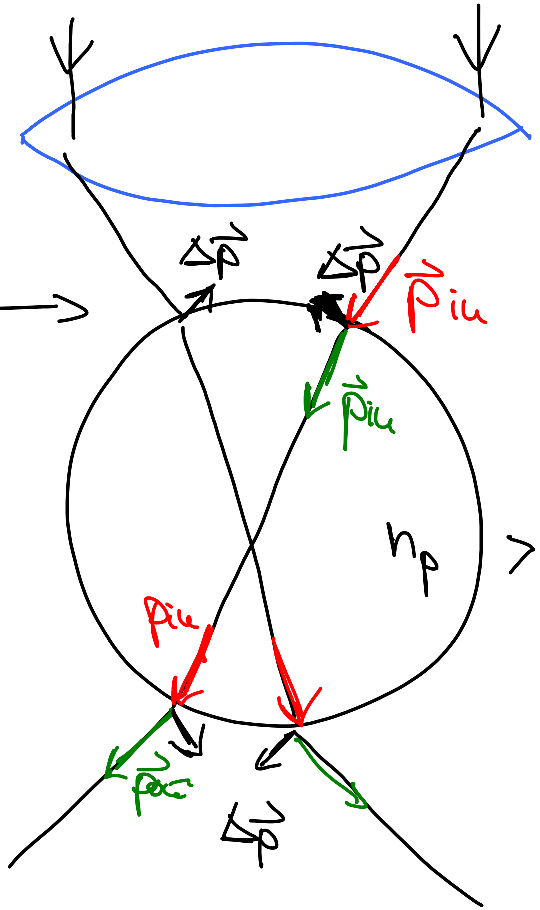
$$W = \frac{1}{2} C U^2 = \frac{1}{2} \frac{Q^2}{C} \propto \frac{1}{C} \rightarrow \frac{1}{\varepsilon}$$



electro-motoric force

- qualitative description (geometrical optics) $a > \lambda$

Note: $\vec{\Delta p}$ has component oppos. to incoming laser beam



$$\vec{\Delta p} = \vec{p}_{in} - \vec{p}_{out}$$

$\Longrightarrow$ particle is forced into focus

gradient force

$$\sum_i \vec{p}_i = 0$$

(gravity: Center of mass is below focus)

Optical trap = Stable potential minimum
Stable against thermal fluctuations!

- <u>Rayleigh regime</u> $(a < \lambda)$ dipol approximation

Dielectric particle in light field with $\vec{E}_0$

→ Polarisation $\vec{P} = \chi \cdot \vec{E}_i$ $\qquad \chi = \frac{\lambda}{4\pi}(\varepsilon_p - \varepsilon_s)$

susceptibility

$n_s^2 = \varepsilon_s$	$s \to \text{Lsg}$
$n_p^2 = \varepsilon_p$	$p \to T$

$$W = -\frac{1}{2}\int \vec{P}\cdot\vec{E}_0 \, dV$$

$V_p \leftarrow$ particle volume

$\varepsilon_p > \varepsilon_s \longrightarrow \chi > 0 \longrightarrow W$ becomes minimal for $\vec{E}_0 = \max \longrightarrow$ focus

$$\vec{F}_{grad} = -\vec{\nabla} W = \frac{1}{2}\nabla \int \vec{P}\vec{E}_0 \, dV$$

$\vec{P}$ for a sphere in a dielectric field $\vec{E}_0$

damping of el field in particle

$$\vec{E}_i = \frac{3 \cdot \varepsilon_s}{\varepsilon_p + 2\varepsilon_s} \cdot \vec{E}_0$$

<u>Example</u> Polystyrene particle $n_p = 1.5 \rightarrow \varepsilon_p = 2.25$

water $n_s = 1.33 \rightarrow \varepsilon_s = 1.76$

$$\vec{E}_i = 0.91 \cdot \vec{E}_0$$

$$W_{grad} = W = -\frac{1}{2} \chi \cdot \vec{E}_i \int \vec{E}_0 \, dV$$

$$= -\frac{1}{8\pi} (\varepsilon_p - \varepsilon_s) \frac{3\varepsilon_s}{\varepsilon_p + 2\varepsilon_s} \int \vec{E}_0^2 \, dV$$

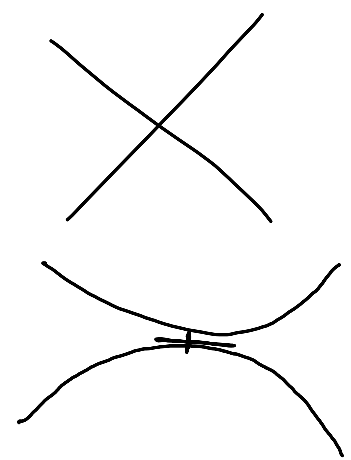
$$\vec{F}_{grad} = -\frac{n_s^2 \cdot a^3}{2}\left(\frac{n^2-1}{n^2+2}\right)\nabla \vec{E}_0^2$$

$\hat{=}$ polarisation of sphere with radius a

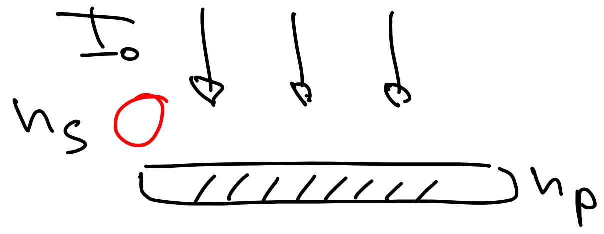
$$n^2 = \frac{\varepsilon_p}{\varepsilon_s}$$

→ particle is forced into focus

$$\nabla \vec{E}_0^2 = \nabla I_0$$



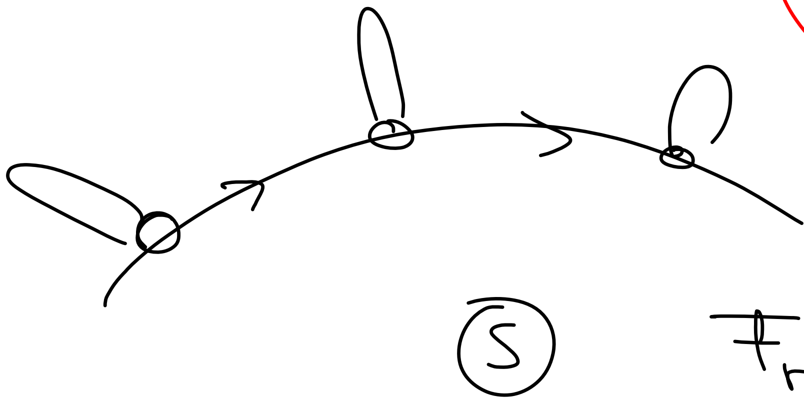
radiation pressure



for perfect reflection

$$p = 2\frac{h}{\lambda/n_s} = 2\cdot\frac{h\nu}{c}\cdot n_s$$

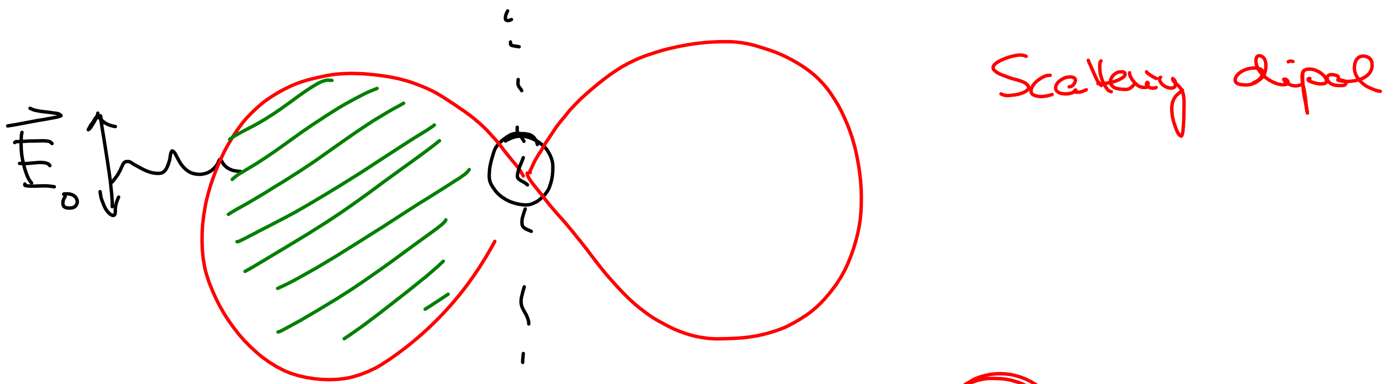
λ in the solvent



$$F_{rad} = \frac{dp}{dt} = \frac{d}{dt}\left(2\cdot\frac{h\nu}{c}\cdot n_s\right) =$$

$$= 2\cdot\frac{I_0}{c}\cdot n_s\cdot D$$ ← prob. of reflection

spherical particle (radius a) n_p



$$\frac{I(\Theta)}{I_0} = \frac{16\pi^4 a^6}{r^2 \lambda^4} \left(\frac{n^2-1}{n^2+2}\right)^2 \cdot \sin^2\Theta$$

$D \to$ integration over (left) halfspace

$$D = \frac{1}{2} \cdot \frac{128\pi^5 a^6}{3\lambda^4} \left(\frac{n^2-1}{n^2+2}\right)^2$$

$$F_{rad} = \frac{I_0}{c} \frac{128 \pi^5 a^6}{3 \lambda^4} \cdot n_s \left(\frac{n^2 - 1}{n^2 + 2} \right)$$

<u>example</u>: $I_0 = 1 W$, $\lambda = 514.5$ nm

$a = \lambda \quad \rightarrow \quad F_{rad} \approx 0.6$ pN

compare weight: $\rho_{ps} \approx 1.05 \frac{g}{cm^3}$

$F_{weight} = 0.285$ pN