NANOPHYSIQUE
INTRODUCTION PHYSIQUE AUX NANOSCIENCES

2. *PRINCIPALES METHODES DE MICROSCOPIE*

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METHODES DE MICROSCOPIE

- **Paramètres Fondamentaux**
- **Microscopes Optiques**
  - **Principe**
  - **Améliorations:** phase contrast, dark field, fluorescent, ...
  - **Cristallographe aux Rayon X**
- **Microscope Electronique**
  - **à Transmission**
  - **à Balayage**
- **Microscope à emission champ**
- **Microscope à effet tunnel électronique**
- **Microscope à force atomique**
- **Optical Tweezers**
- **Light Scattering**

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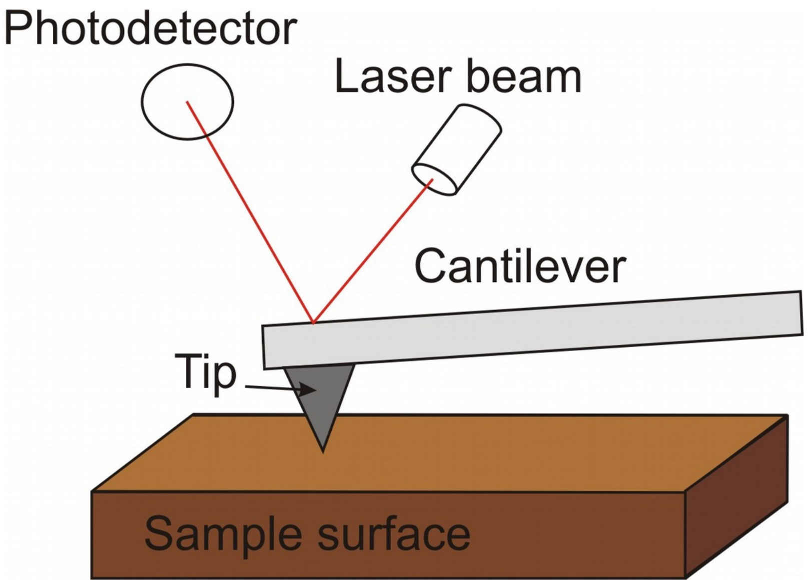
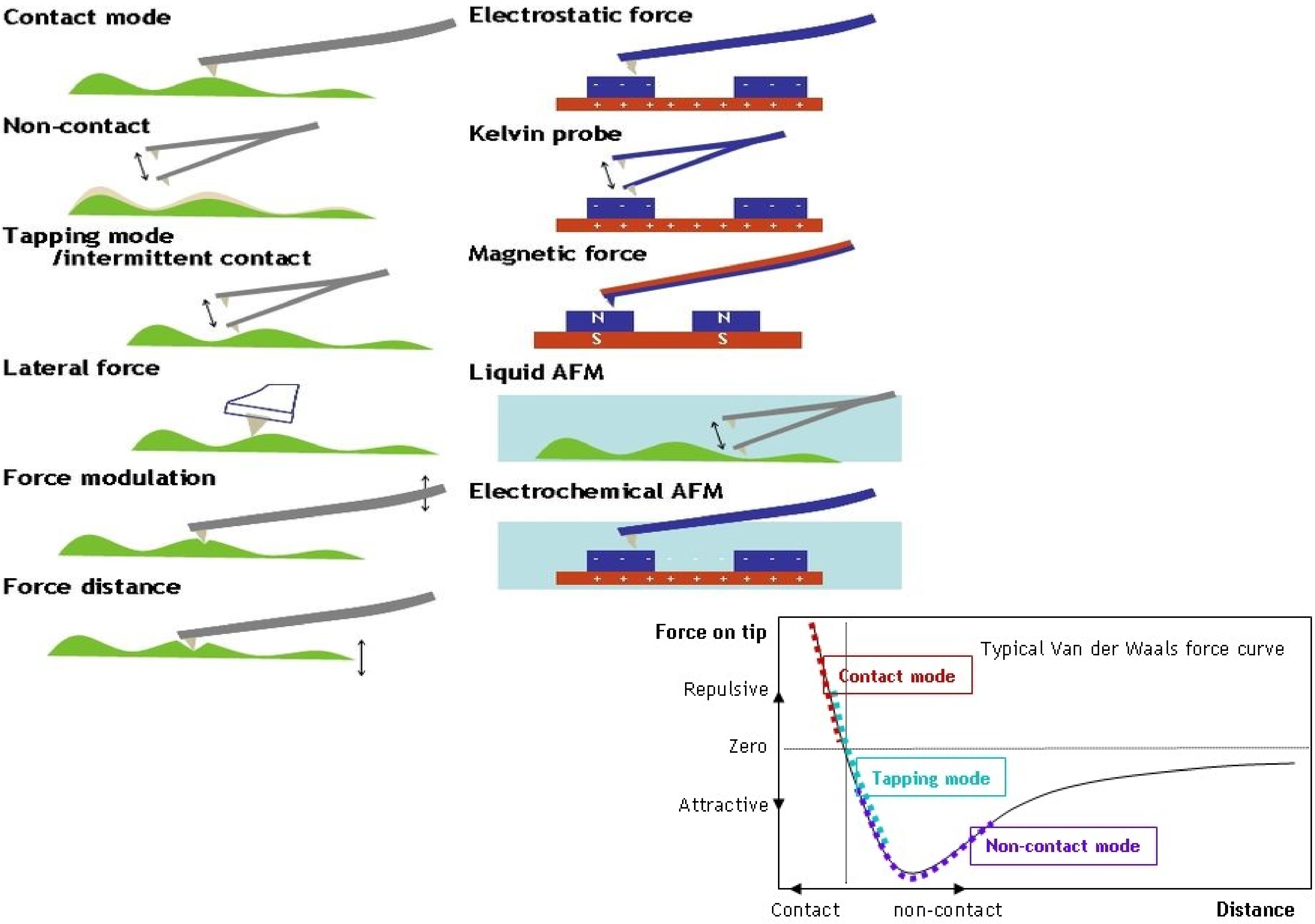
Microscope à force atomique



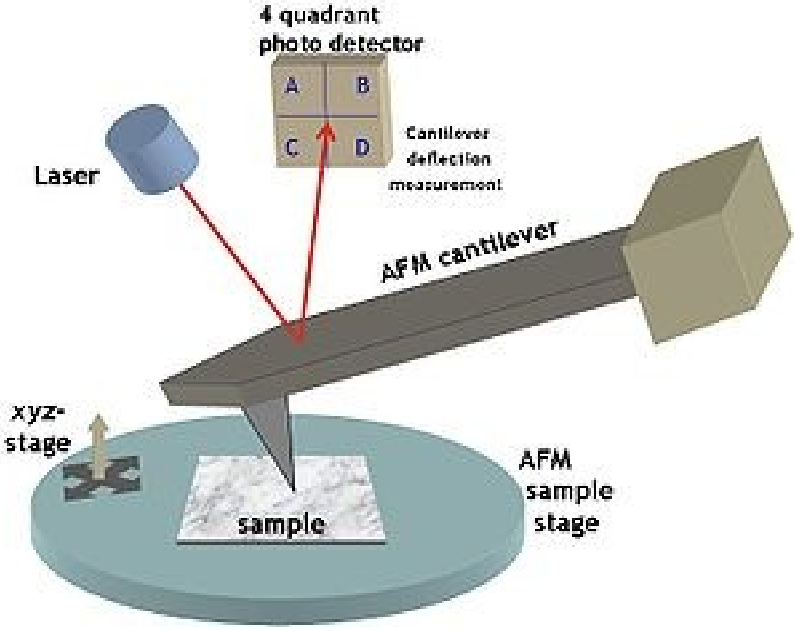
	STM	**AFM**
Lateral Resolution	0.5-1 nm	0.5 nm
Vertical Resolution	2D only	0.05nm
Field of view	1-2 X 1-2 mm	100 x 100 μm
Vertical range		100 μm
Preparation	Couche conductrice	----
Environment	vide	L'air, liquide

Kurganskaya, I.; Luttge, A.; Barron, A. The Application of VSI (Vertical Scanning Interferometry) to the Study of Crystal Surface Processes, Connexions Web site. http://cnx.org/content/m22326/1.4/, Jul 13, 2009.

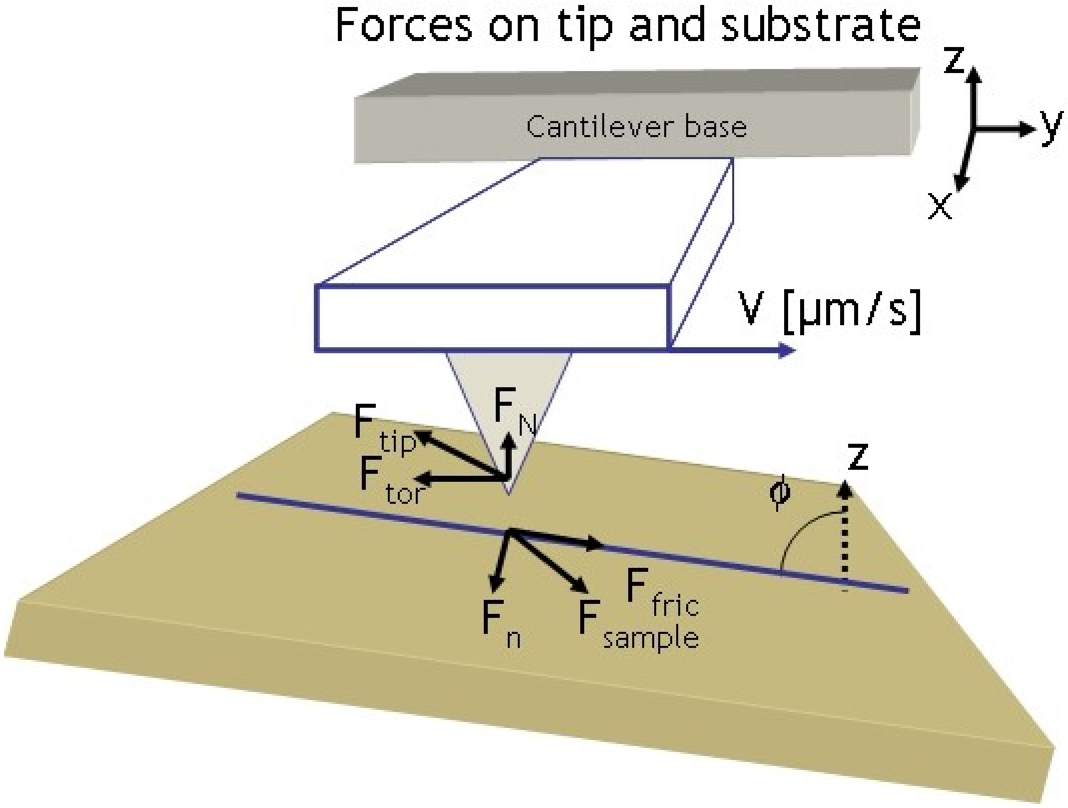
AFM: les modes de fonctionnement



Microscope à force atomique



Signal de droit-gauche: A+C-(B+D)
Signal de haut en bas: A+B-(C+D)



Microscope à force atomique

I. PRINCIPE GÉNÉRAL: UNE OSCILLATEUR CLASSIQUE

$$\ddot{u} + 2\beta\dot{u} + \omega_0^2 u = \gamma \cos \omega t + \frac{1}{m} F\left(D, u\right)$$

où

$D =$ distance entre la surface et la position de la pointe quand le cantilever n'est pas défléchi.
$z =$ distance entre la surface et la position de la pointe actuelle
$u = z - D =$ déviation
$m =$ mass effictive
$\omega_0 = \sqrt{\frac{k}{m}} =$ la fréquence de résonanance de l'oscillateur
$k =$ la raideur du cantilever
$\beta =$ un terme de dissipation
$\gamma =$ l'amplitude de l'excitation
$\omega =$ fréquence de l'excitation
$F\left(D, u\right) =$ la force d'ineteraction pointe-surface

N.B. $Q \equiv \frac{\omega_0}{2\beta}$ est *le facteur de qualité.*

Microscope à force atomique

II. CASE I: CONTACT MODE

Ne pas d'excitation:

$$\ddot{u} + 2\beta\dot{u} + \omega_0^2 u = \frac{1}{m} F(D, u) \Longrightarrow ku = F(D, u)$$

e.g.

$$ku \simeq F(D) + uF'(D) \Longrightarrow u = \frac{F(D)}{k - F'(D)}, \text{ Si } k \gg F'(D), \; u \simeq \frac{F(D)}{k}$$

III. CASE II: LE MODE RÉSONNANT LINÉAIRE

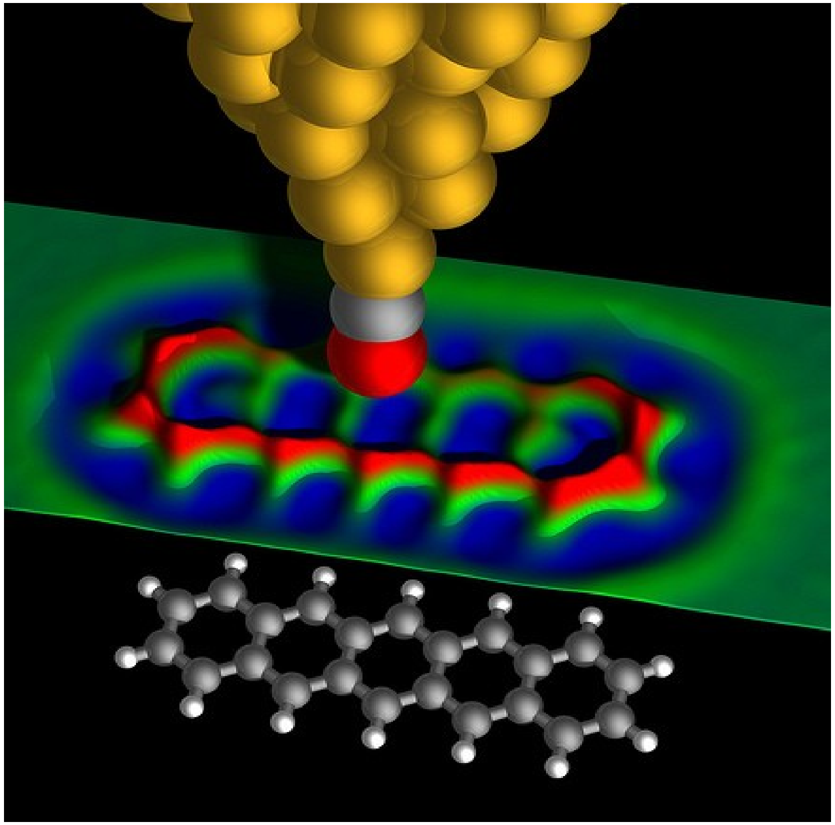
$$\ddot{u} + 2\beta\dot{u} + \omega_0^2 u \simeq \gamma \cos \omega t + \frac{1}{m} F(D) + u \frac{1}{m} F'(D)$$

de sorte que

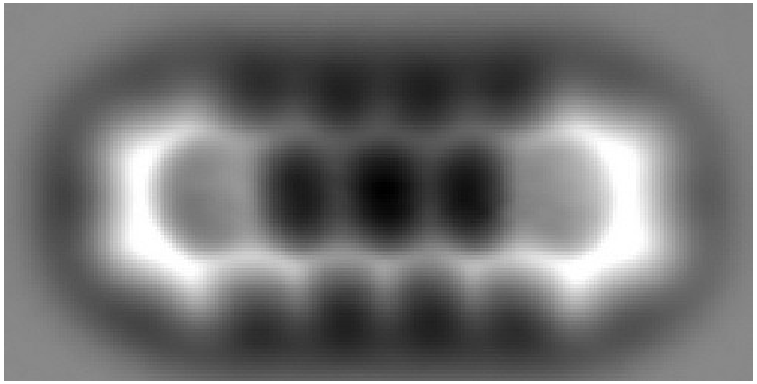
$$\ddot{u} + 2\beta\dot{u} + \omega_0^2 \left(1 - \frac{1}{k} F'(D)\right) u \simeq \gamma \cos \omega t + \frac{1}{m} F(D)$$

Ça veux dire que il y a un changement de fequence natural de l'oscillateur.

AFM Recherche actuelle ...



Imaging the "anatomy" of a pentacene molecule - 3D rendered view: By using an atomically sharp metal tip terminated with a carbon monoxide (CO) molecule, IBM scientists were able to measure in the short-range regime of forces which allowed them to obtain an image of the inner structure of the molecule. The colored surface represents experimental data. (Image courtesy of IBM Research/Zurich)



http://www.electroiq.com/articles/stm/2009/08/ibm-pushes-afm-to-image-molecular-structure.html

Resume

	Optique	**Xray**	**Confocal**	**TEM/SEM**	**STM**	**AFM**
Lateral Resolution	200nm	25nm	200nm	0.1nm/3nm	0.1 nm	0.5 nm
Vertical Resolution	2D only	------	500nm	------	2D only	0.05nm
Field of view	grande	50μm	grande	Bayalage	1-2 X 1-2 mm	100 x 100 μm
Vertical range	-----	------	Limité par le temps (1-1000 sec/mm2/tranche)	------	-------	100 μm
Preparation	------	------	--------	tres mince	Couche conductrice	----
Environment	L'air, liquide, ...	L'air, liquide	liquide	vide	vide	L'air, liquide

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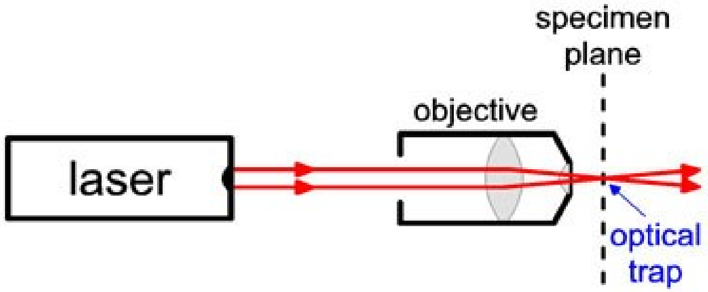
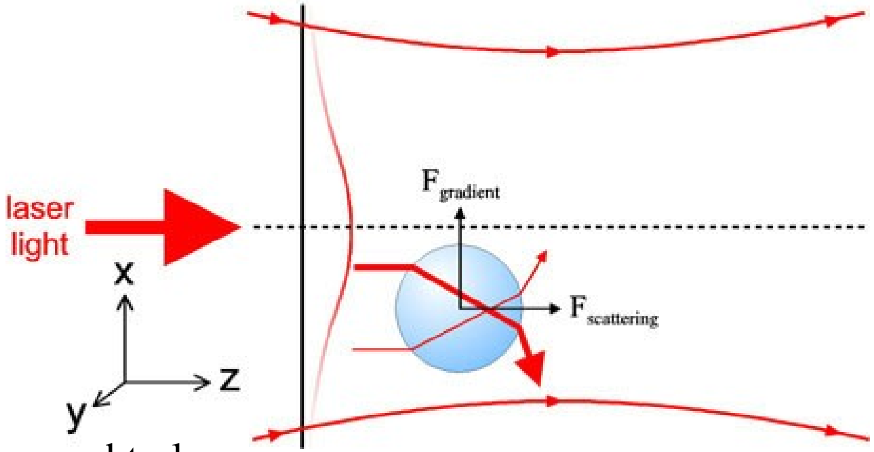
Optical Tweezers

Optical Tweezers use light to manipulate microscopic objects as small as a single atom. The radiation pressure from a focused laser beam is able to trap small particles. In the biological sciences, these instruments have been used to apply forces in the pN-range and to measure displacements in the nm range of objects ranging in size from 10 nm to over 100 mm.



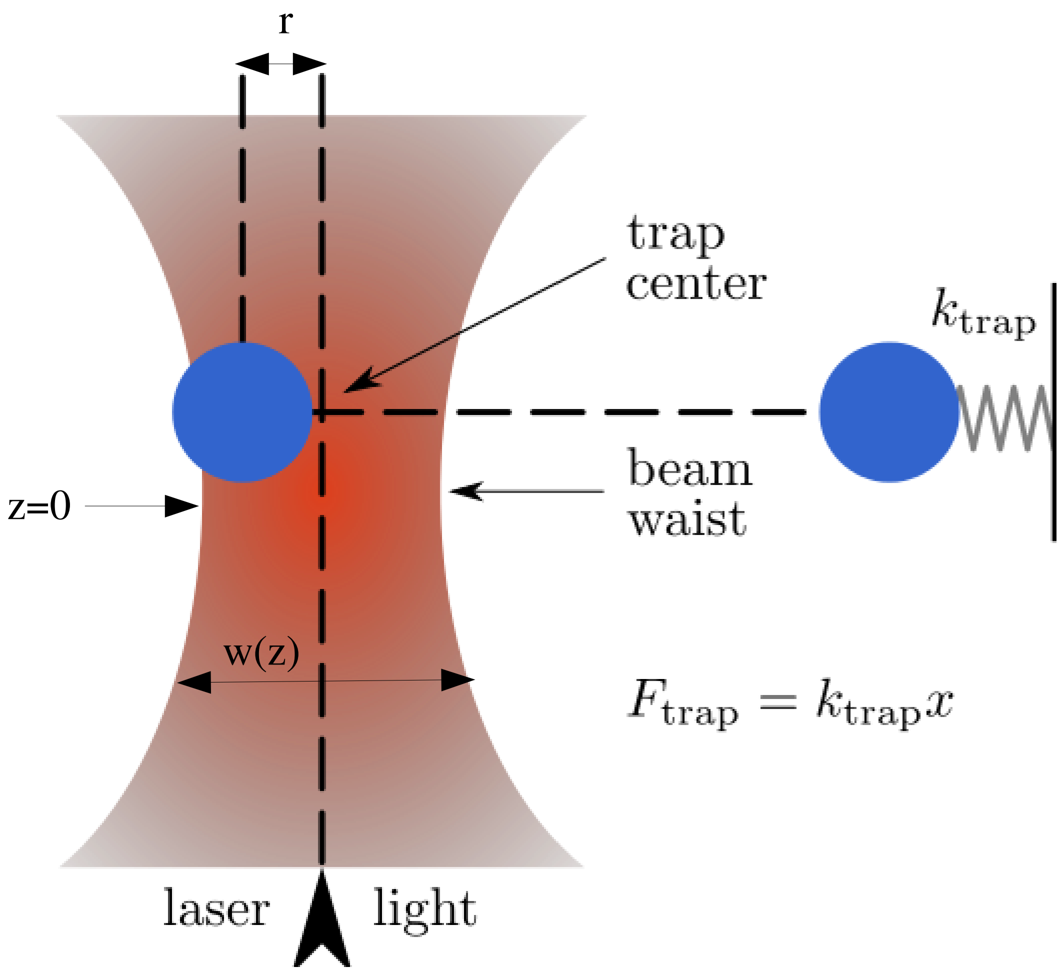
3 regimes:

- D >> λ ==> ray optics
- D ~ λ ==> Maxwell's equations
- D << λ ==> Electrostatics



Source: https://blocklab.stanford.edu/optical_tweezers.html

Optical Tweezers

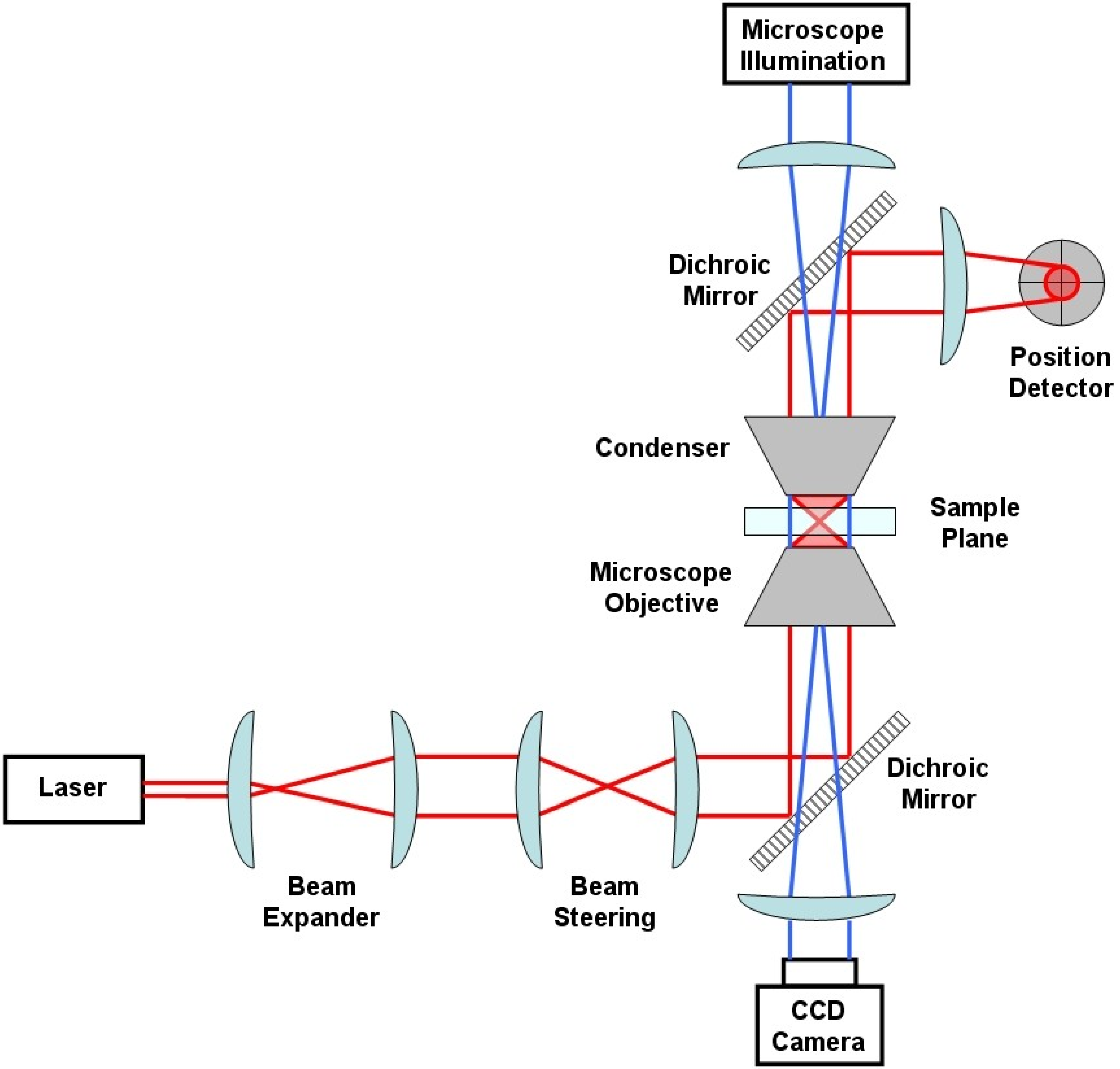


$$I(\boldsymbol{r}) = \frac{1}{2\eta} E^2(\boldsymbol{r}) = I_0 \left(\frac{w_0}{w(z)}\right)^2 \exp\left(-\frac{2r^2}{w(z)^2}\right)$$

$$w(z) = w_0 \sqrt{1 + \left(\frac{z}{z_R}\right)^2}$$

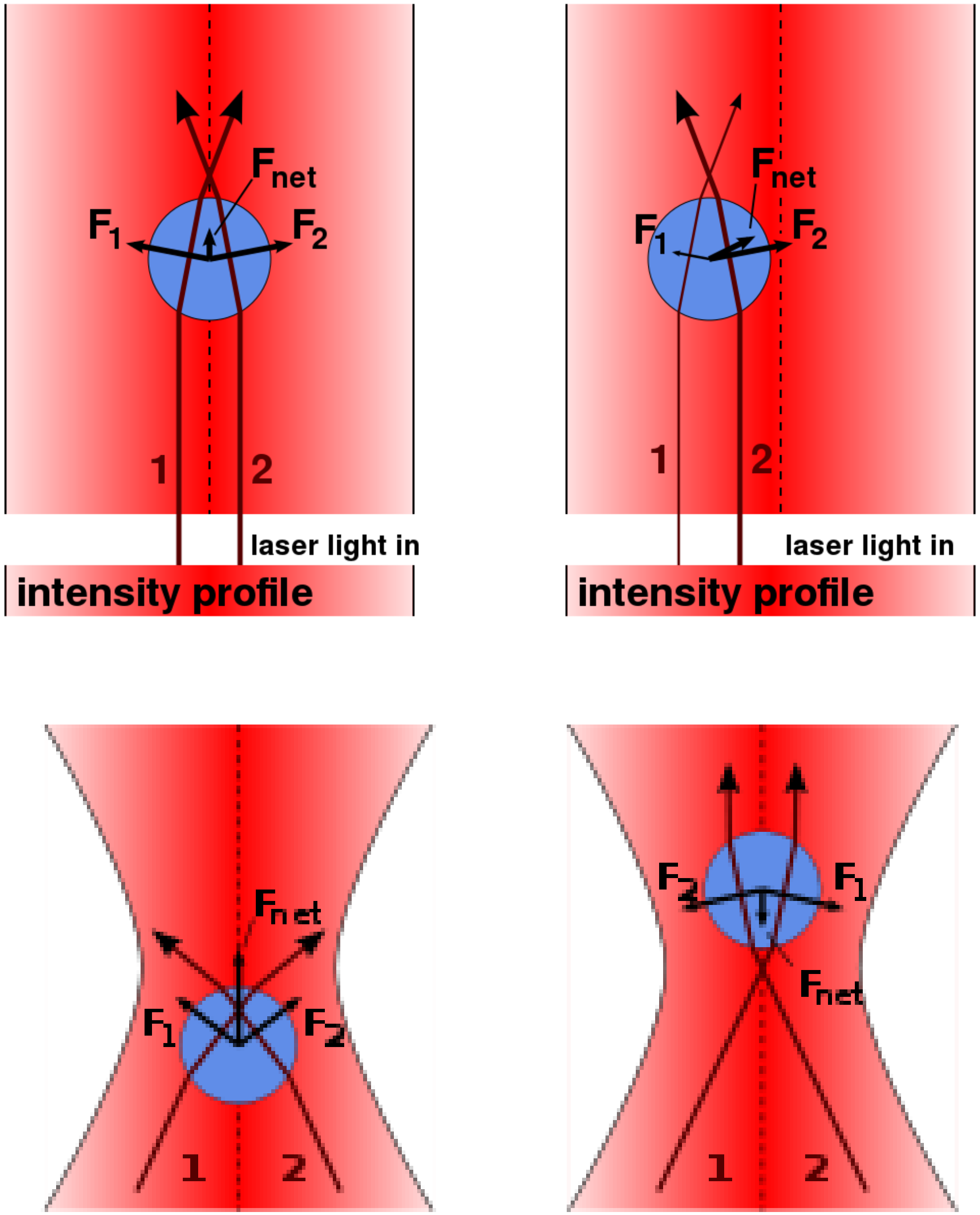
$$z_R = \frac{\pi w_0^2}{\lambda}$$

Optical Tweezers



Optical Tweezers: D >> λ ==> ray optics

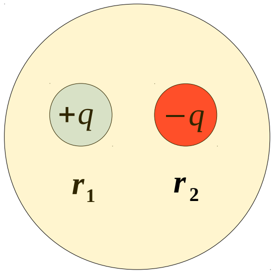
Force is due to change in momentum of refracted light.



Source: wikipedia

Optical Tweezers: D << λ

Particle is treated as a point (induced) dipole



$$\boldsymbol{R}=\frac{\boldsymbol{r}_1+\boldsymbol{r}_1}{2} \qquad \boldsymbol{r}=\boldsymbol{r}_1-\boldsymbol{r}_1 \qquad \boldsymbol{d}=q\,\boldsymbol{r}$$

$$\boldsymbol{F}_i=q_i\left\{\boldsymbol{E}(\boldsymbol{r}_i)+\frac{d\,\boldsymbol{r}_i}{dt}\times\boldsymbol{B}(\boldsymbol{r}_i)\right\}$$

$$\boldsymbol{F}_{total}=q\left\{\boldsymbol{r}\cdot\nabla\,\boldsymbol{E}(\boldsymbol{R})+\frac{d\,\boldsymbol{r}}{dt}\times\boldsymbol{B}(\boldsymbol{R})\right\}+\text{higher order in }r$$

$$=\boldsymbol{d}\cdot\nabla\,\boldsymbol{E}(\boldsymbol{R})+\frac{d\,\boldsymbol{d}}{dt}\times\boldsymbol{B}(\boldsymbol{R})+\text{higher order in }r$$

For dielectric sphere

$$\alpha=\frac{\pi D^3\epsilon_0}{2}\frac{\epsilon-\epsilon_0}{\epsilon+2\epsilon_0}$$

$$\approx\frac{\pi D^3\epsilon_0}{2}\frac{n^2-n_0^2}{n^2+2n_0^2}$$

Proof = exercise!

Assuming linear dielectric: $\boldsymbol{d}=\alpha\,\boldsymbol{E}$

and using one of Maxwell's equations: $\nabla\times\boldsymbol{E}=-\frac{\partial\,\boldsymbol{B}}{\partial\,t}$

$$\boldsymbol{F}_{total}=\alpha\left\{\nabla\,E(\boldsymbol{R})^2+\frac{\partial}{\partial\,t}\underbrace{(\boldsymbol{E}(\boldsymbol{R})\times\boldsymbol{B}(\boldsymbol{R}))}_{\text{power per unit area}}\right\}+\text{higher order in }r$$

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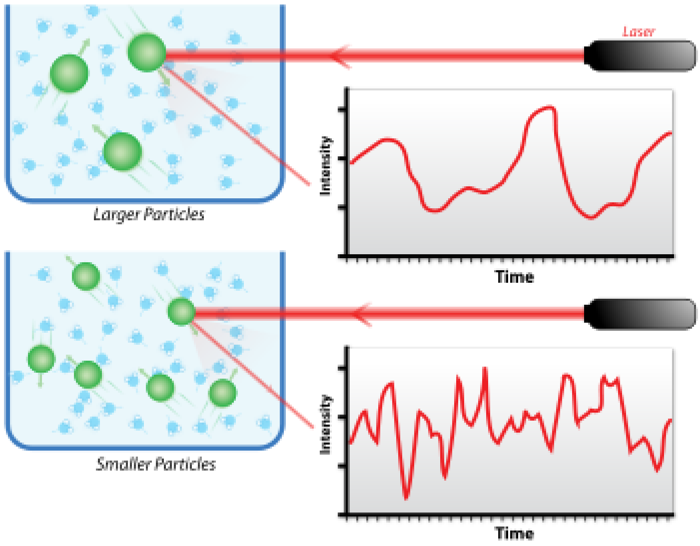
Dynamic light scattering

- Typically used for particles diffusing in a liquid bath
- Determines size of particles



Field auto-correlation function (what you want):

$$g_1(q,t) = \frac{\langle E(q,t) E(q,t+\tau) \rangle}{\langle E(q,t) E(q,t) \rangle}$$

Intensity auto-correlation function (what you measure):

$$g_2(q,t) = \frac{\langle I(q,t) I(q,t+\tau) \rangle}{\langle I(q,t) I(q,t) \rangle}$$

$$g_2(q,t) \sim 1 + \mathrm{const} \times [g_1(q,t)]^2$$

$$g_1(q,t) = \exp\left(-q^2 D t\right), \qquad D = \text{diffusion constant}$$

$$q = \frac{4\pi n_0}{\lambda} \sin\left(\frac{\theta}{2}\right)$$