Optical methods in chemistry
or
Photon tools for chemical sciences

Session 9:

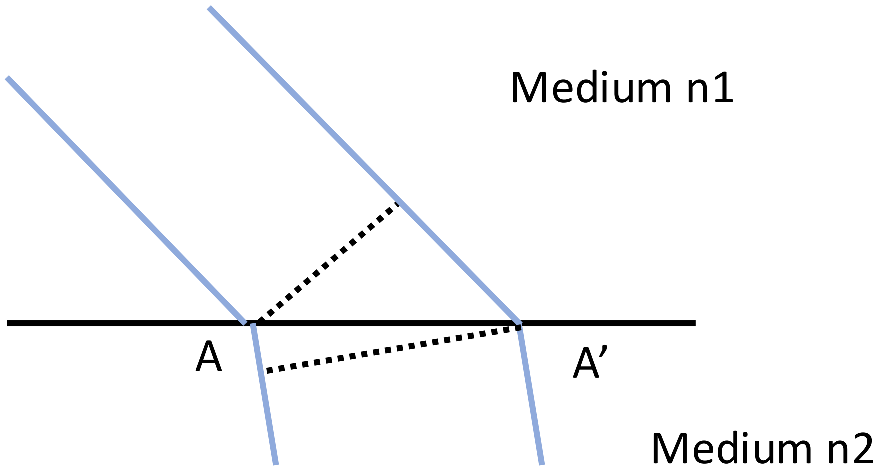
Course layout – contents overview and general structure

- Introduction and ray optics
- Wave optics
- Beams
- From cavities to lasers
- More lasers and optical tweezers
- From diffraction and Fourier optics
- Microscopy
- Spectroscopy
- **Electromagnetic optics**
- Absorption, dispersion, and non-linear optics
- Ultrafast lasers
- Introduction to x-rays
- X-ray diffraction and spectroscopy
- Summary

Today: Going back to some basics.

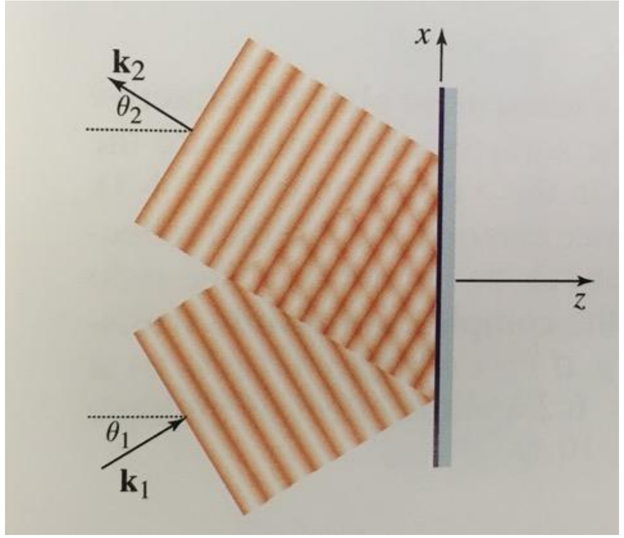
Next week: Non-linear optics

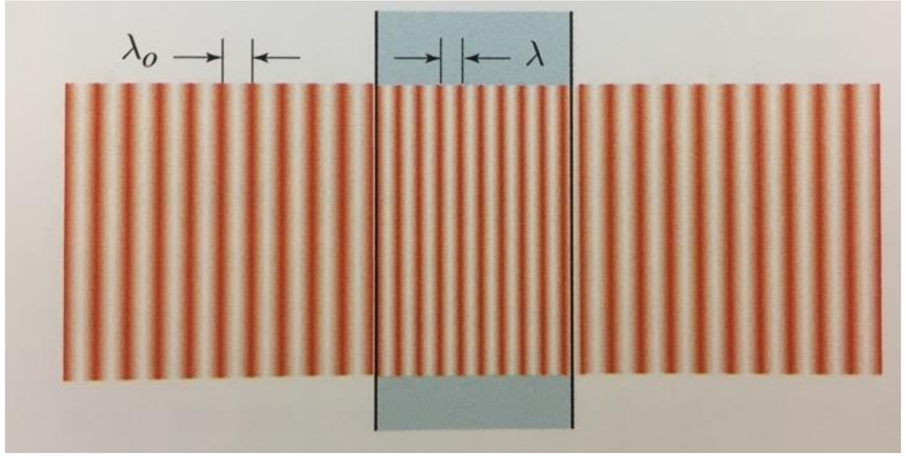
Recap: Ray optics and refraction and reflection

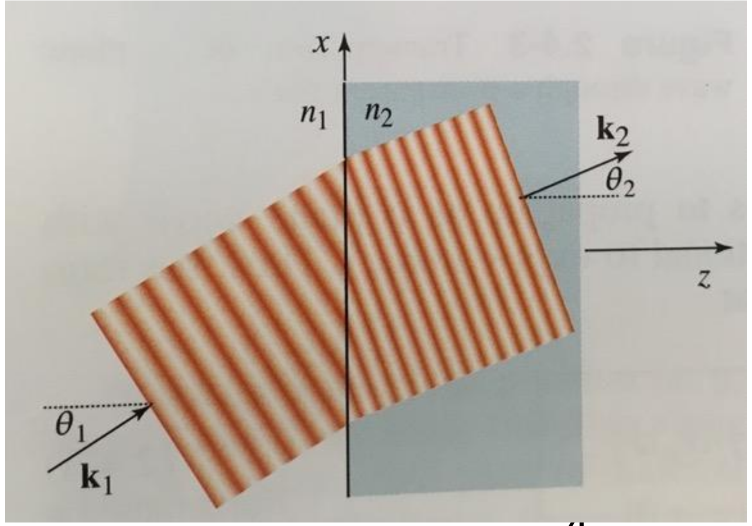


- Same time means same distance travelled, t= const
- From geometry: sin
- Relation:
- Results in Snell's law

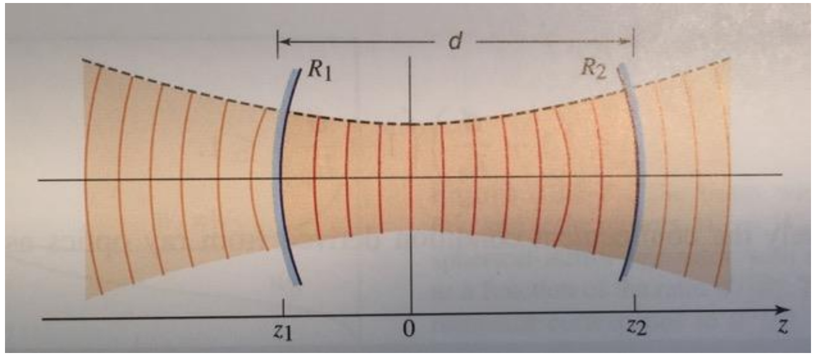
Recap: Wave description of light

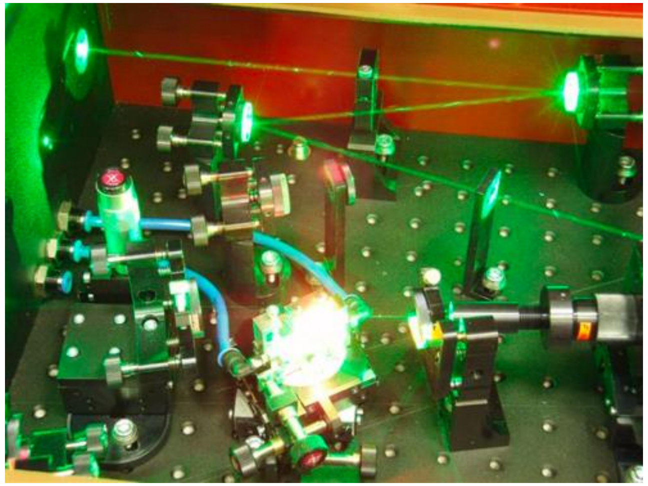


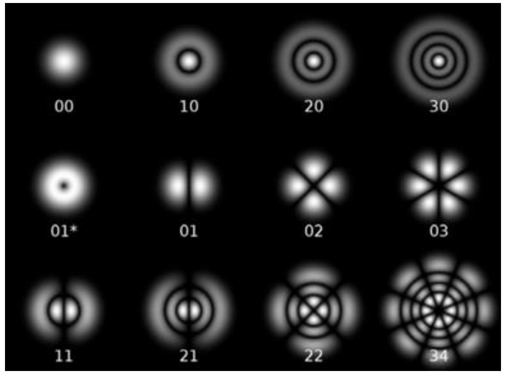


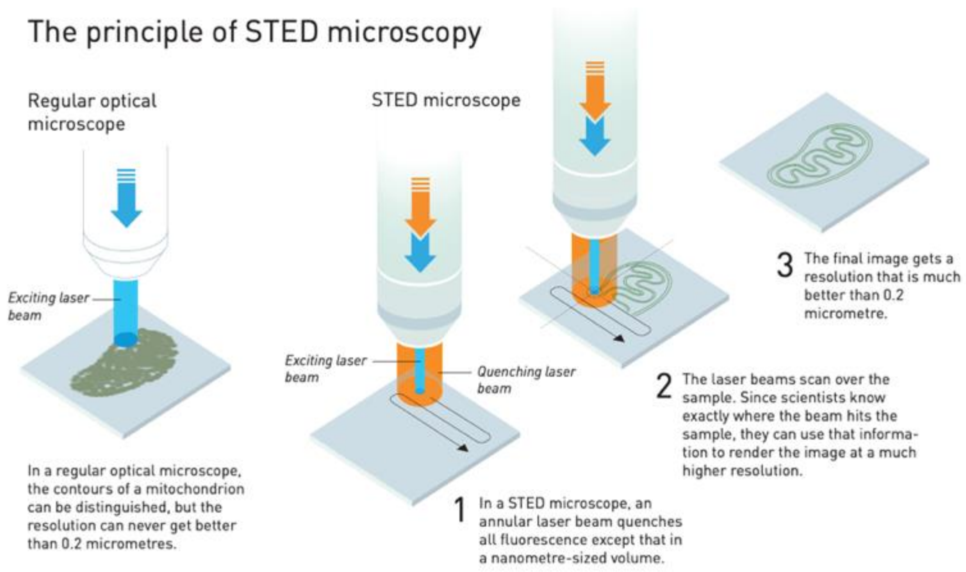


So far we have done well: Fourier optics, beam optics, lasers…

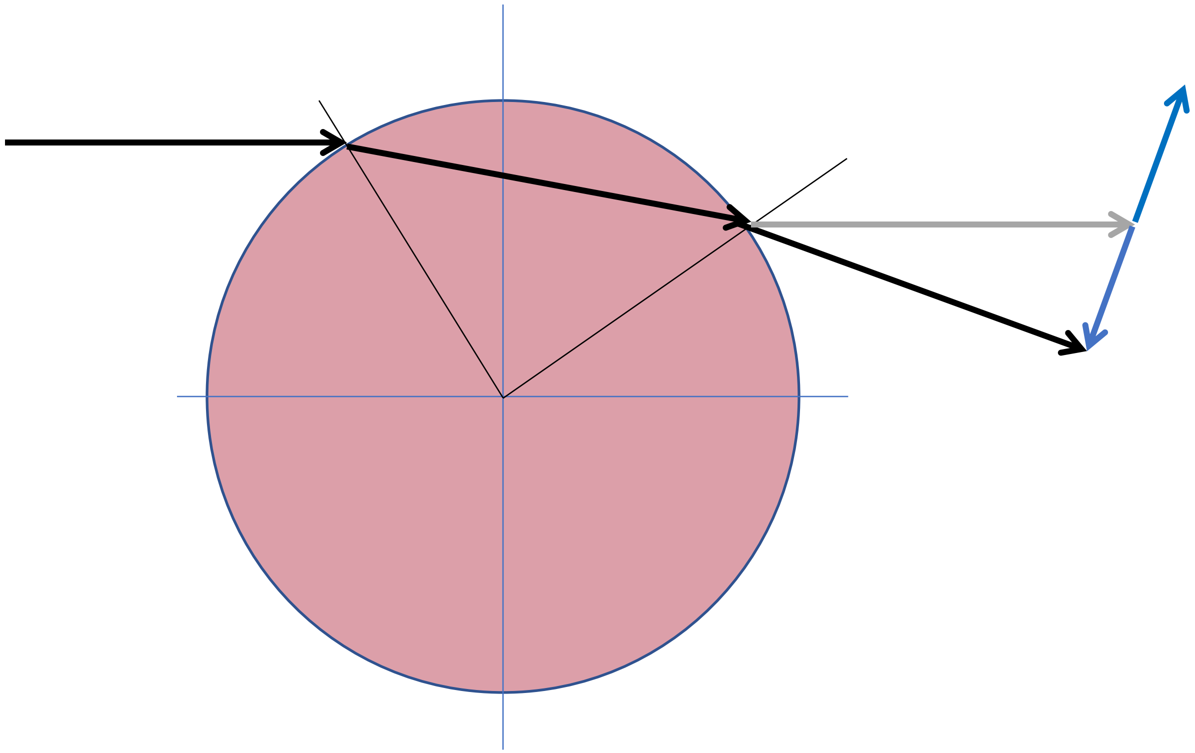








Even trapping of particles with photons (particle character)



Some boundary conditions:

- Optically thicker sample in optically thinner medium
- Transparent sample, i.e., negligible scattering and reflection compared to transmission

Process:

- Rays are refracted, leading to momentum change
- Action equals reaction, sphere is pushed …………wards
- With equal illumination there is……

But we are missing something: details of interaction with matter!

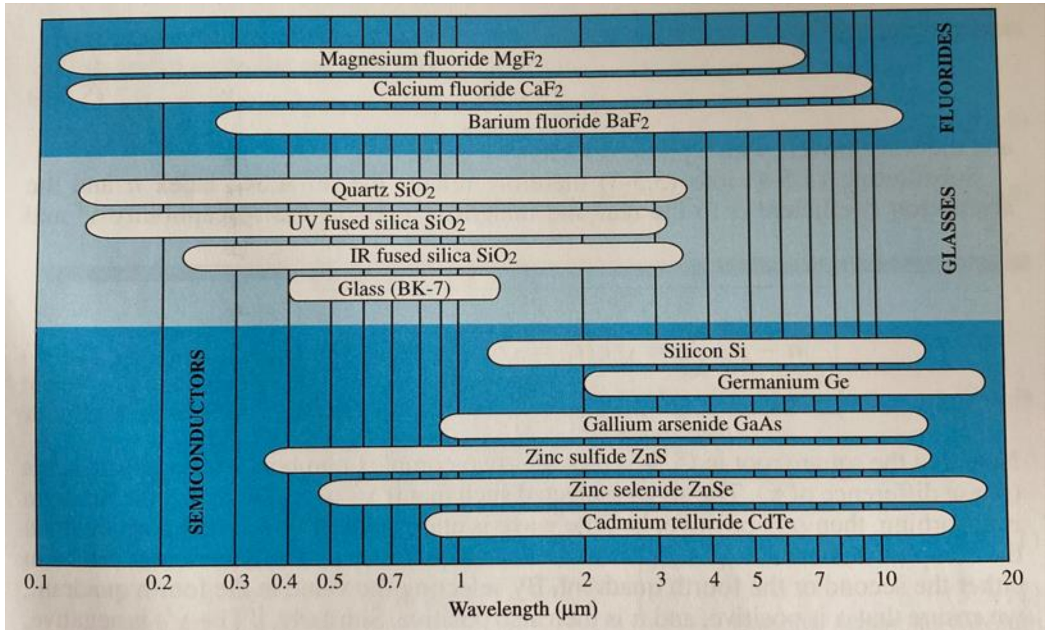
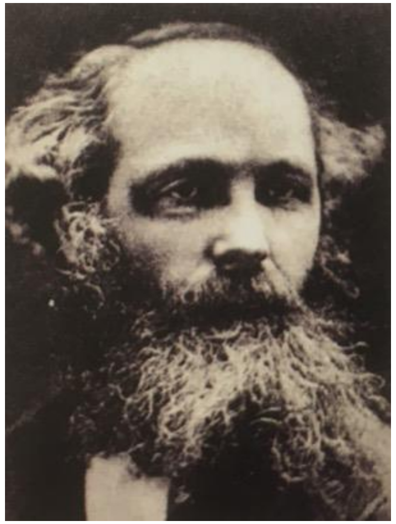


Figure 5.5-1 Spectral bands within which selected optical materials transmit light.

Welcome to EM description of light!



James Maxwell
1831 - 1879

$$\nabla \times \mathcal{H} = \epsilon_o \frac{\partial \mathcal{E}}{\partial t}$$

$$\nabla \times \mathcal{E} = -\mu_o \frac{\partial \mathcal{H}}{\partial t}$$

$$\nabla \cdot \mathcal{E} = 0$$

$$\nabla \cdot \mathcal{H} = 0,$$

Familiar wave equation:

Maxwell equation in medium

$$\nabla \times \mathcal{H} = \frac{\partial \mathcal{D}}{\partial t}$$

$$\nabla \times \mathcal{E} = -\frac{\partial \mathcal{B}}{\partial t}$$

$$\nabla \cdot \mathcal{D} = 0$$

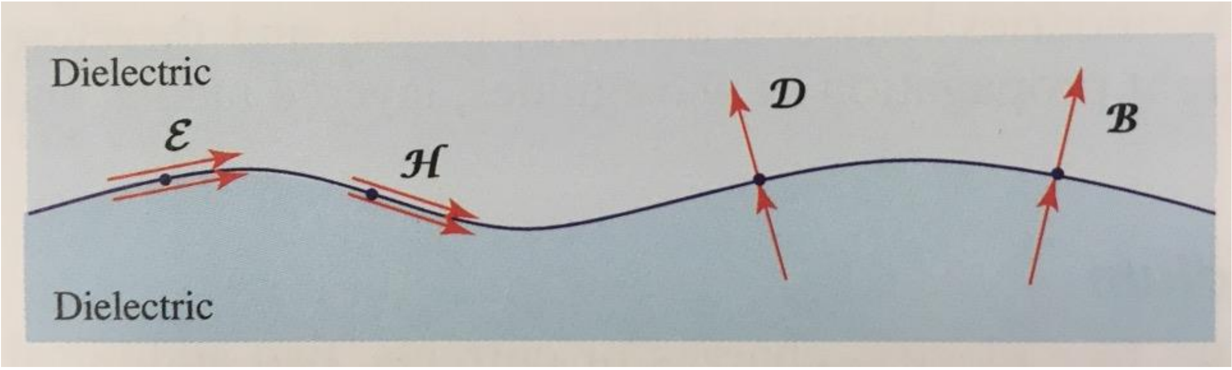
$$\nabla \cdot \mathcal{B} = 0.$$

$$\mathcal{D} = \epsilon_o \mathcal{E} + \mathcal{P}$$

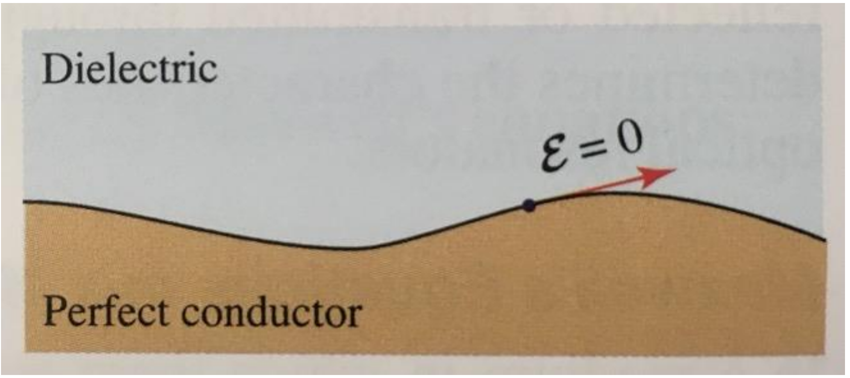
$$\mathcal{B} = \mu_o \mathcal{H} + \mu_o \mathcal{M}.$$

Boundary conditions at interfaces

Two dielectric media

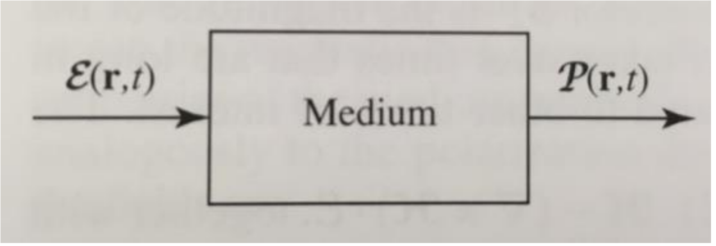


Dielectric and conducting media



Electromagnetic waves in dielectric media

General



But stick with linear, nondispersive, homogenous, and isotropic media right now:

$$\mathcal{P} = \epsilon_o \chi \mathcal{E},$$

This leads to the following Maxwell and wave equations wave equations

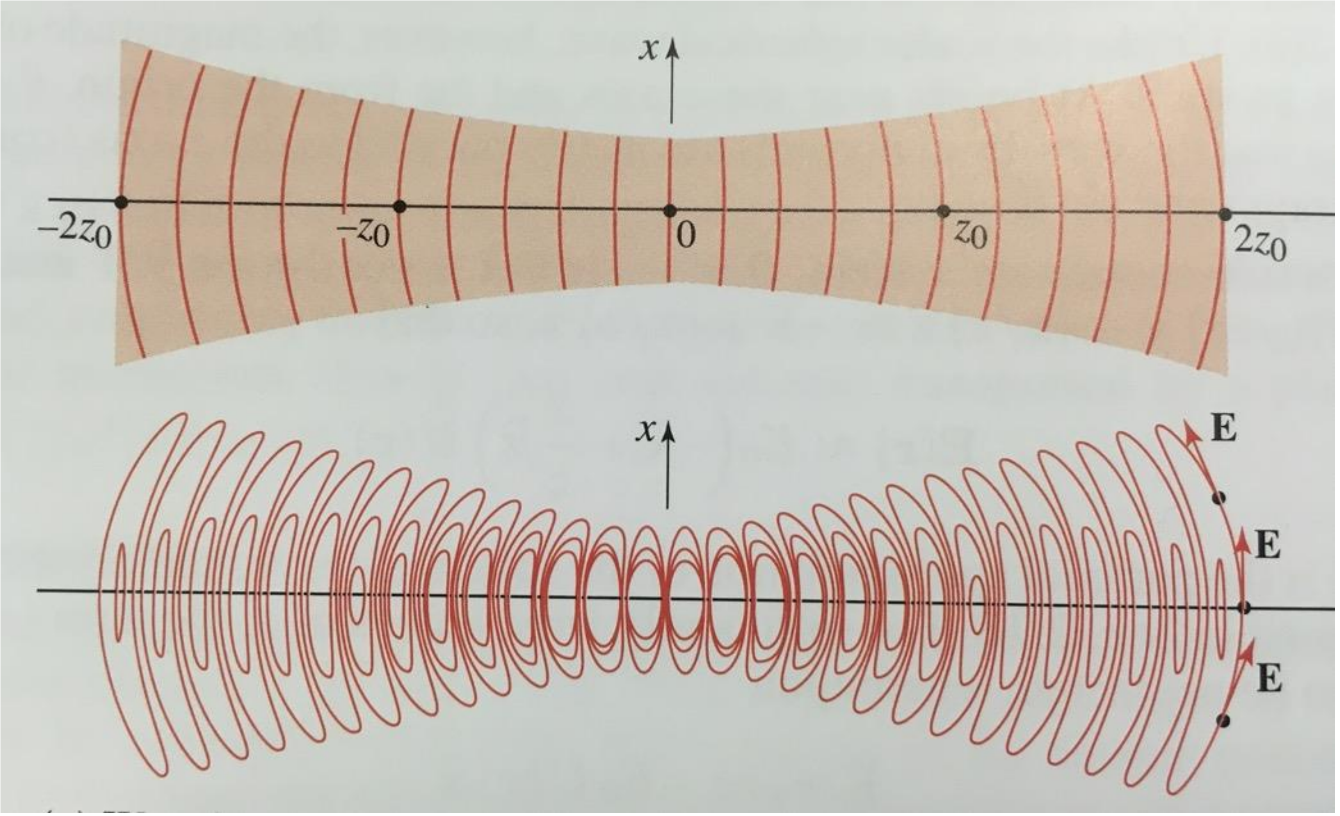
$$\nabla \times \mathcal{H} = \epsilon \frac{\partial \mathcal{E}}{\partial t}$$

$$\nabla \times \mathcal{E} = -\mu \frac{\partial \mathcal{H}}{\partial t}$$

$$\nabla \cdot \mathcal{E} = 0$$

$$\nabla \cdot \mathcal{H} = 0.$$

A note on wavefronts



Back to optical tweezers: Now small particles compared to wavelength

Lorentz force on dipole

$$\mathbf{F} = (\mathbf{p} \cdot \nabla)\mathbf{E} + \frac{d\mathbf{p}}{dt} \times \mathbf{B}$$

$$= \alpha \left[(\mathbf{E} \cdot \nabla)\mathbf{E} + \frac{d\mathbf{E}}{dt} \times \mathbf{B} \right]$$

$$= \alpha \left[\frac{1}{2}\nabla E^2 + \frac{d}{dt}(\mathbf{E} \times \mathbf{B}) \right]$$

$$= \frac{1}{2}\alpha \nabla E^2$$

$$\mathbf{p} = \alpha \mathbf{E}$$

Trapping condition in e-m description

288 OPTICS LETTERS / Vol. 11, No. 5 / May 1986

Observation of a single-beam gradient force optical trap for dielectric particles

A. Ashkin, J. M. Dziedzic, J. E. Bjorkholm, and Steven Chu

AT&T Bell Laboratories, Holmdel, New Jersey 07733

Gradient force

$$\mathbf{F} = \frac{1}{2}\alpha\nabla E^2 = \frac{2\pi n_0 r^3}{c}\left(\frac{m^2-1}{m^2+2}\right)\nabla I(\mathbf{r})$$

>

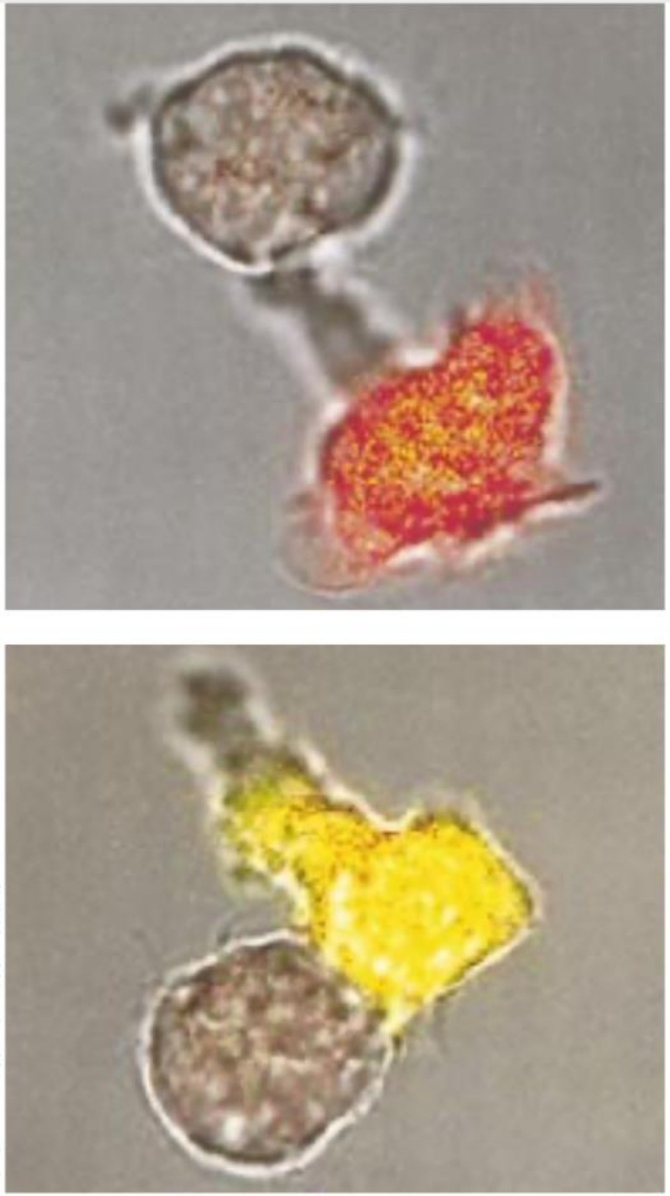
Scattering force

$$\mathbf{F}_{\rm scat}(\mathbf{r}) = \frac{8\pi n_0 k^4 r^6}{3c}\left(\frac{m^2-1}{m^2+2}\right)^2 I(\mathbf{r})\hat{z}$$

α, induced dipole of sphere

n_o, refractive index and $m=n_1/n_o$ relative index.

Optical tweezers in biology (example, Scientific American)



XUNBIN WEI *Beckman Laser Institute*

Laser Scissors and Tweezers

Researchers are using lasers to grasp single cells and tinier components in vises of light while delicately altering the held structures. These lasers offer new ways to investigate and manipulate cells

by Michael W. Berns

POLARITY OF *T* CELLS is borne out in studies made possible by laser tweezers. *B* cells, which provoke calcium release by *T* cells, were carefully positioned alongside *T* cells using tweezers. Positioning of the *B* cell at one end of a quiescent *T* cell elicited no change; a fluorescent red stain in the *T* cell remained red (*top*). But when the *B* cell touched the other end of the *T* cell, calcium was released, signaled by yellow fluorescence (*bottom*).

Ref: Scientific American, April 1998, page 62 onwards

Optical tweezers on the nanoscale

nature nanotechnology

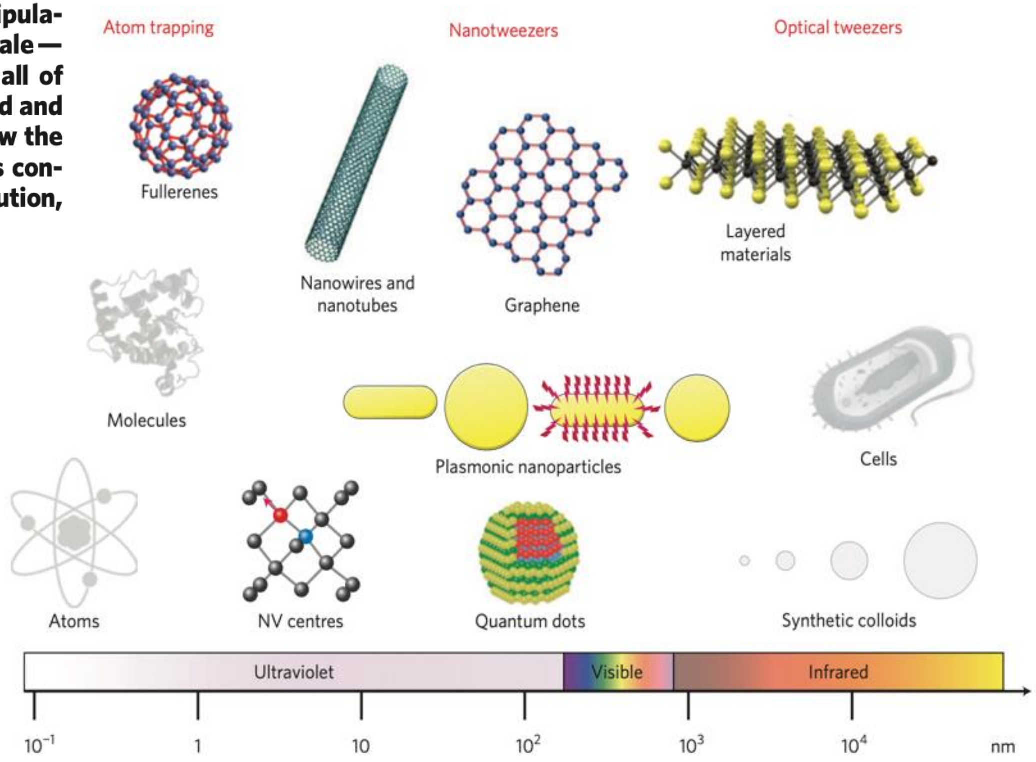
REVIEW ARTICLE

PUBLISHED ONLINE: 7 NOVEMBER 2013 | DOI: 10.1038/NNANO.2013.208

Optical trapping and manipulation of nanostructures

Onofrio M. Maragò[1]*, Philip H. Jones[2], Pietro G. Gucciardi[1], Giovanni Volpe[3] and Andrea C. Ferrari[4]*

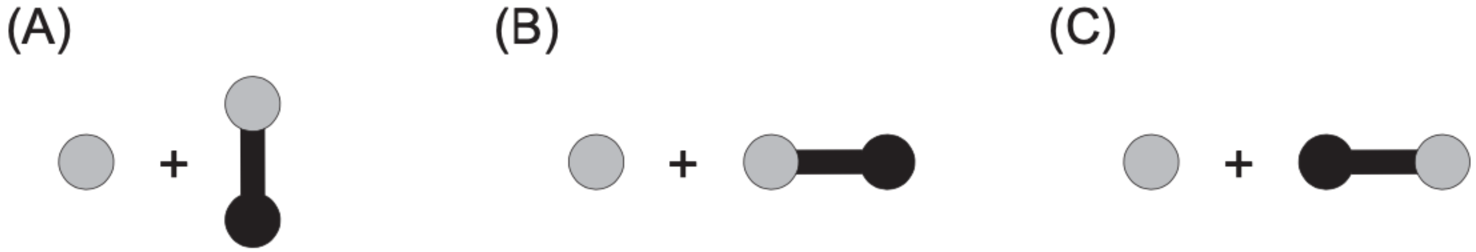
Optical trapping and manipulation of micrometre-sized particles was first reported in 1970. Since then, it has been successfully implemented in two size ranges: the subnanometre scale, where light–matter mechanical coupling enables cooling of atoms, ions and molecules, and the micrometre scale, where the momentum transfer resulting from light scattering allows manipulation of microscopic objects such as cells. But it has been difficult to apply these techniques to the intermediate — nanoscale — range that includes structures such as quantum dots, nanowires, nanotubes, graphene and two-dimensional crystals, all of crucial importance for nanomaterials-based applications. Recently, however, several new approaches have been developed and demonstrated for trapping plasmonic nanoparticles, semiconductor nanowires and carbon nanostructures. Here we review the state-of-the-art in optical trapping at the nanoscale, with an emphasis on some of the most promising advances, such as controlled manipulation and assembly of individual and multiple nanostructures, force measurement with femtonewton resolution, and biosensors.



More on chemistry:

Stereochemistry: Study of the relative spatial arrangement of atoms that form the structure of molecules and their manipulation.

Example:



Need: Control and manipulation of molecules

Following pages based on Stapelfeldt group work (Aarhus) as well as

REVIEWS OF MODERN PHYSICS, VOLUME 75, APRIL 2003

***Colloquium*: Aligning molecules with strong laser pulses**

Henrik Stapelfeldt

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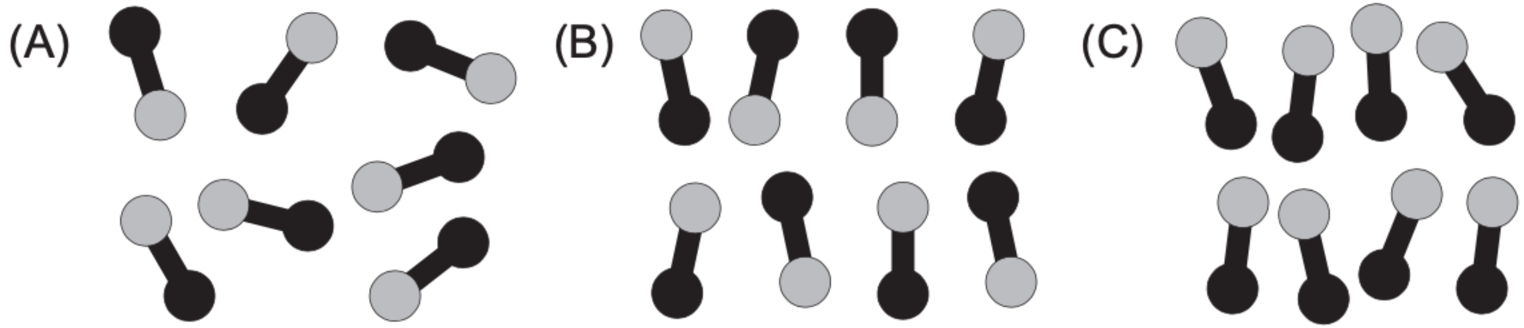
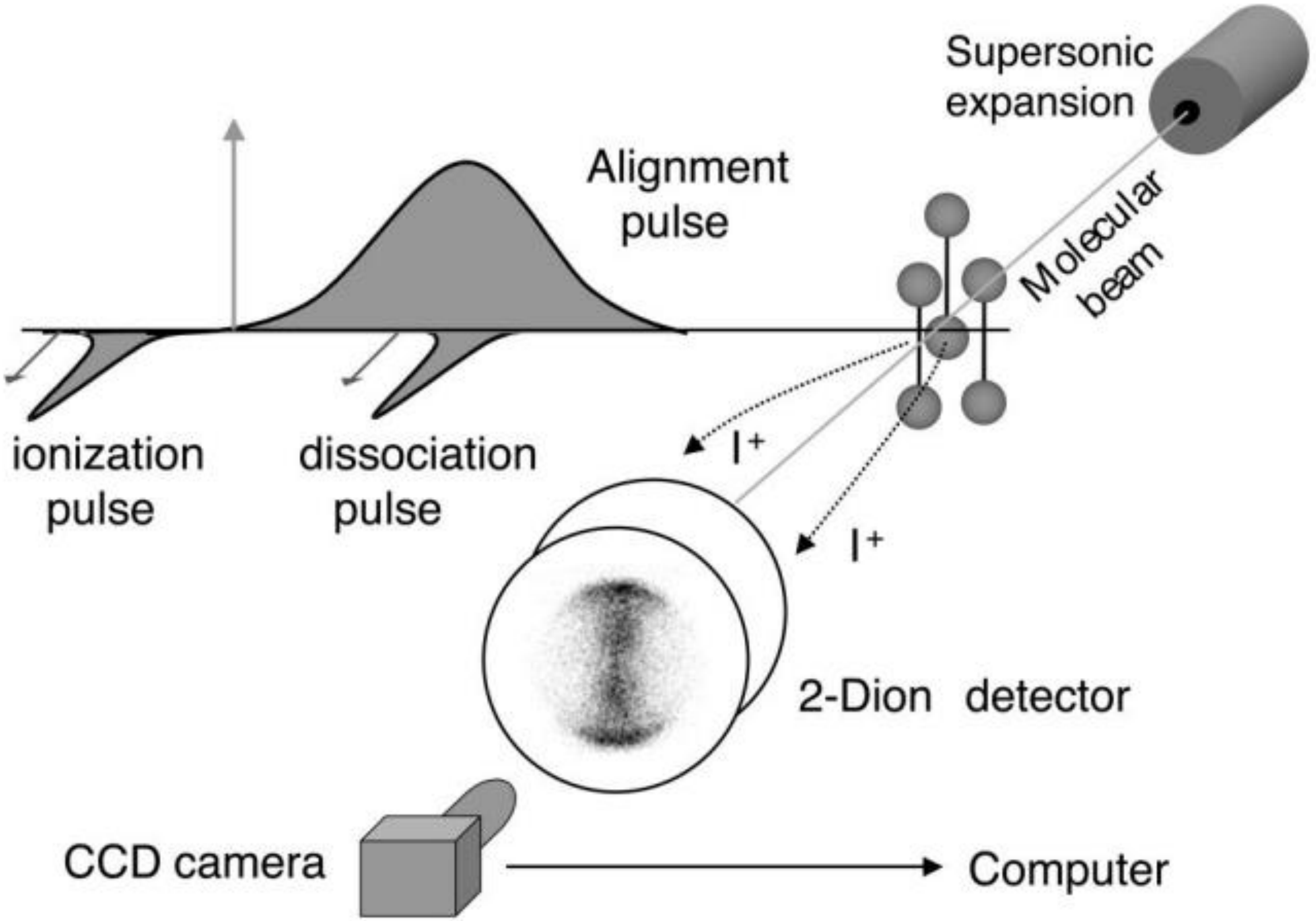
Tamar Seideman

Steacie Institute for Molecular Sciences, National Research Council of Canada, Ottawa, Ontario K1A 0R6, Canada

Laser alignment of molecules



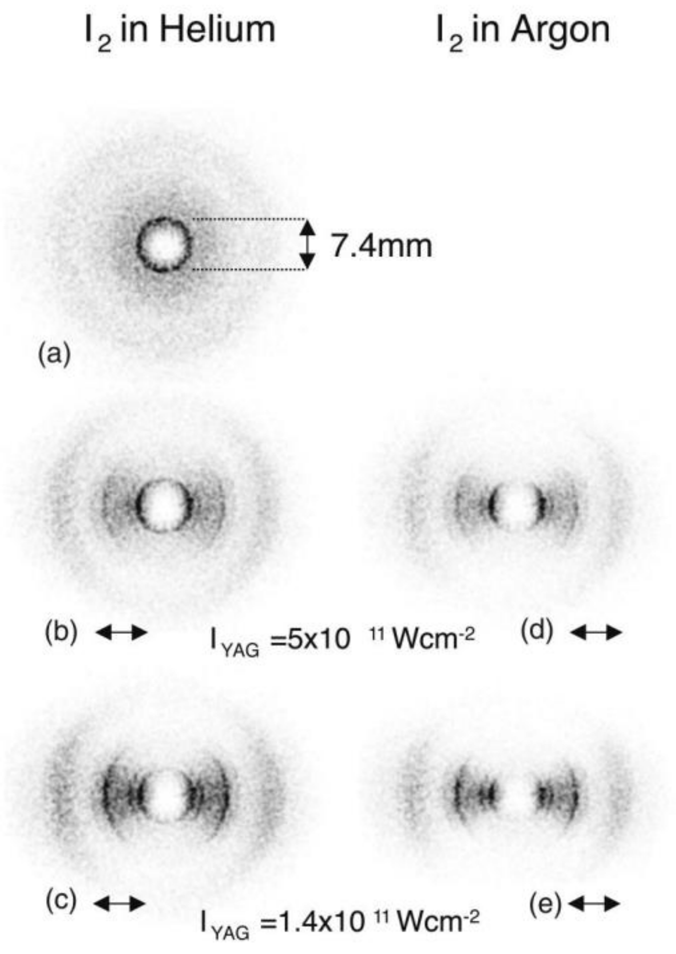
Experimental setup



Detection scheme: Coulomb explosion imaging

- Fragment whole molecule through sudden ionization
- Use ionization laser pulse shorter than alignment pulse
- Use “imaging” spectrometers

Some data examples



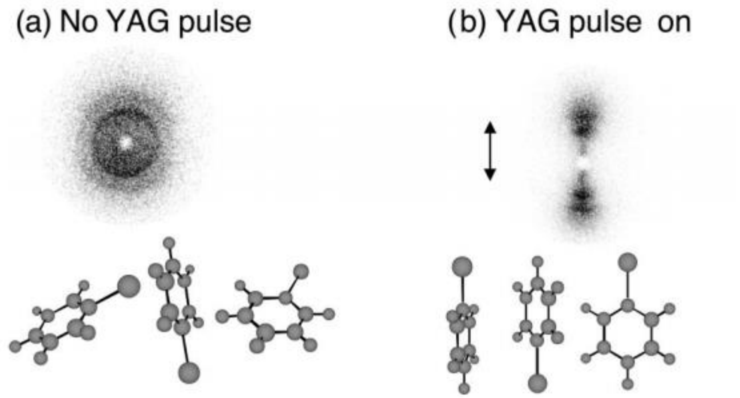


FIG. 9. Ion images of I^+ recorded when iodobenzene is irradiated by a circularly polarized, 100-fs, 8×10^{13}-W/cm^2, 800-nm pulse. (a) No alignment field. (b) In the presence of a linearly polarized (vertical) alignment field with intensity 1.2×10^{12} W/cm^2. The spatial orientation of the molecules is illustrated below the two images.

Final note: There is also impulsive alignment

The end.