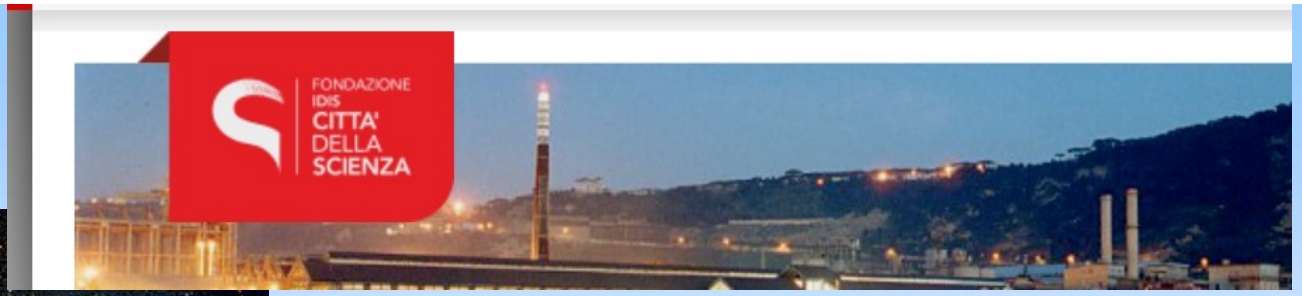


Antonio Sasso
Dipartimento di Fisica «E. Pancini»
Università di Napoli *Federico II*

Gli effetti meccanici della luce: Manipolare la materia con la luce

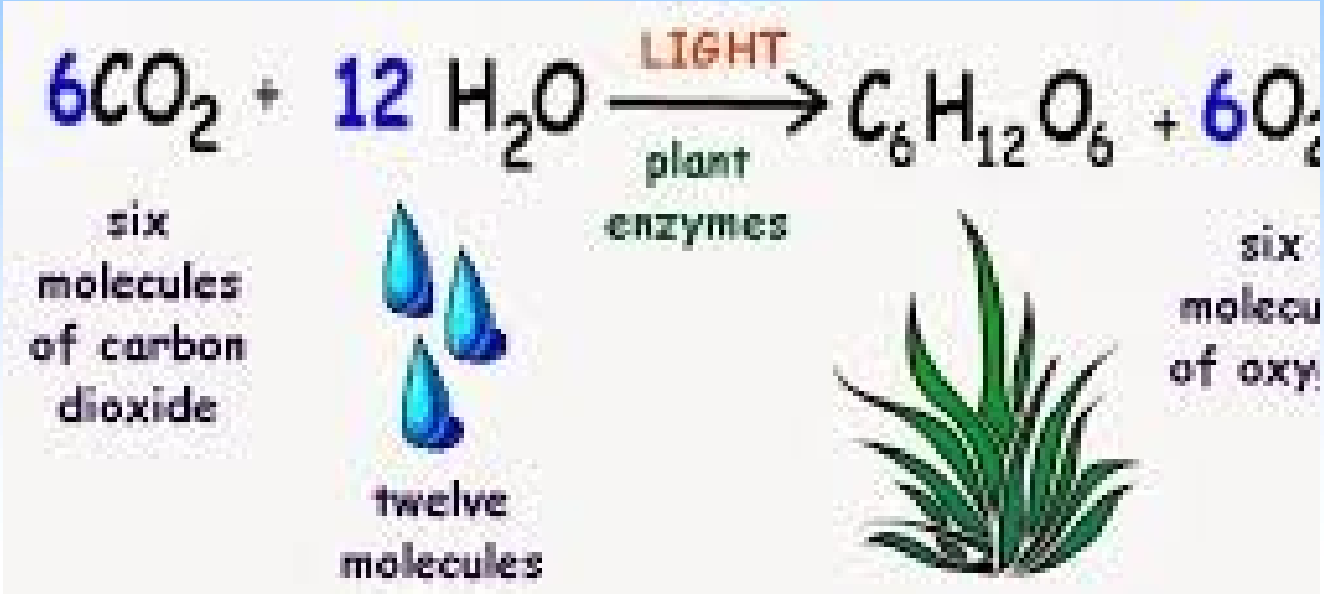
Big Bang: ~14 Miliardi di anni fa

Prime stelle: ~550 milioni di anni dopo il Big Bang

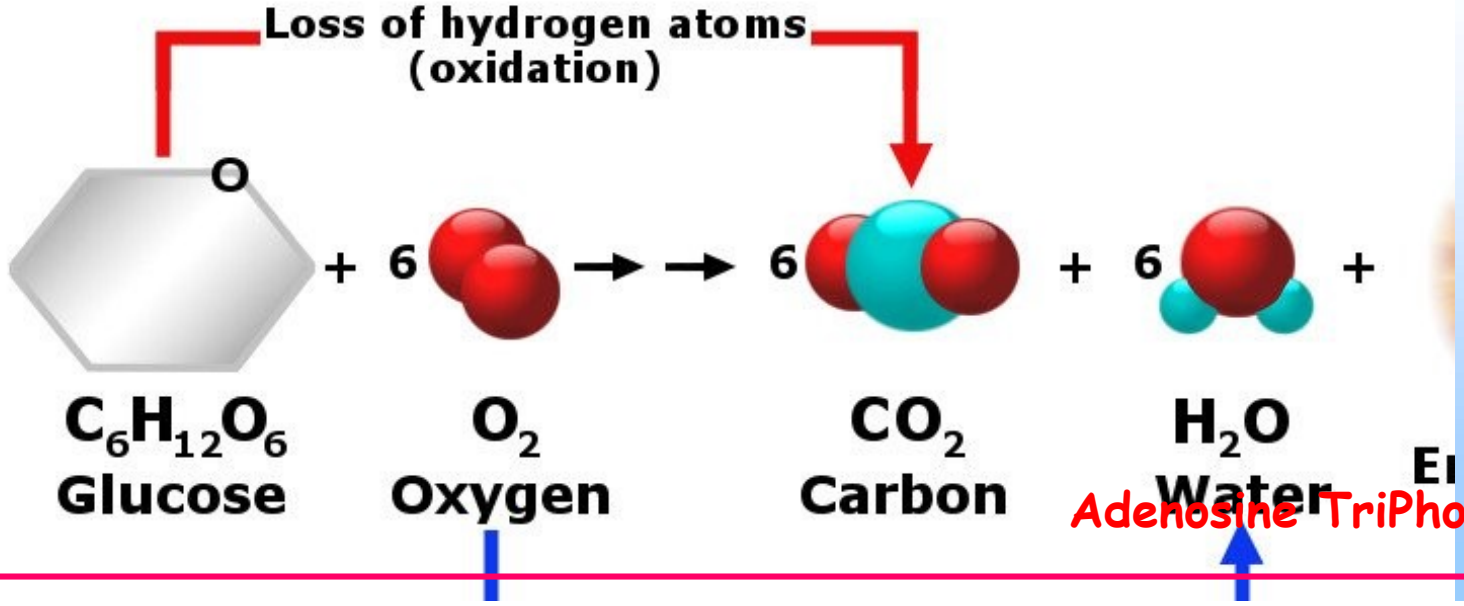
Vi sono molte più cose in terra e in cielo, Orazio, di quanto ne conosca l'umana filosofia".

(Amleto, fine I atto).

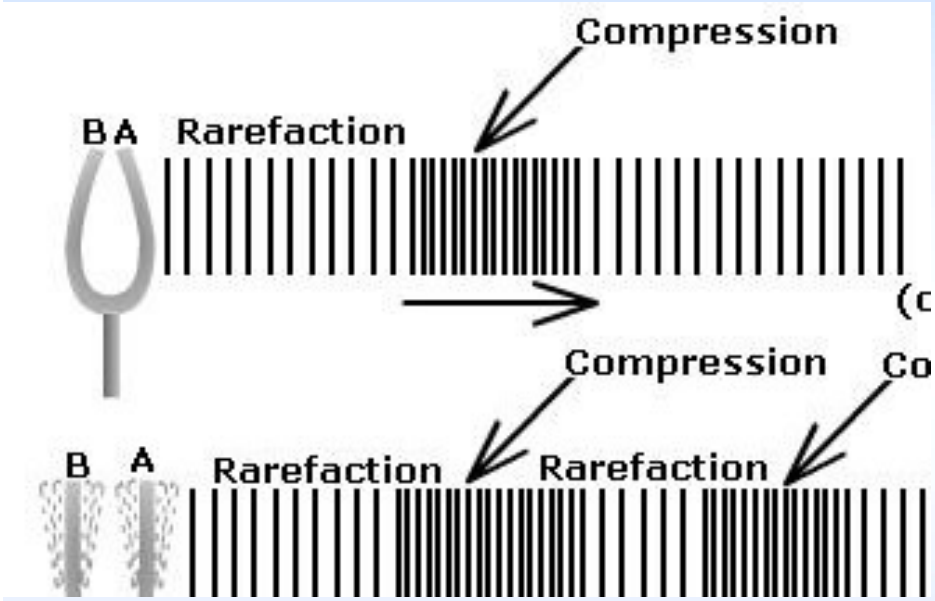
La luce alla base dei meccanismi della vita: Fotosintesi Clorofilliana



Respirazione Cellulare



ONDE


Compression
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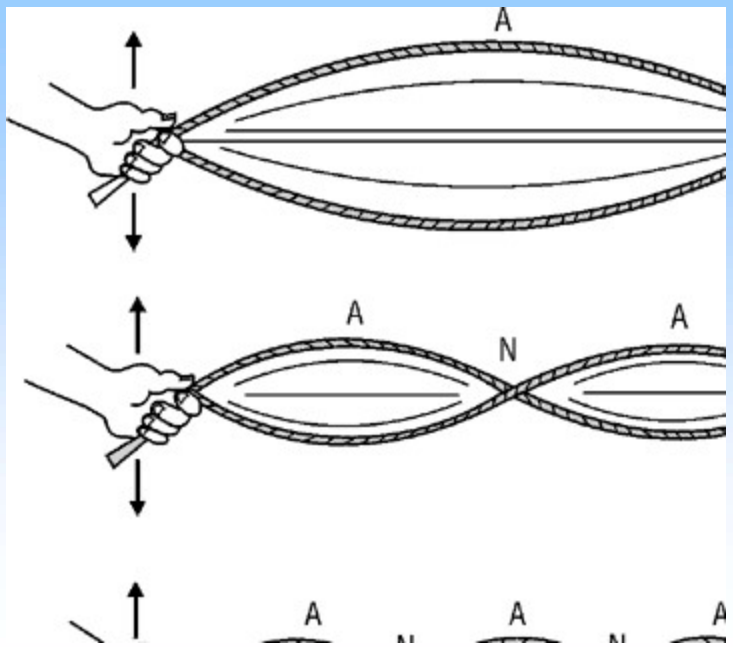
Rarefaction


A
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A

Natura della Luce

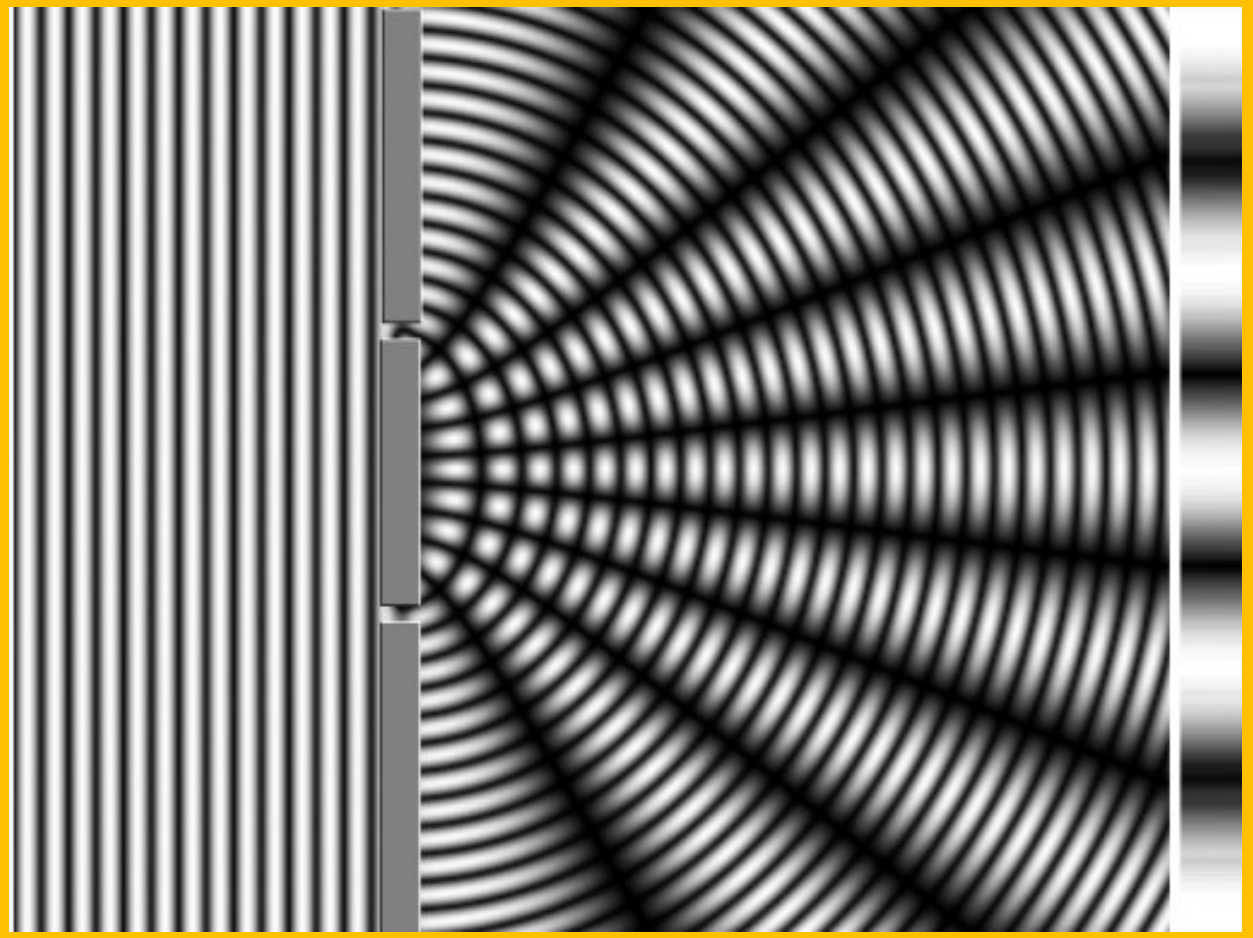
a) la luce come insieme di corpuscoli (o particelle)

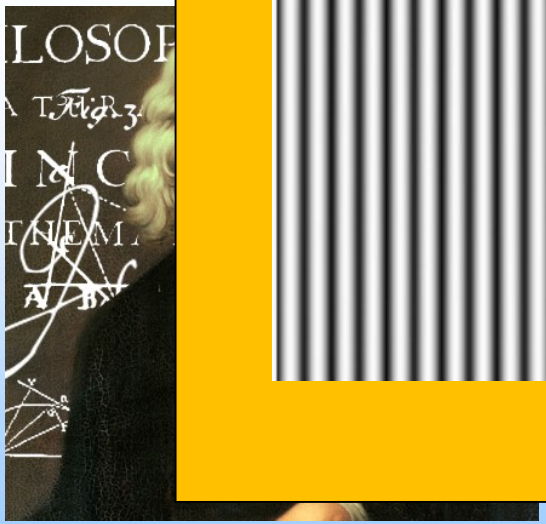
b) la luce come insieme di onde

ipotesi

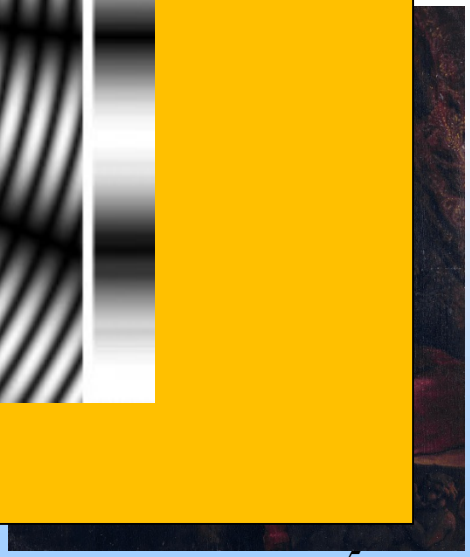
Doppia fenditura

Schermo
(con frange di interferenza)



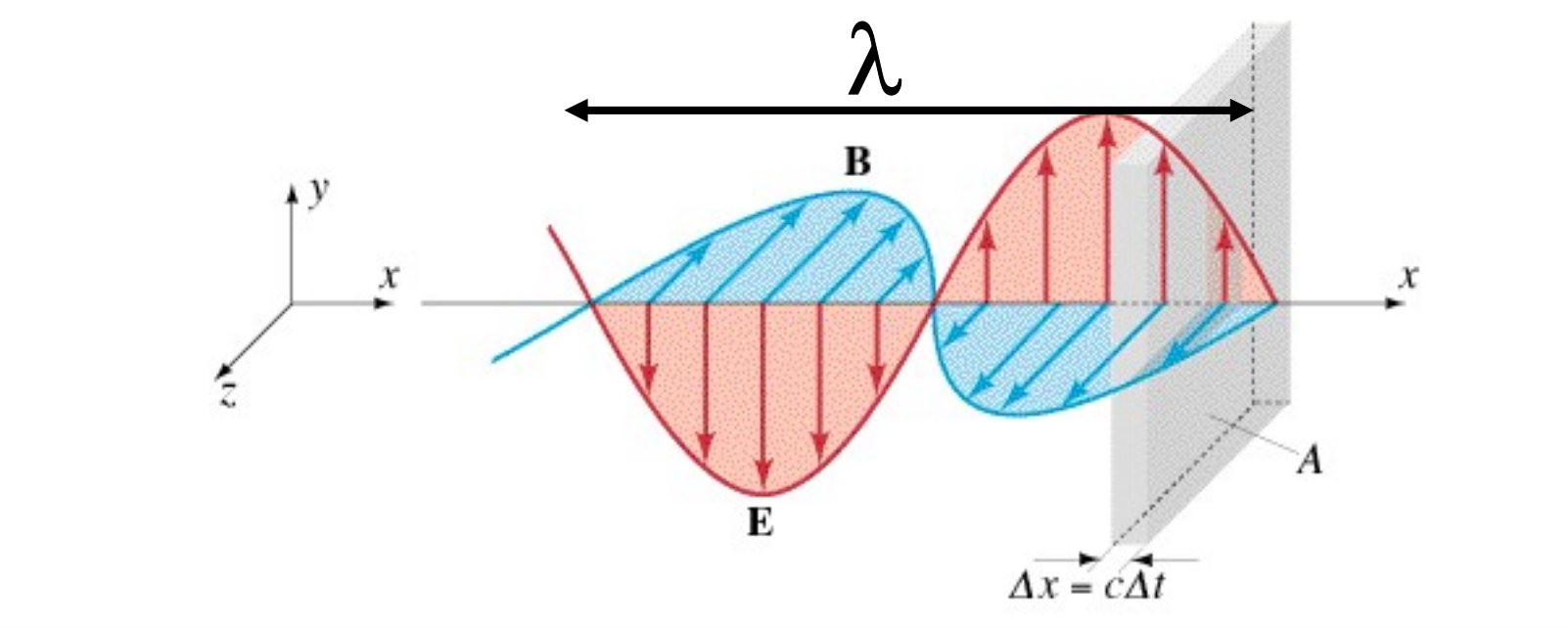


Isaac Newton
1642-1727



Christiaan Huyghens
1629-1695

La luce è un'onda elettromagnetica

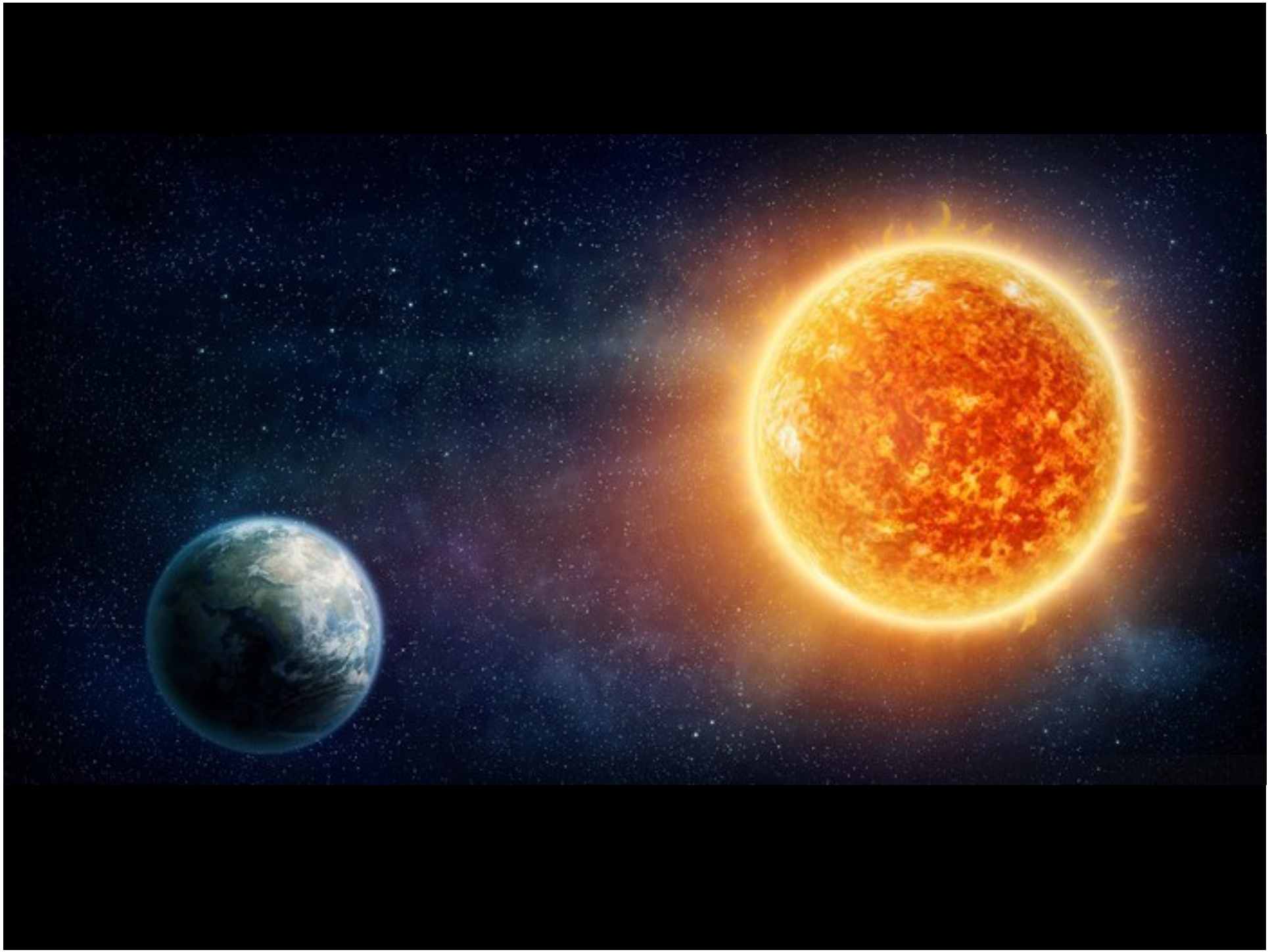


Lunghezza d'onda λ : periodo spaziale

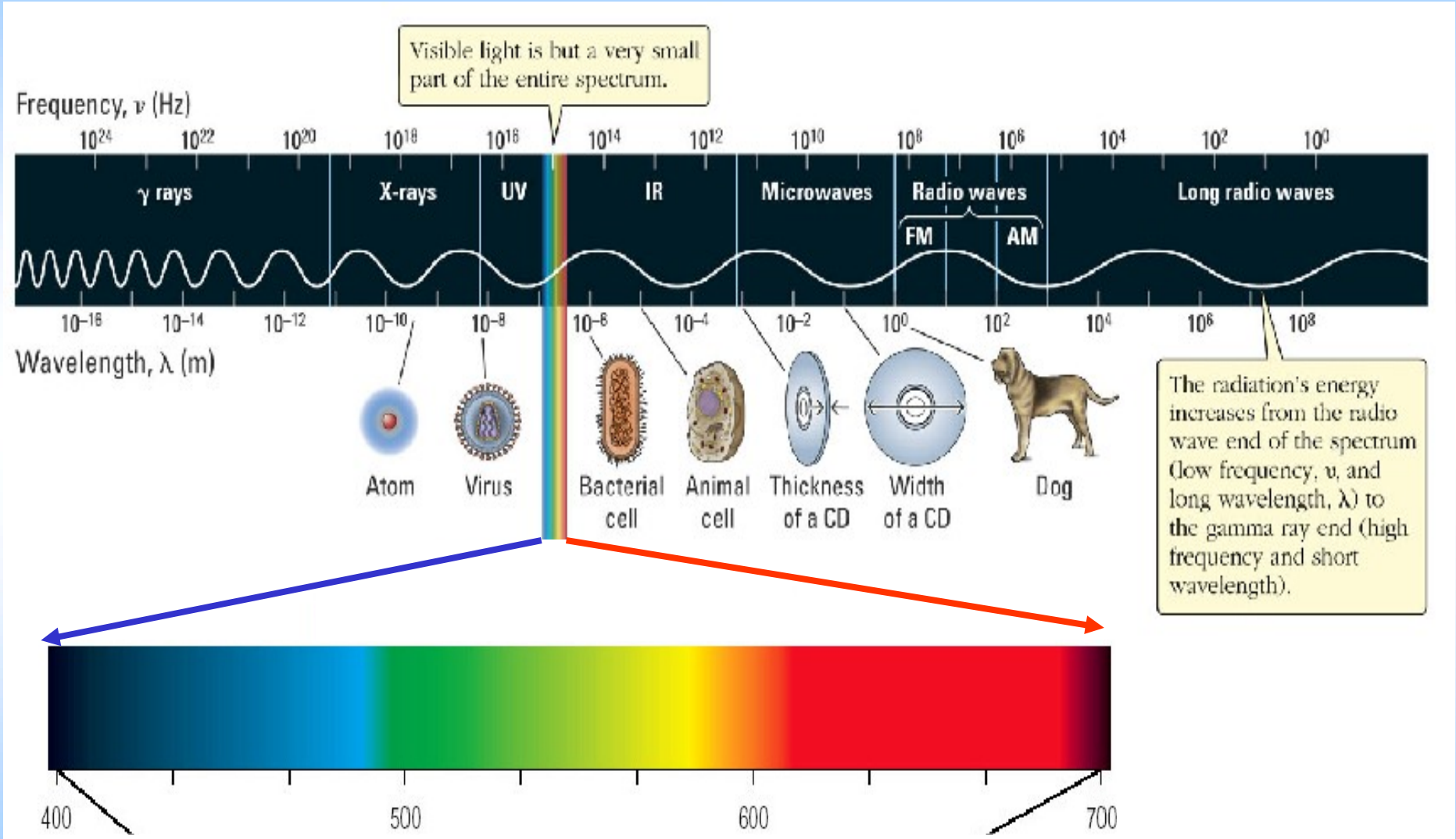
Frequenza ν : inverso del periodo temporale

$$\lambda \nu = c$$

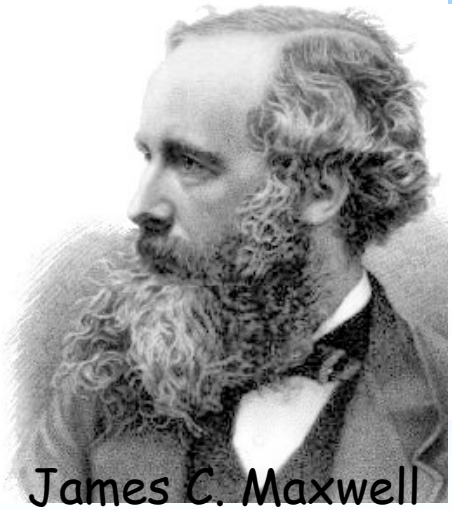
$$c = 3\ 10^{8}\ \text{m/s}$$



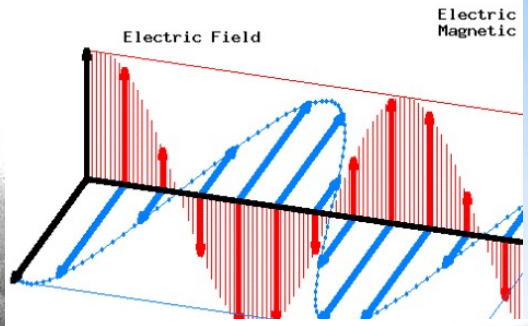
Spettro elettromagnetico

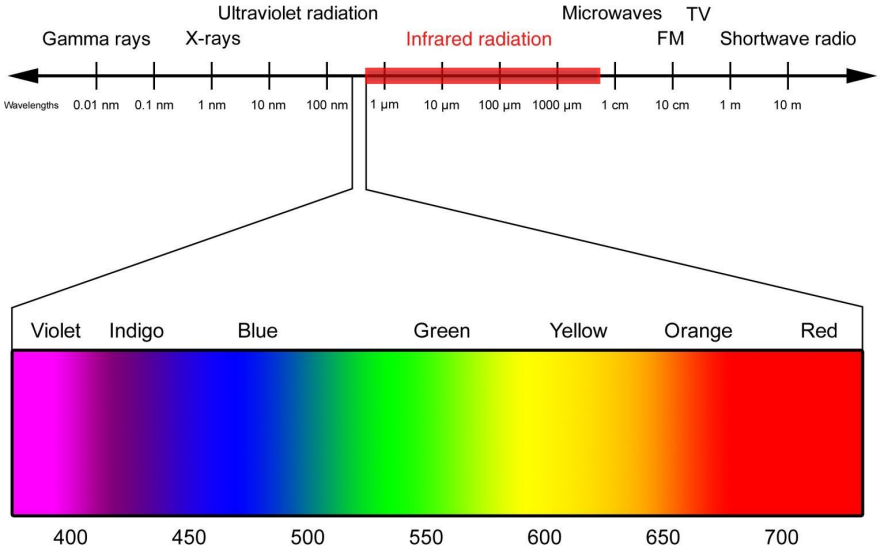


Teoria elettromagnetica



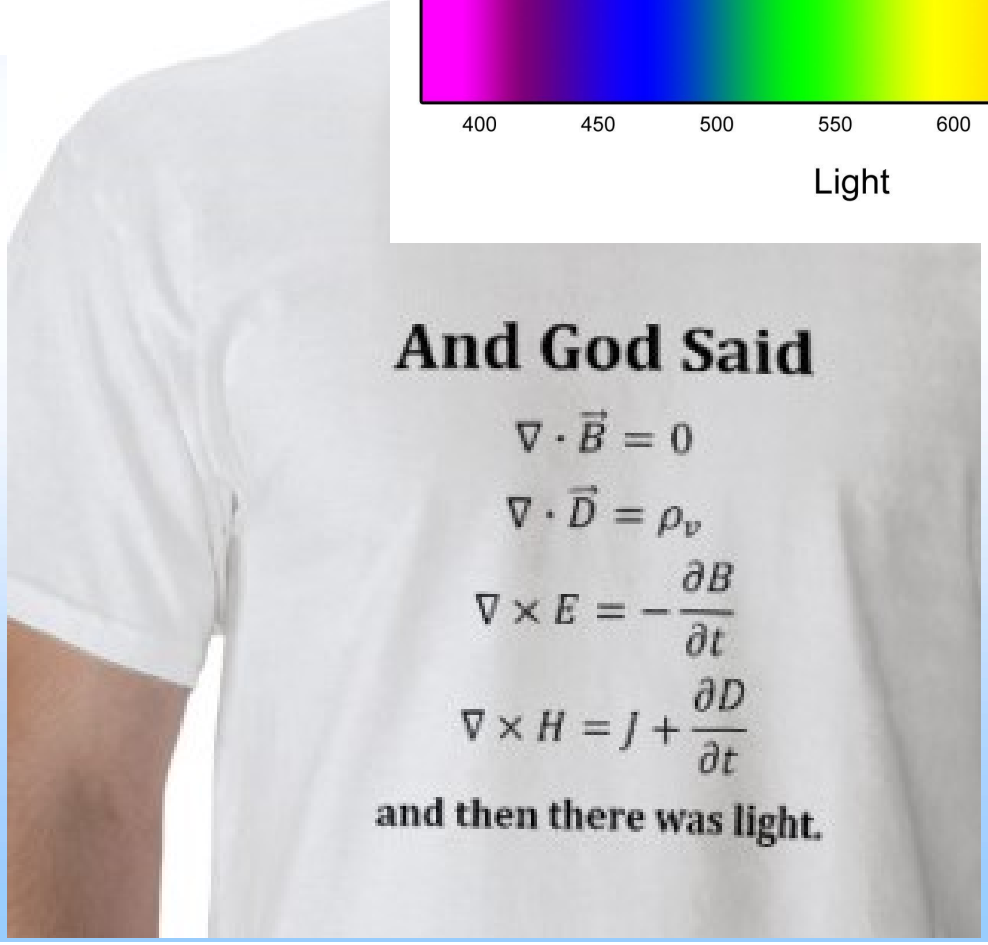
James C. Maxwell
1831-1879



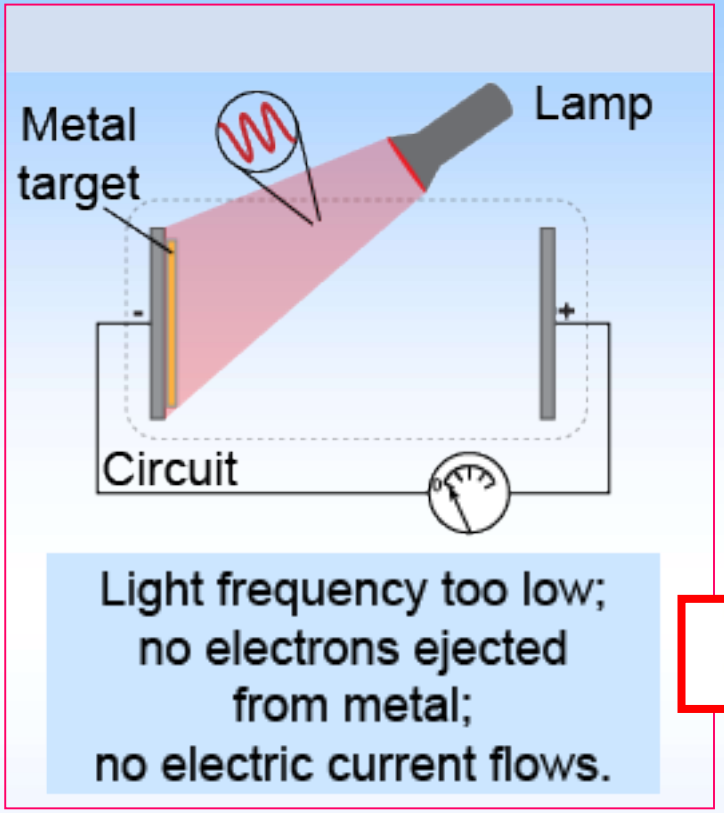


Light

Nome
Legge di Gauss elettrica
Legge di Faraday
Legge di Gauss magnetica
Legge di Ampère-Maxwell

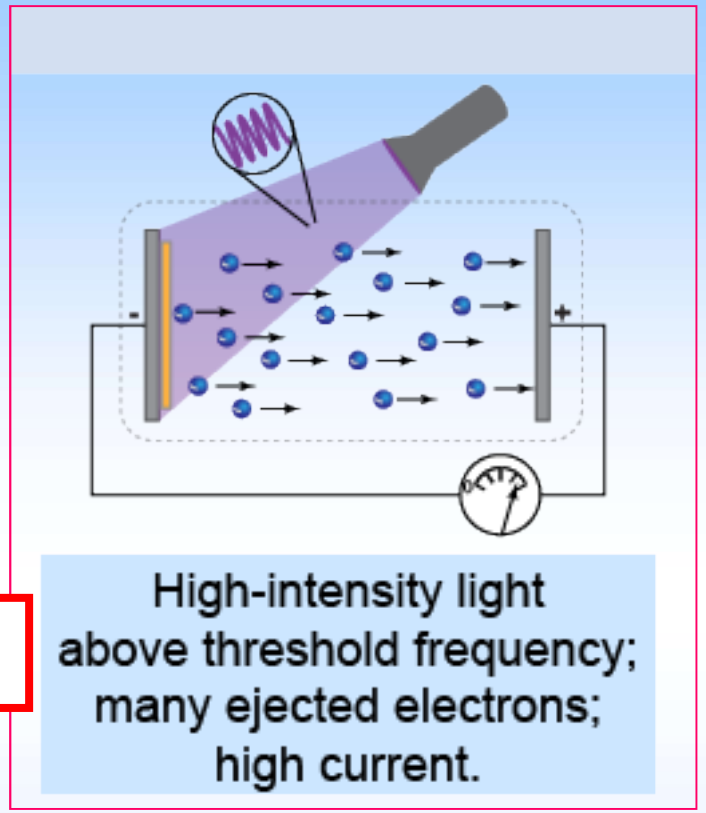


Effetto fotoelettrico: il fotone

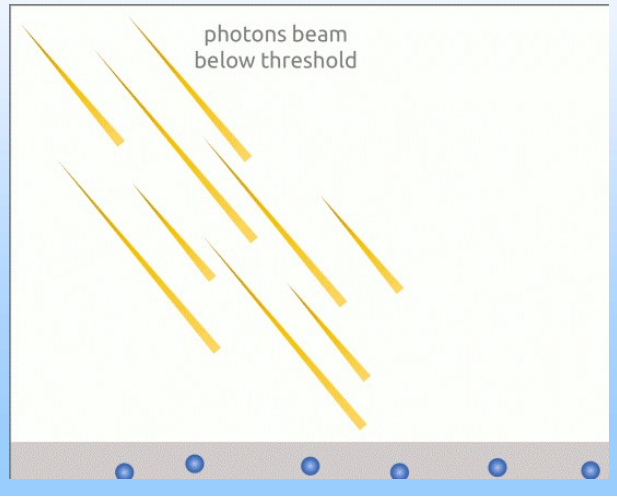


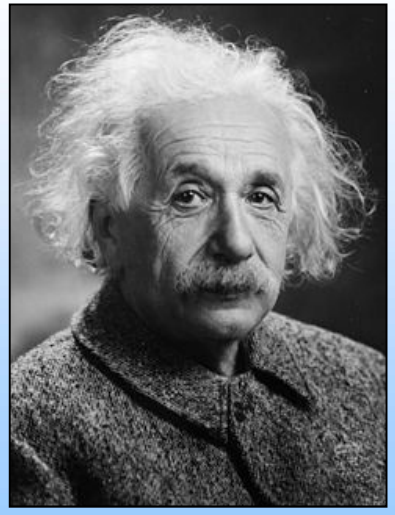
Light frequency too low;
no electrons ejected
from metal;
no electric current flows.

$E_{photon} = h\nu$

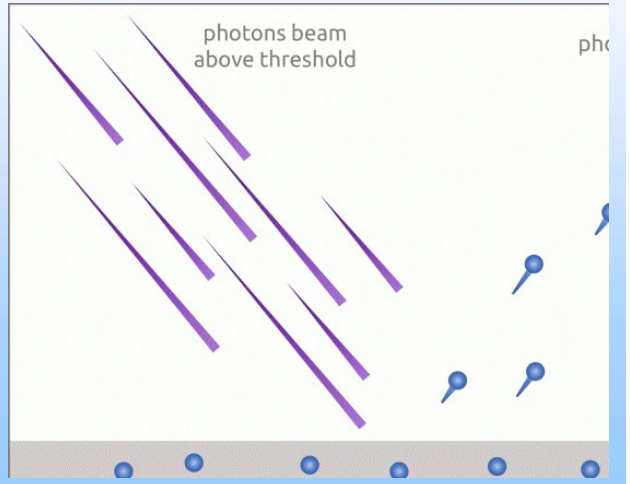


High-intensity light
above threshold frequency;
many ejected electrons;
high current.



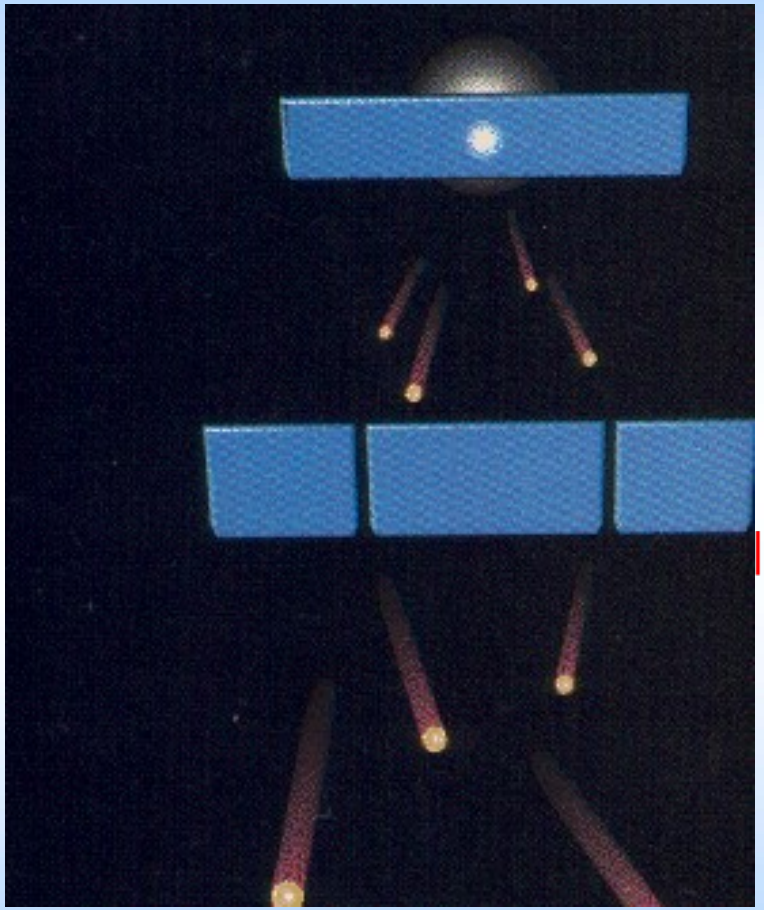


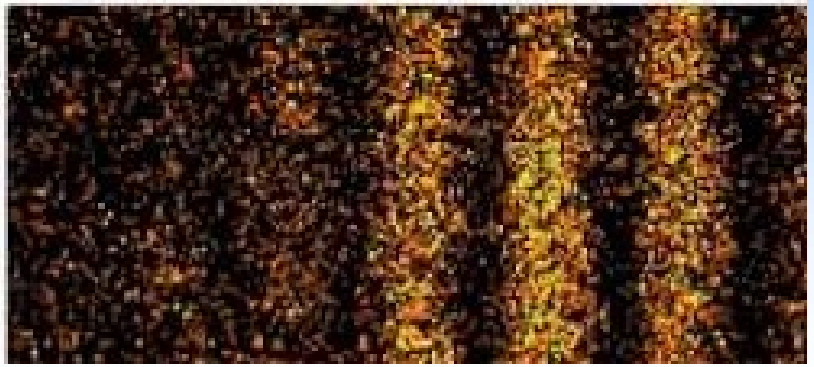
Albert Einstein 1879-1955



Onda o corpuscolo?.....tutte e due

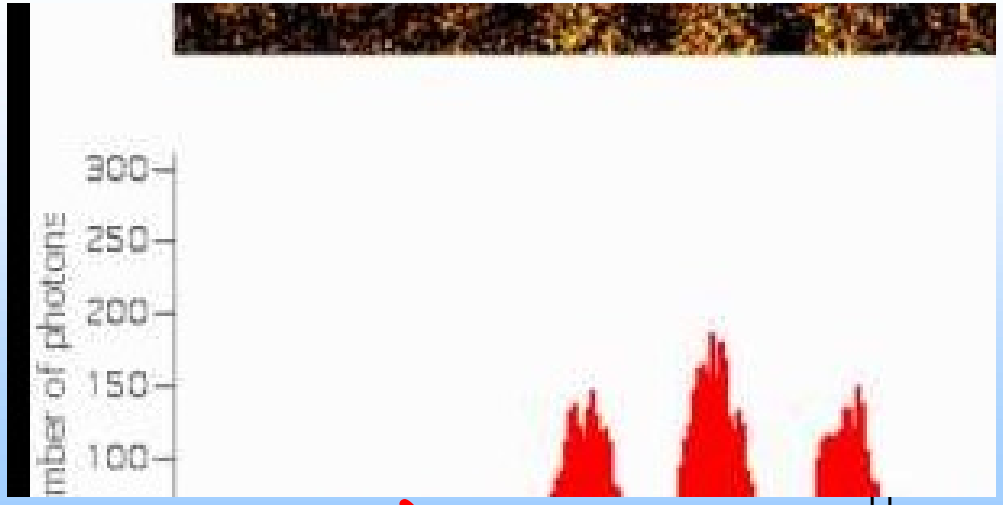
Interferenza della doppia fenditura (Young) con singolo fotone





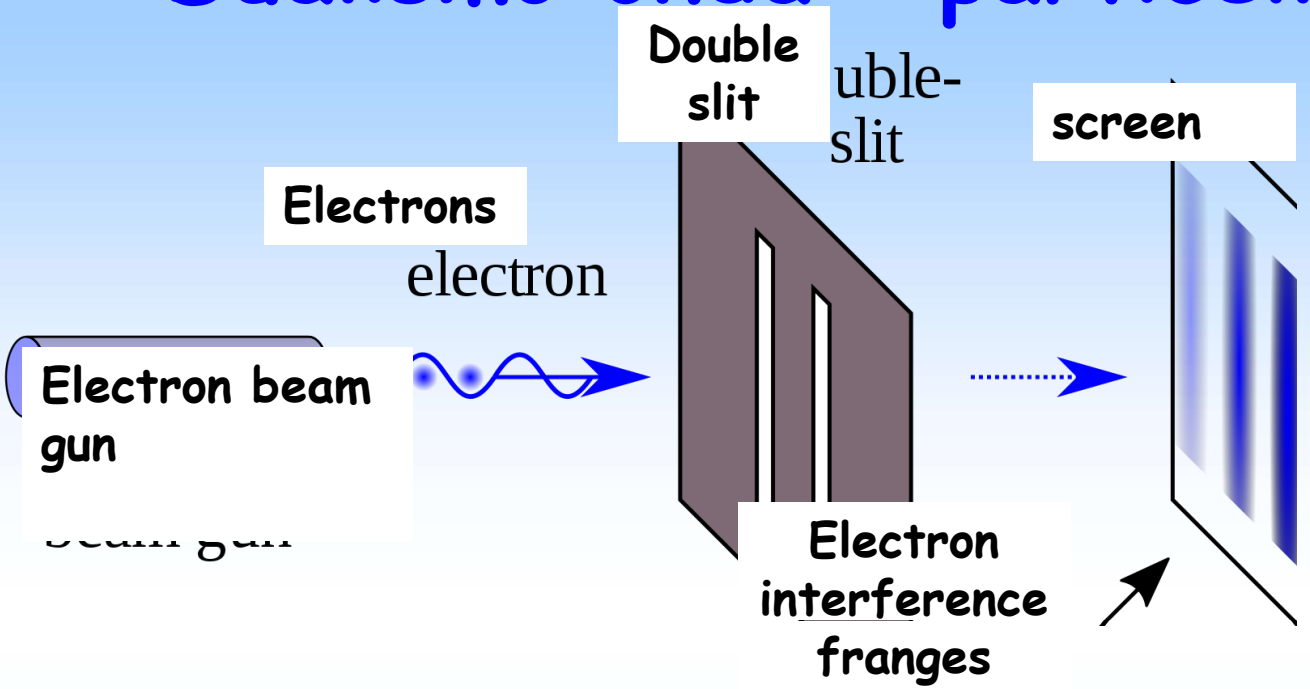
$$\Psi = a\Psi(A) + b\Psi(B)$$

$$|\Psi|^2 = |a|^2|\Psi(A)|^2 + |b|^2|\Psi(B)|^2 + 2a \cdot b\,\Psi(A)\Psi(B)$$



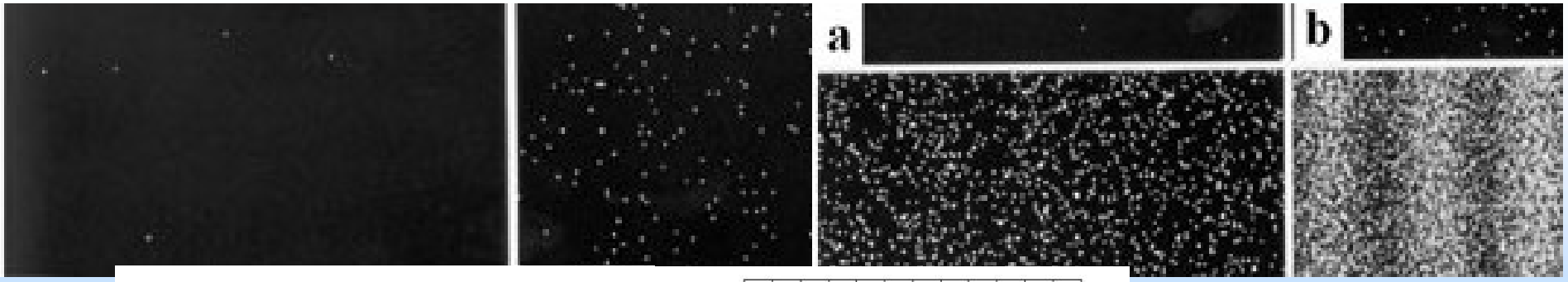
Principio di Complementarità (Niels Bohr, 1927)

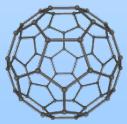
Dualismo onda - particella

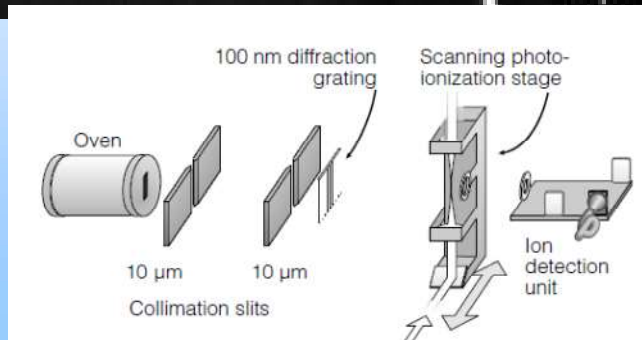


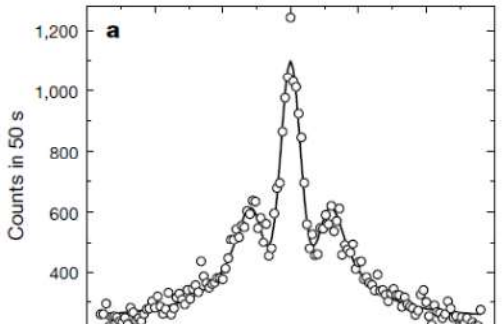
Louis de Broglie
1892-1987

$$\lambda_{dB} = \frac{h}{mv}$$







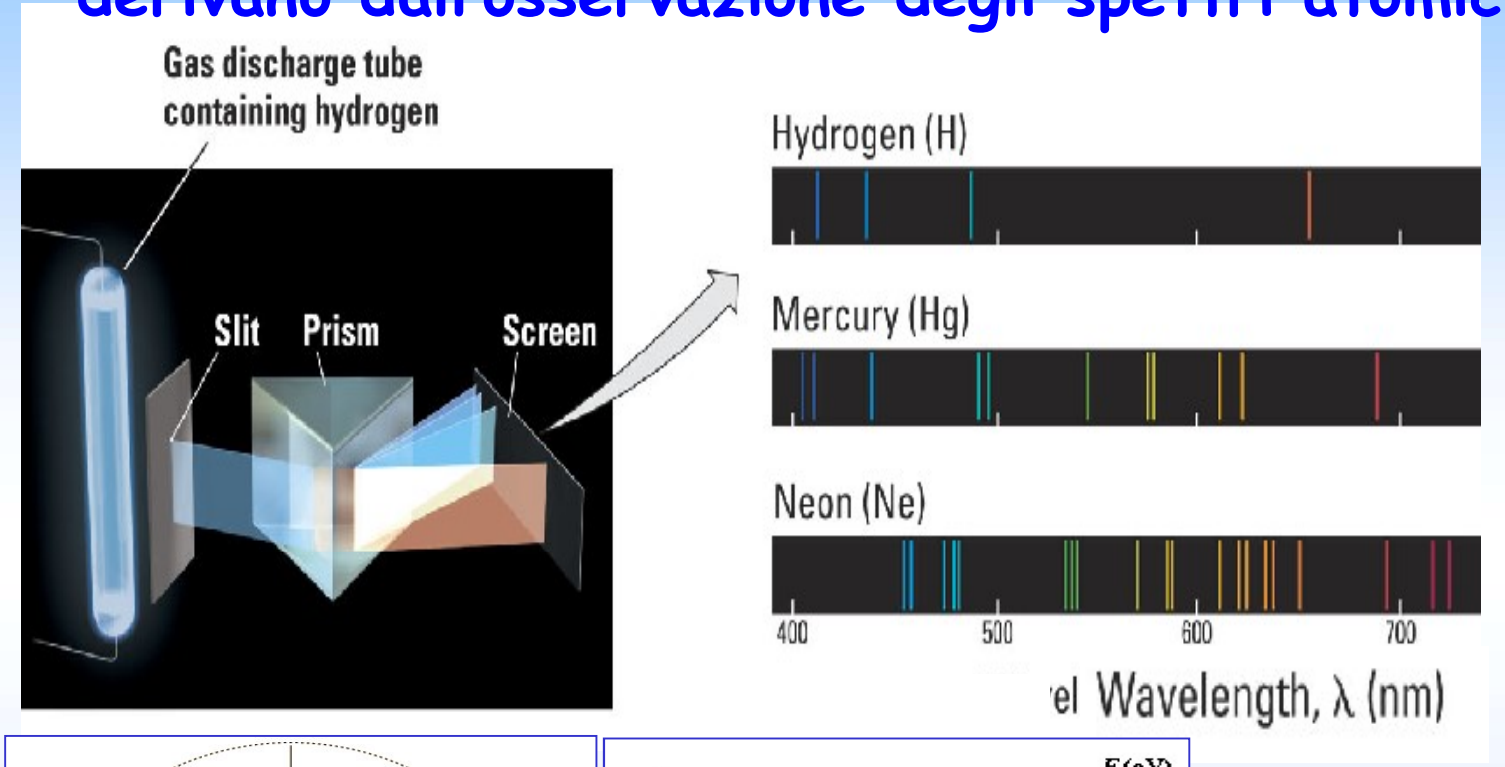


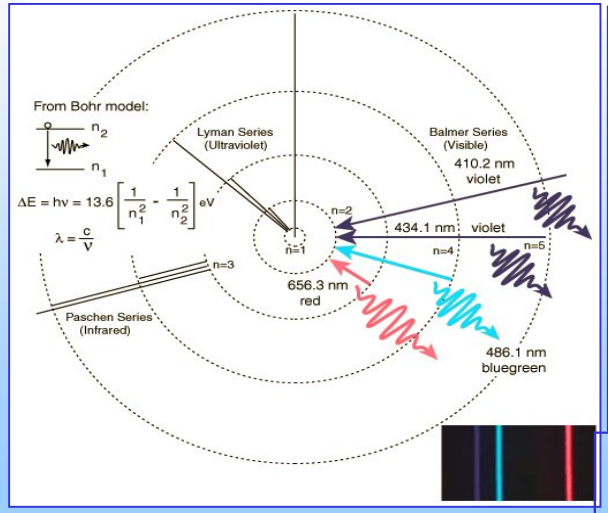
letters to nature

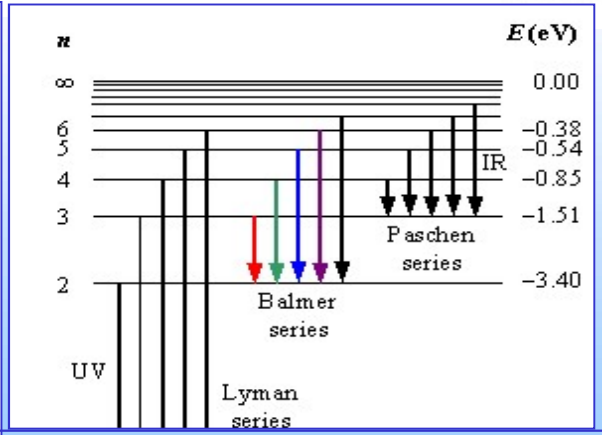
Wave–particle duality of C_{60} molecules

Markus Arndt, Olaf Nairz, Julian Vos-Andreae, Claudia Keller, Gerbrand van der Zouw & Anton Zeilinger

Molte delle nostre conoscenze della struttura della materia derivano dall'osservazione degli spettri atomici



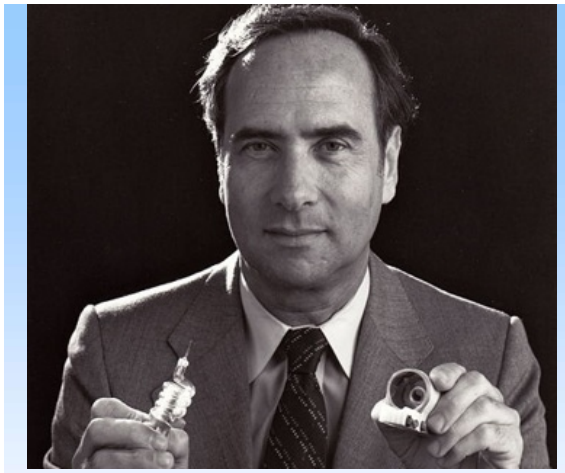




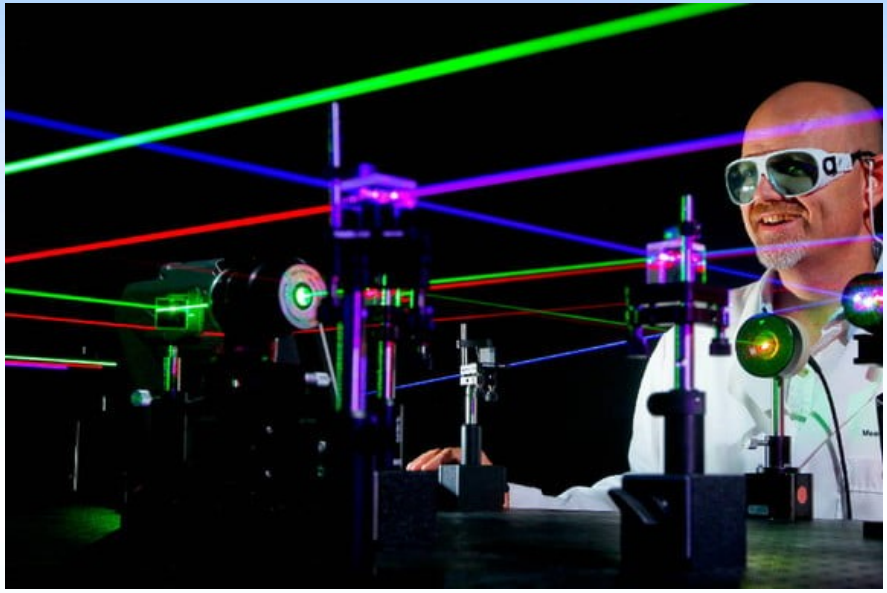
Schema energetico dell'atomo di idrogeno
Con le principali serie (Lyman, Balmer, Paschen)

L'invenzione del LASER (1960)

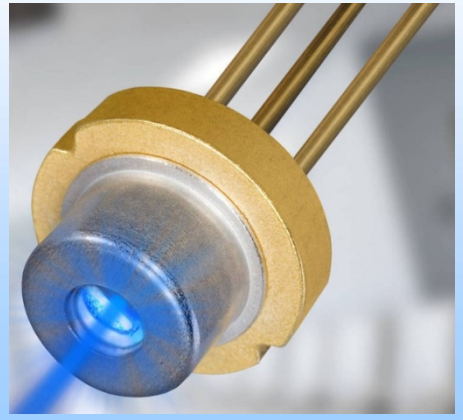
Light **A**mplification by **S**timulated **E**mission of **R**adiation



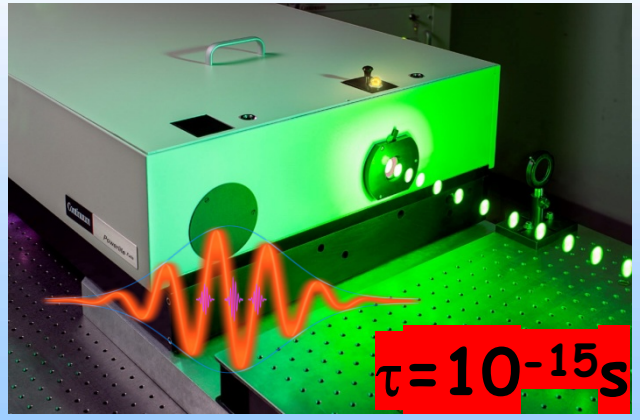
Theodore H.Maiman
1927-2007



Laser a diodo

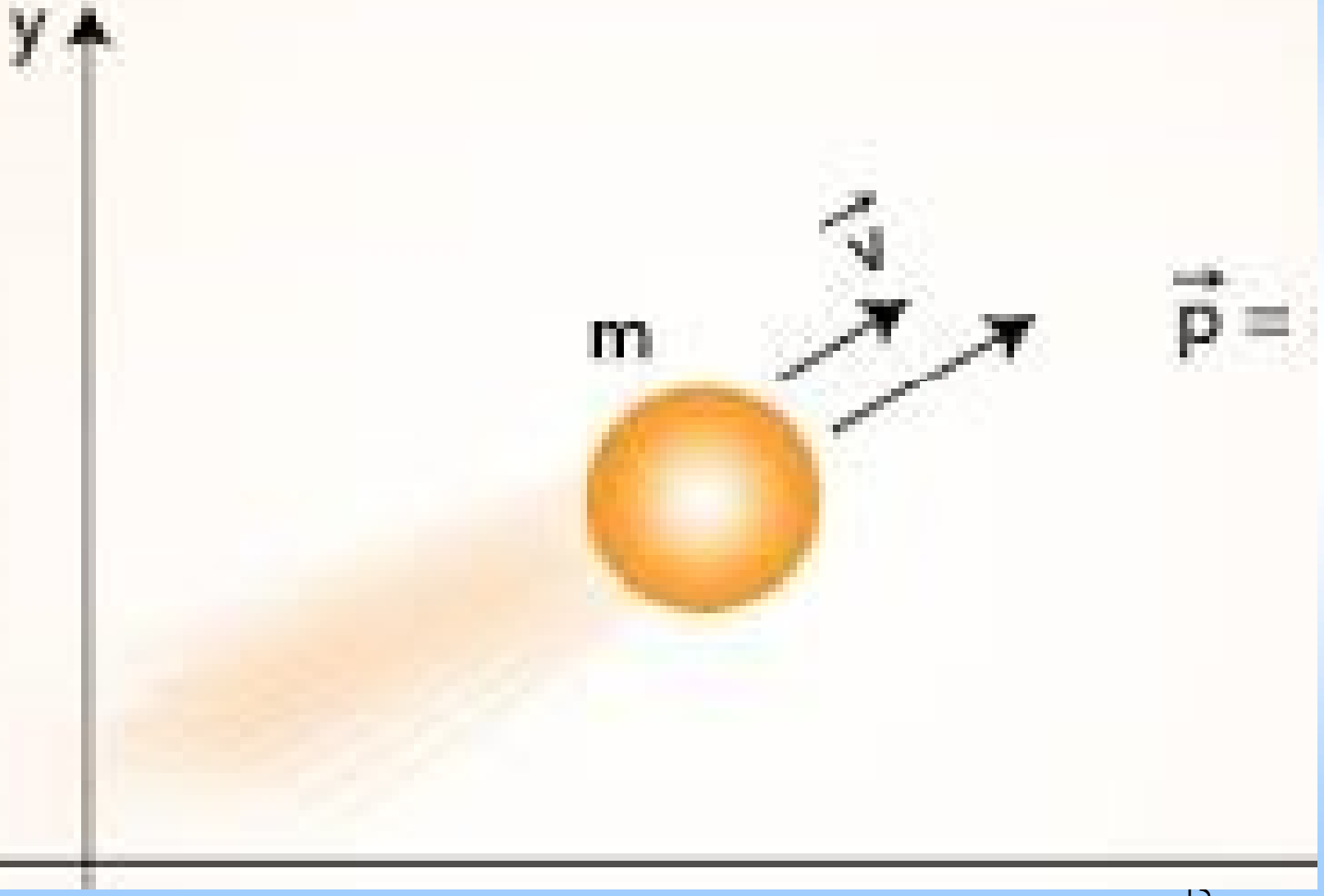


Laser ultraveloci



Laser per fusione nucleare

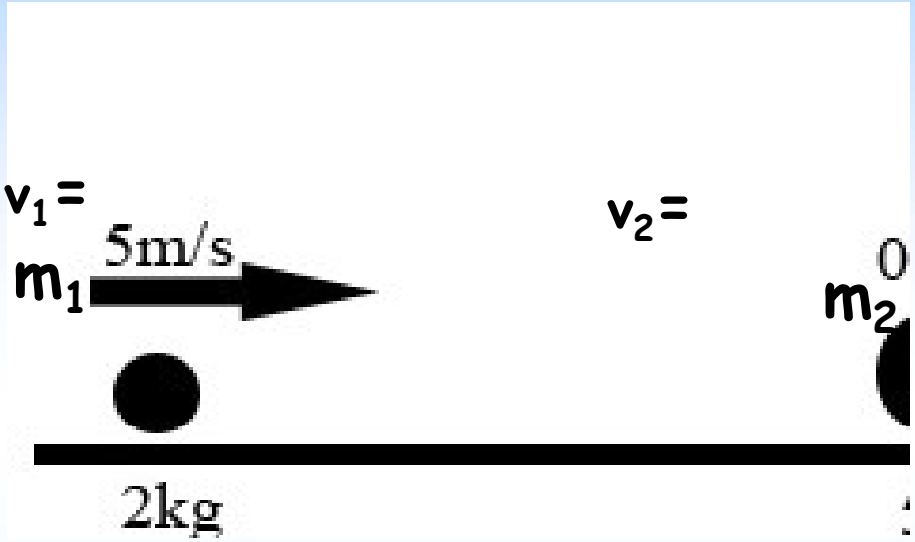
MOMENTO di una particella: massa x velocità



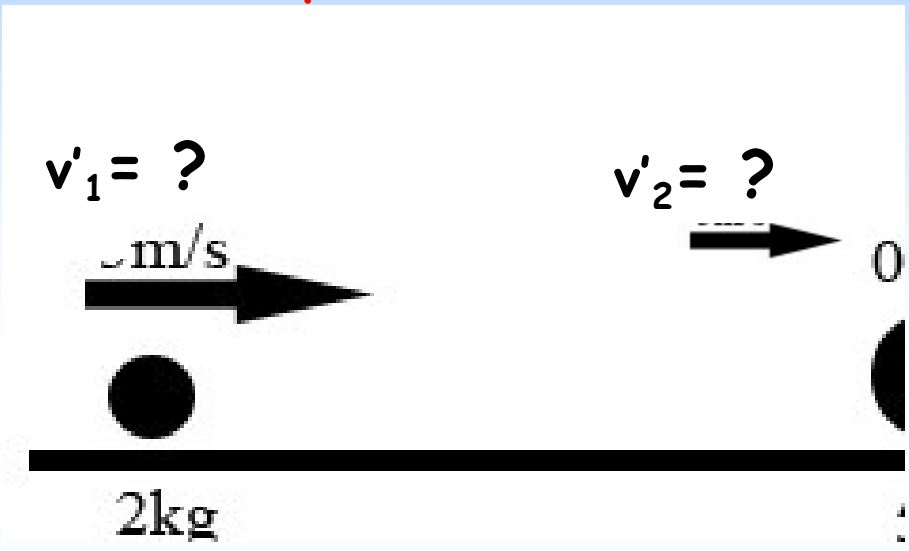
TIRO AL
BARATTOLO

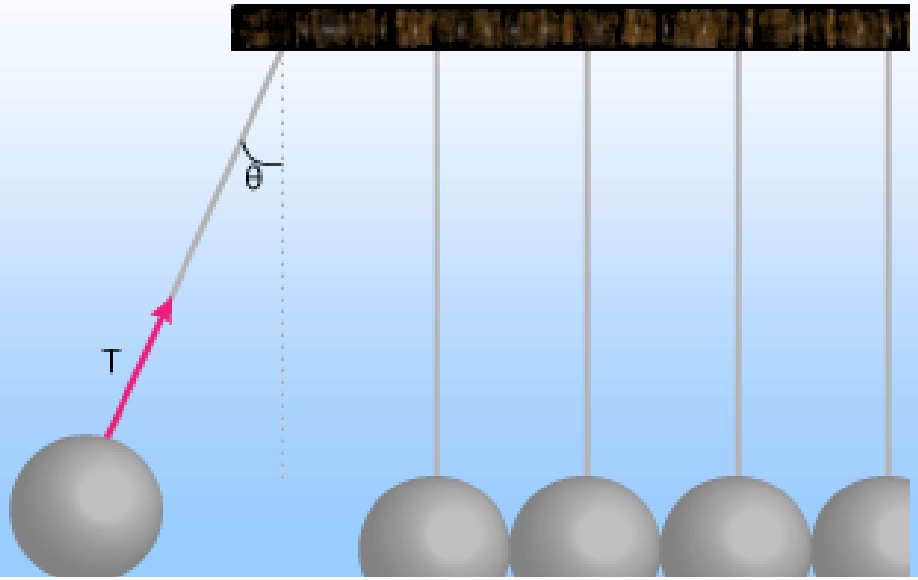
Conservazione del momento

Prima dell'urto



Dopo l'urto



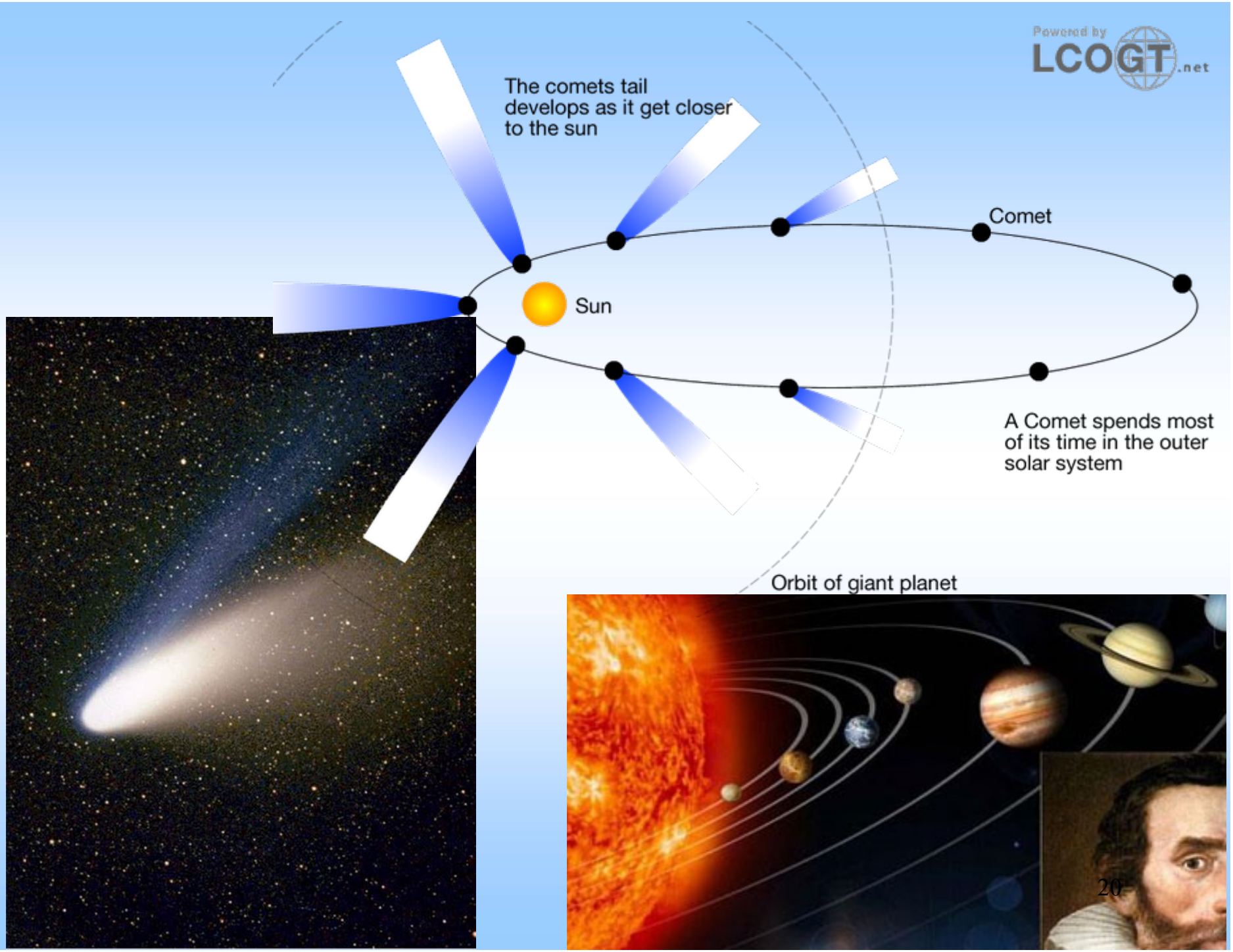


Ma la luce trasporta momento?

MOMENTO di un fotone:

il fotone ha m=0 e v=c ma……

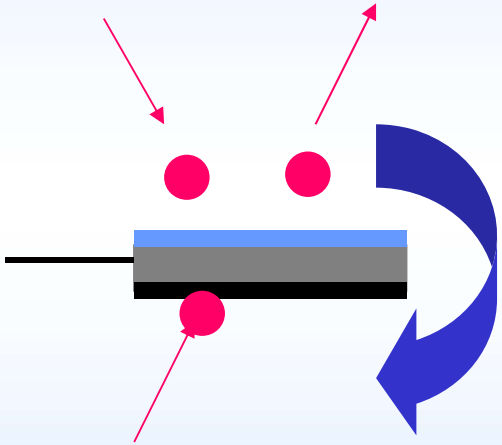
$$p_{fotone} = \frac{E}{c} = \frac{h}{c}$$


Powered by LCOGT.net
The comets tail develops as it get closer to the sun
Comet
Sun
A Comet spends most of its time in the outer solar system
Orbit of giant planet

Solar radiometer (by W. Crookes, 1874)

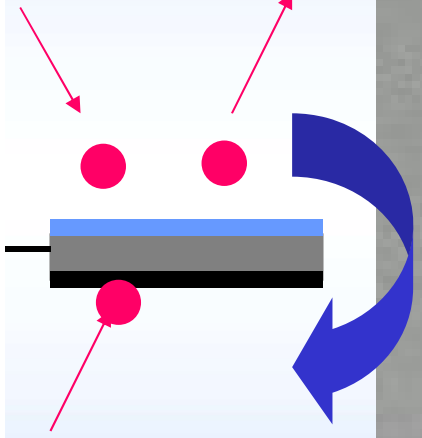
Solar radiometer (by W. Crookes, 1874)

$$P = 2\frac{h\nu}{c}$$



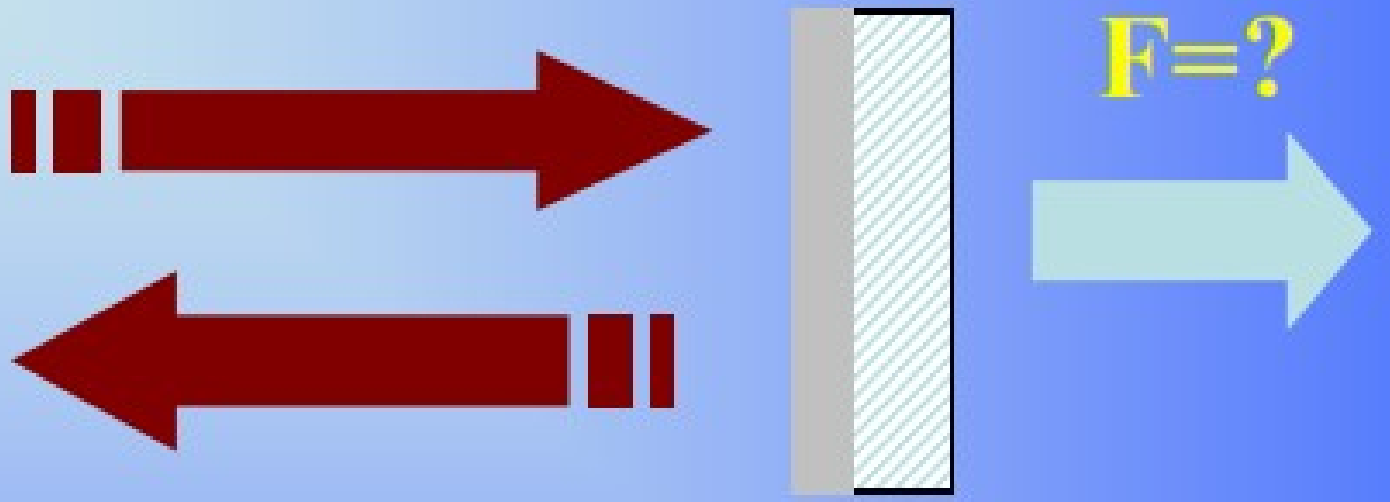
$$P = \frac{h\nu}{c}$$

$$P = 2\frac{h\nu}{c}$$



$$P = \frac{h\nu}{c}$$

Optical force on a macro-scopic body: a mirror



$\Phi = 1\,\mu m$

$M = 10^{-18}\ Kg$

$$Power = \frac{nhc}{\lambda} = P$$

$$momentum = \frac{}{\lambda}$$

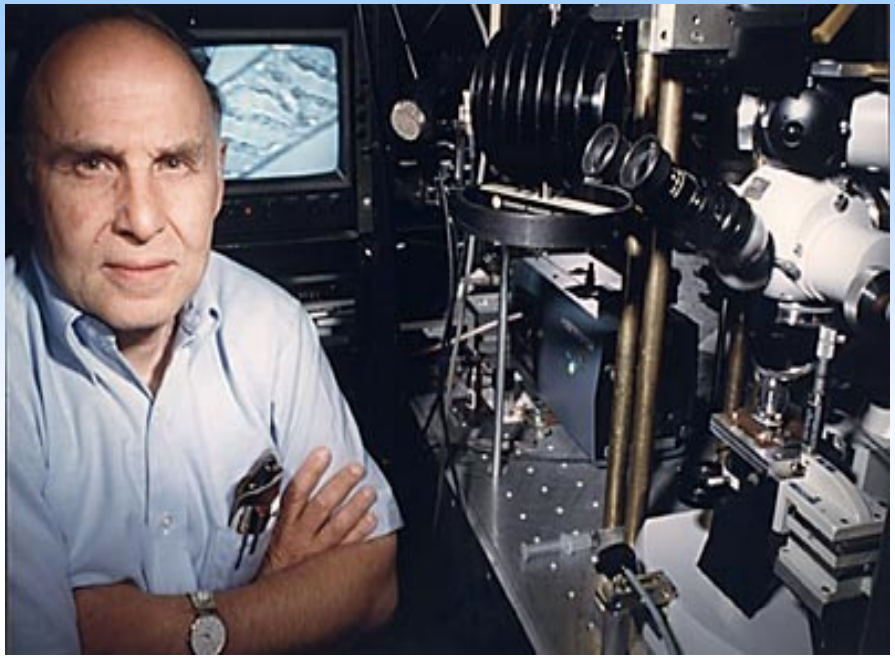
use Newto laws.....

$$F = rate\ of\ change\ of\ momentum = \frac{2P}{c}$$

$$F$$

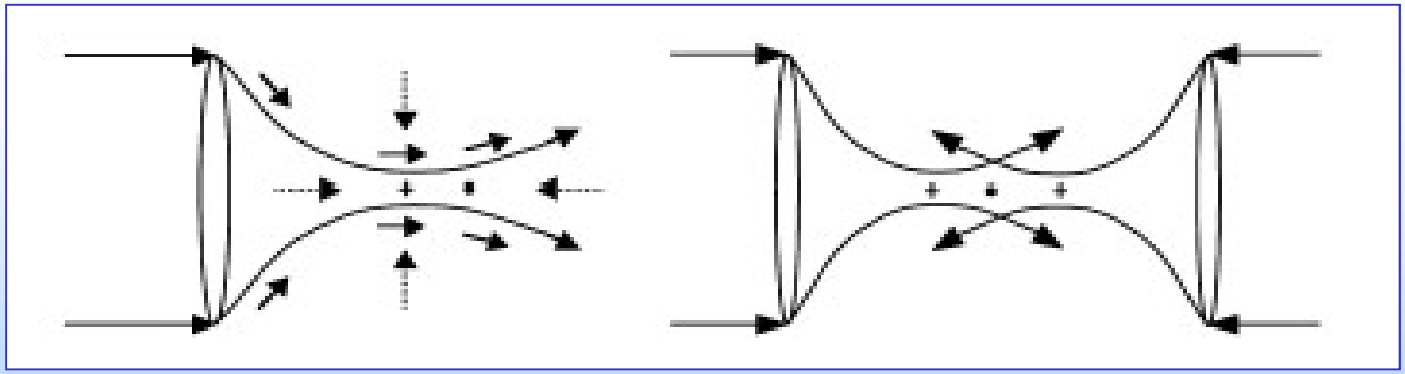
$F \approx pN$ for mW of laser power

Pioneer of optical trapping



- 1969/70: **A. Ashkin, V.L. Letokhov** – suggest to employ radiation pressure for manipulation with atoms, molecules and microparticles
- 1986: **A. Ashkin** - single beam optical trap – *Optical tweezers*
- 1987: **A. Ashkin** – optical tweezers moves with bacteria and viruses without their damage

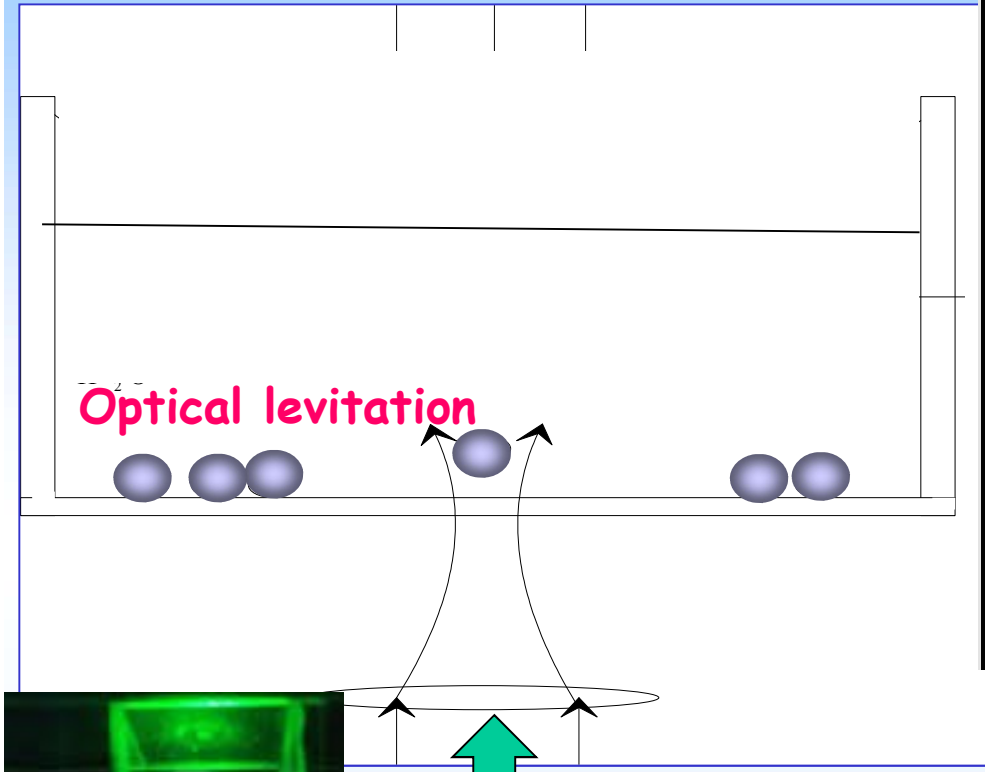
Idea:
One or two-tighly focused beams

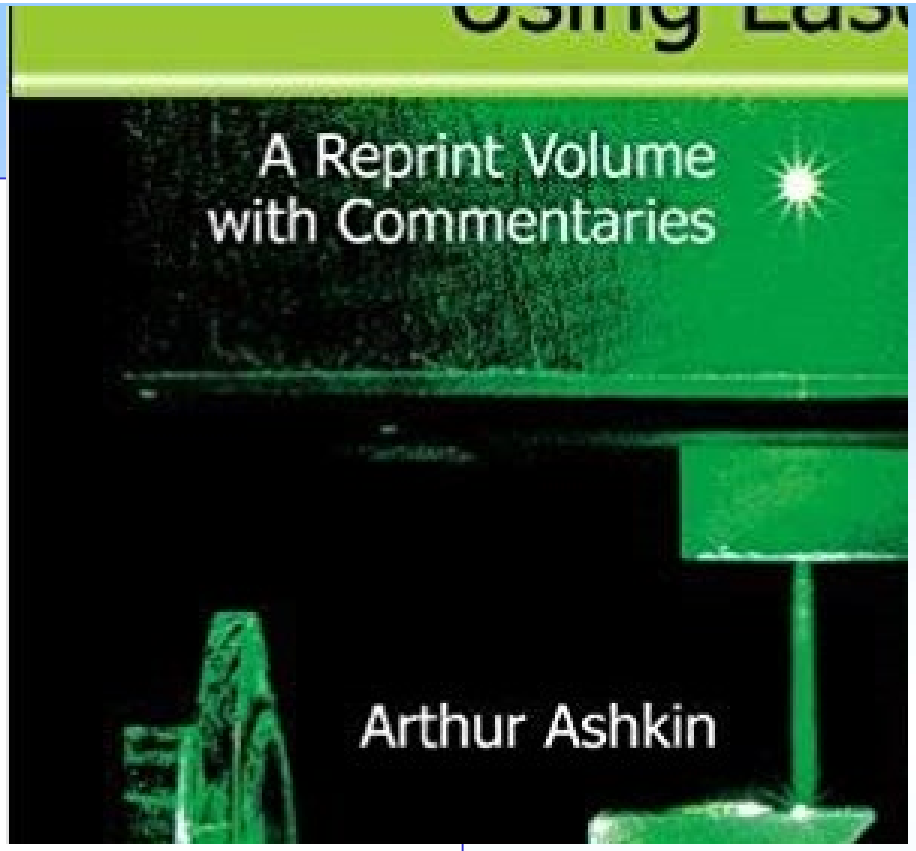


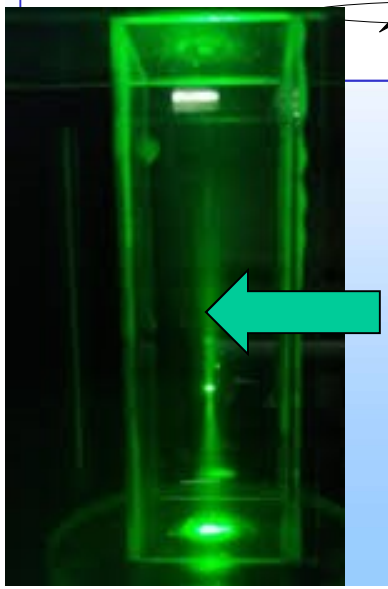
Useless for thermal atoms (only recently by Laser Cooling, BEC) but.....

effective for microparticles!

Optical Levitation



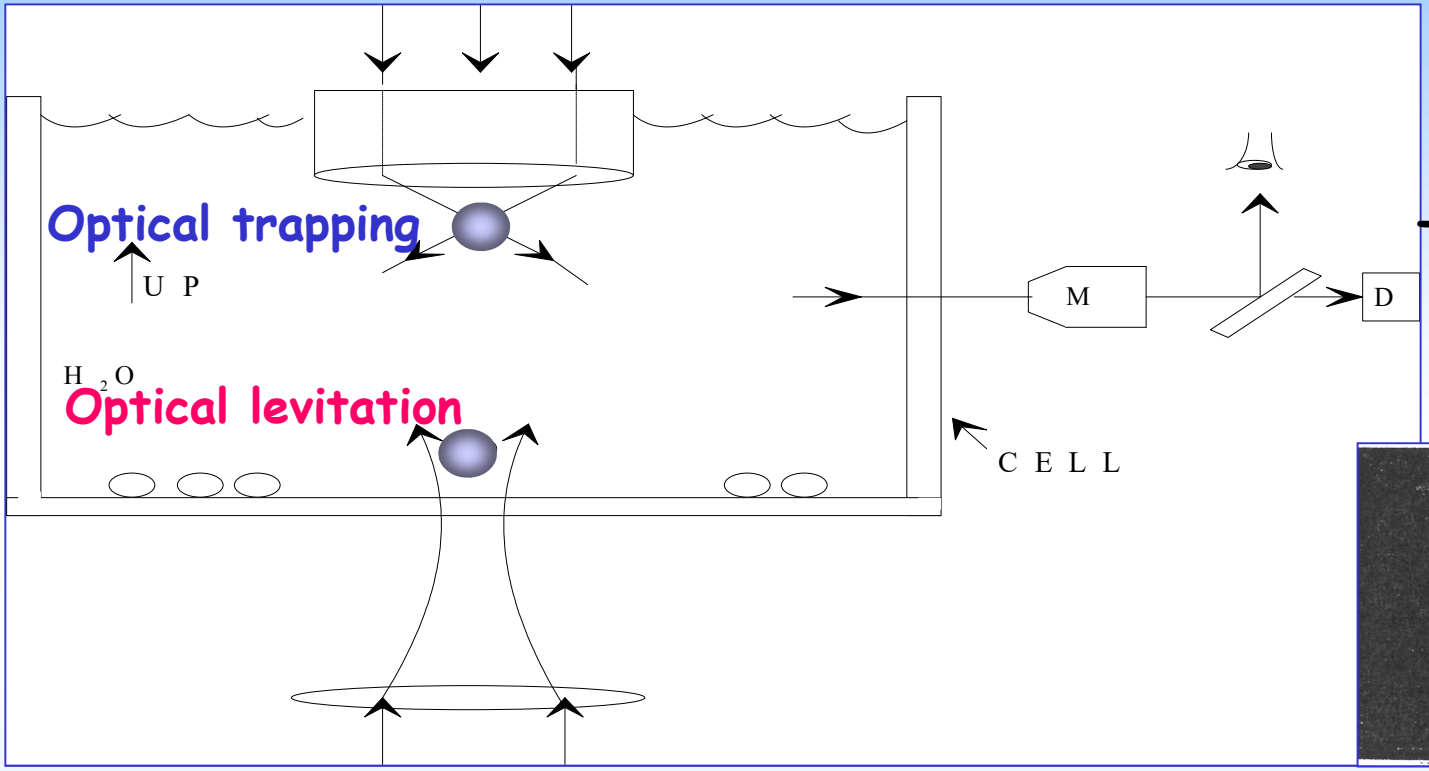




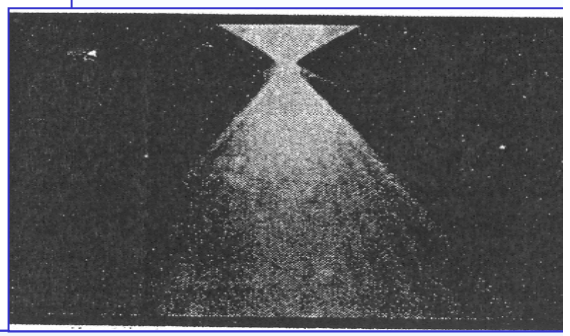
Levitazione in acqua e

in vuoto

Optical Tweezers (Pinzette Ottiche)
(A. Ashkin Opt. Lett. (11), 1986)



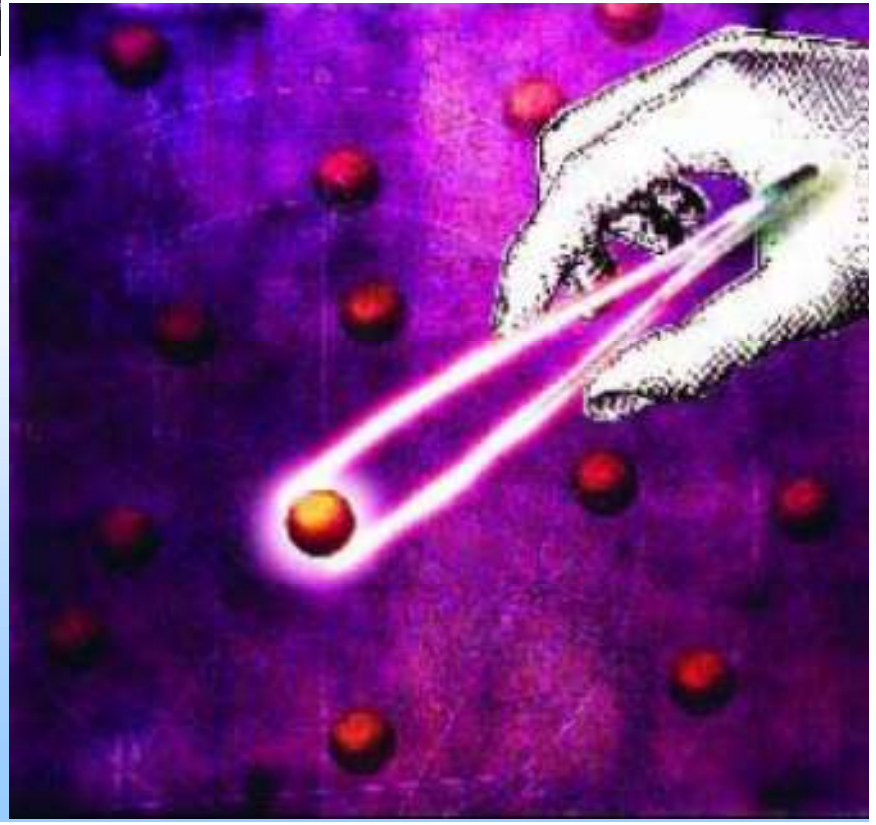
Trapping observation



Neutral dielectric particles
(size: 20nm-200μm force: 10 – 200 pN)

Biological materials: virus, bacteria, cells,…molecular motors, biological bonds, …

Le pinzette ottiche:
Manipolare la materia con la luce

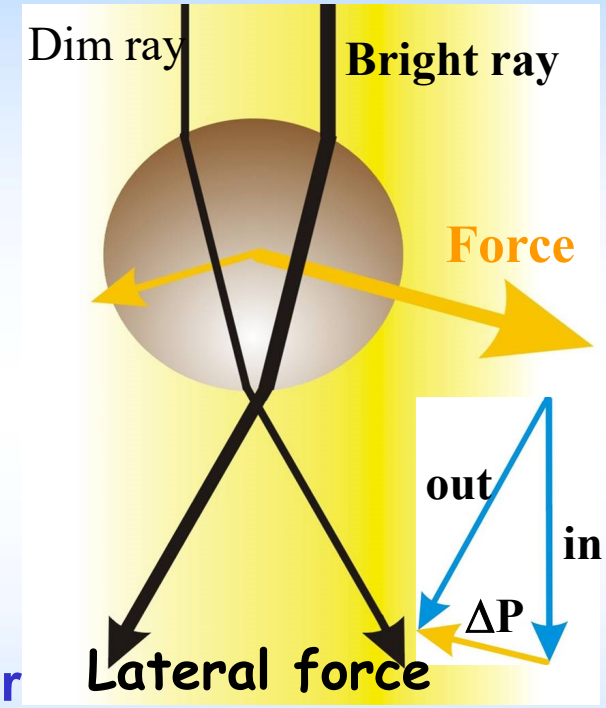


Le navi spaziali saranno a vela. Viaggeranno spinte dal "vento solare"

Barche che si muovono grazie alla conversione di energia solare in energia elettrica (fotovoltaico)

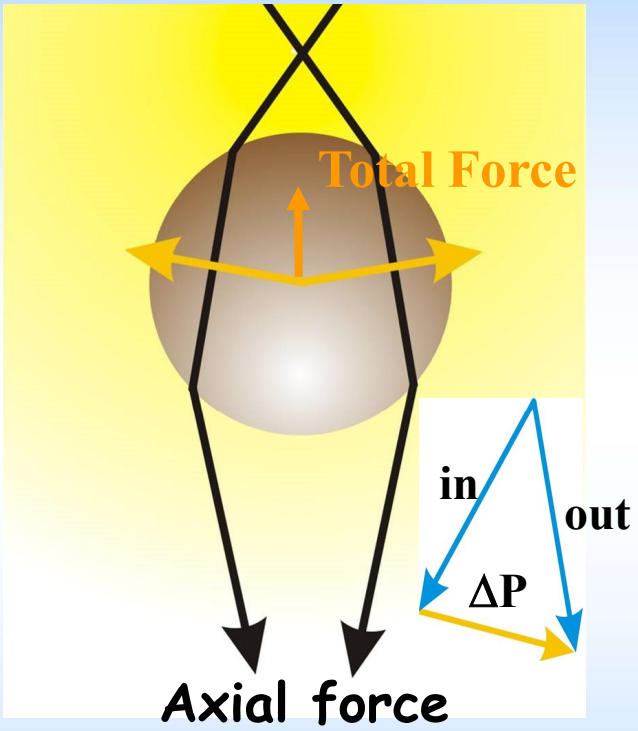
Geometrical optics approximation (Mie) ($a \gg \lambda$)

ater



Momentum change

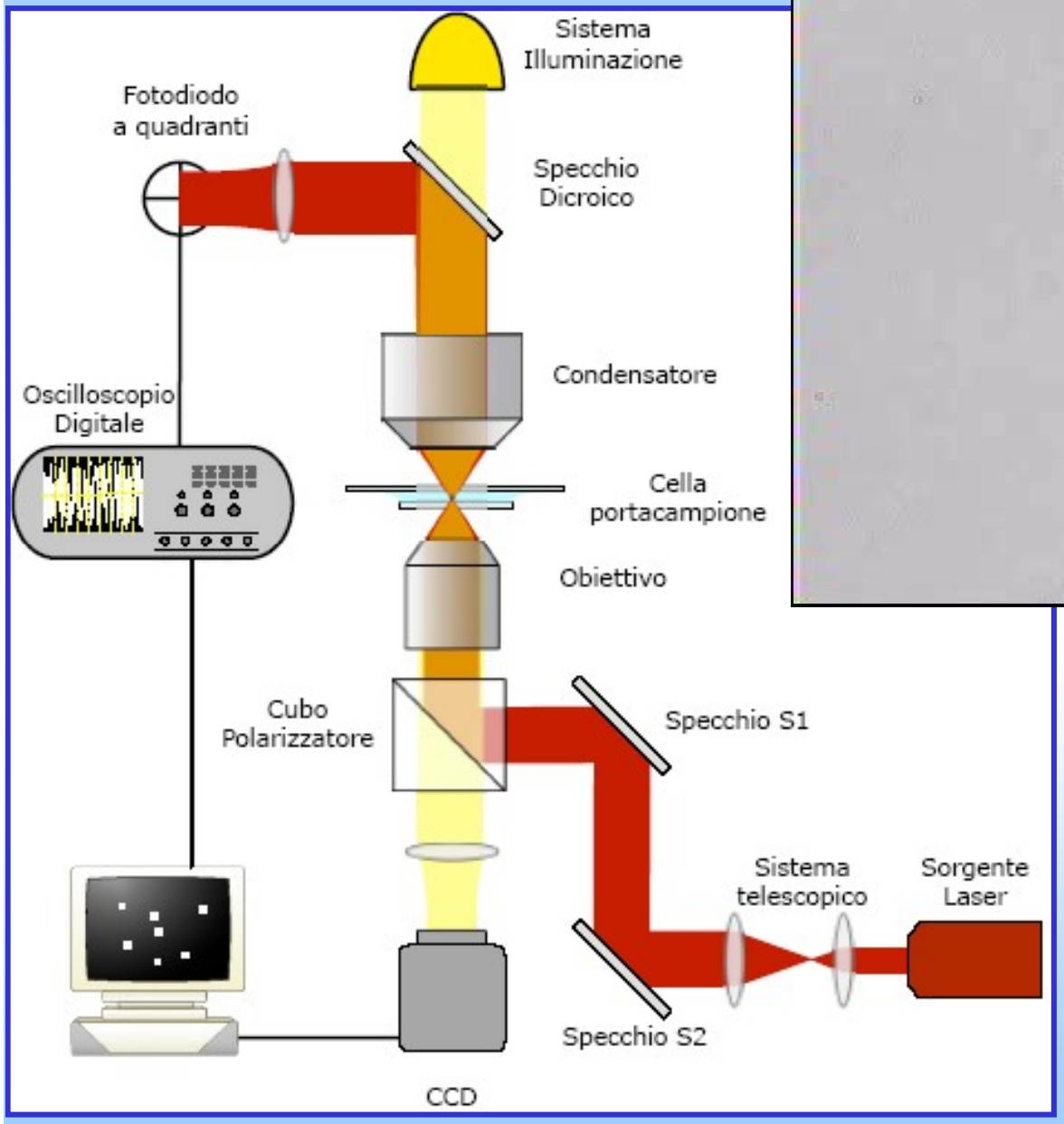
$$\vec{F} = -\frac{d\vec{P}}{dt}$$

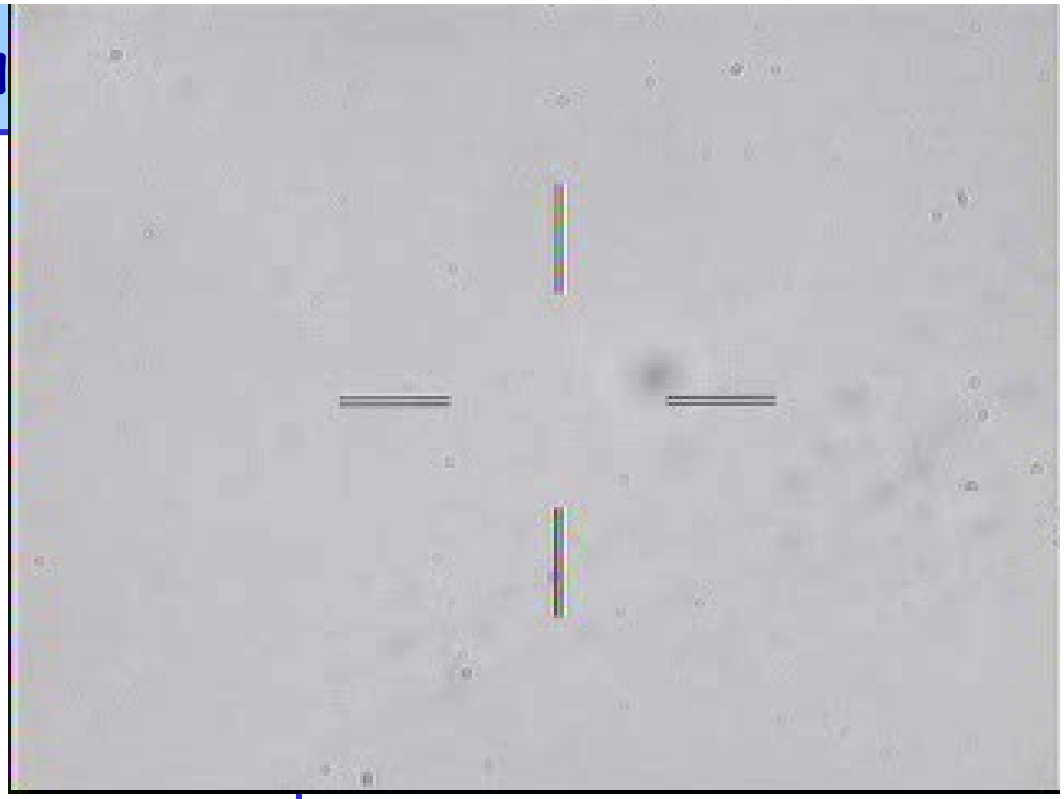


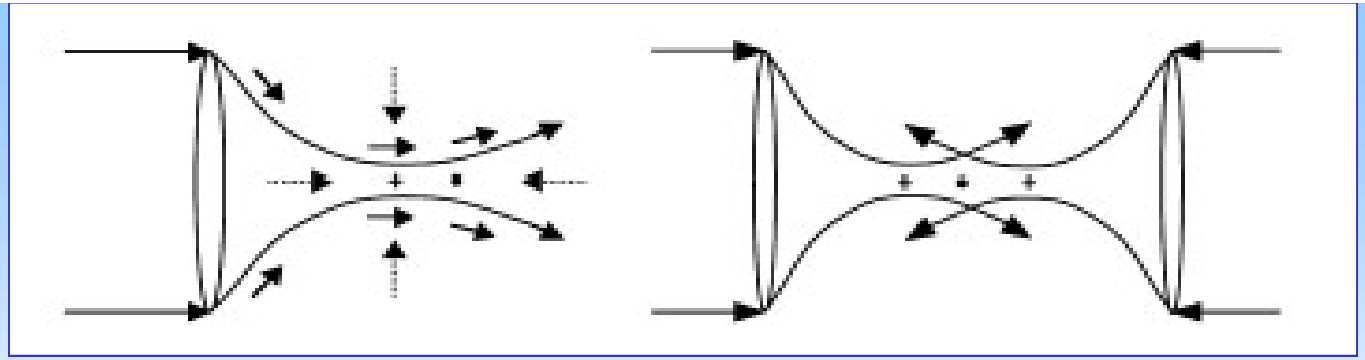
Elastic force

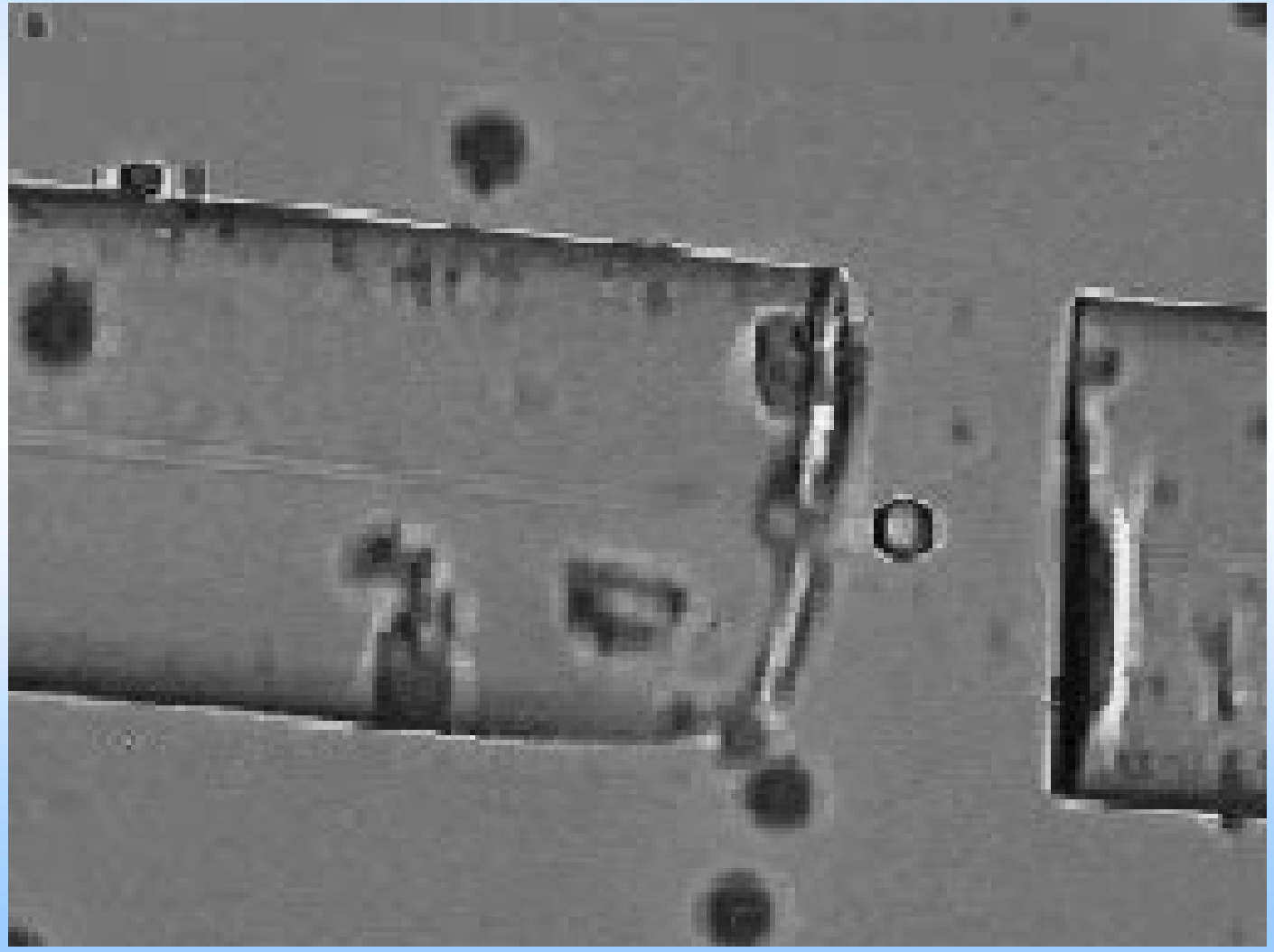
$$F_{z,grad} = -kz$$

Optical Tweezers setu







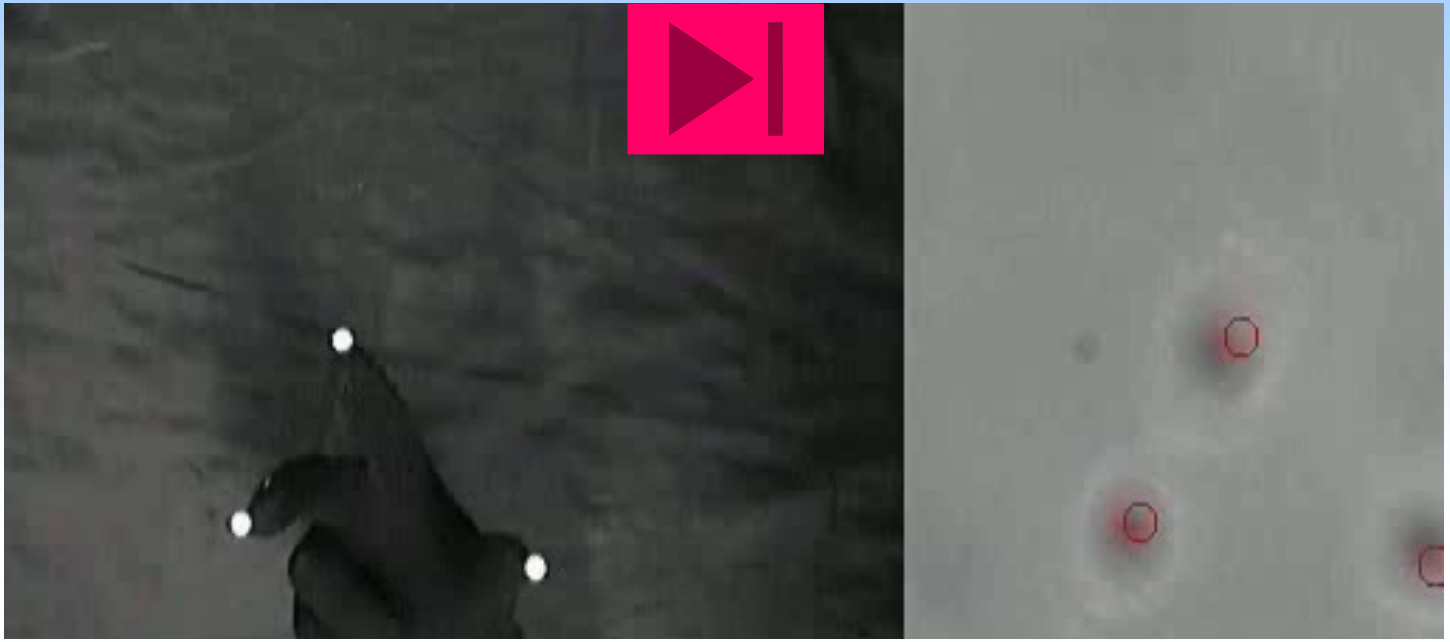


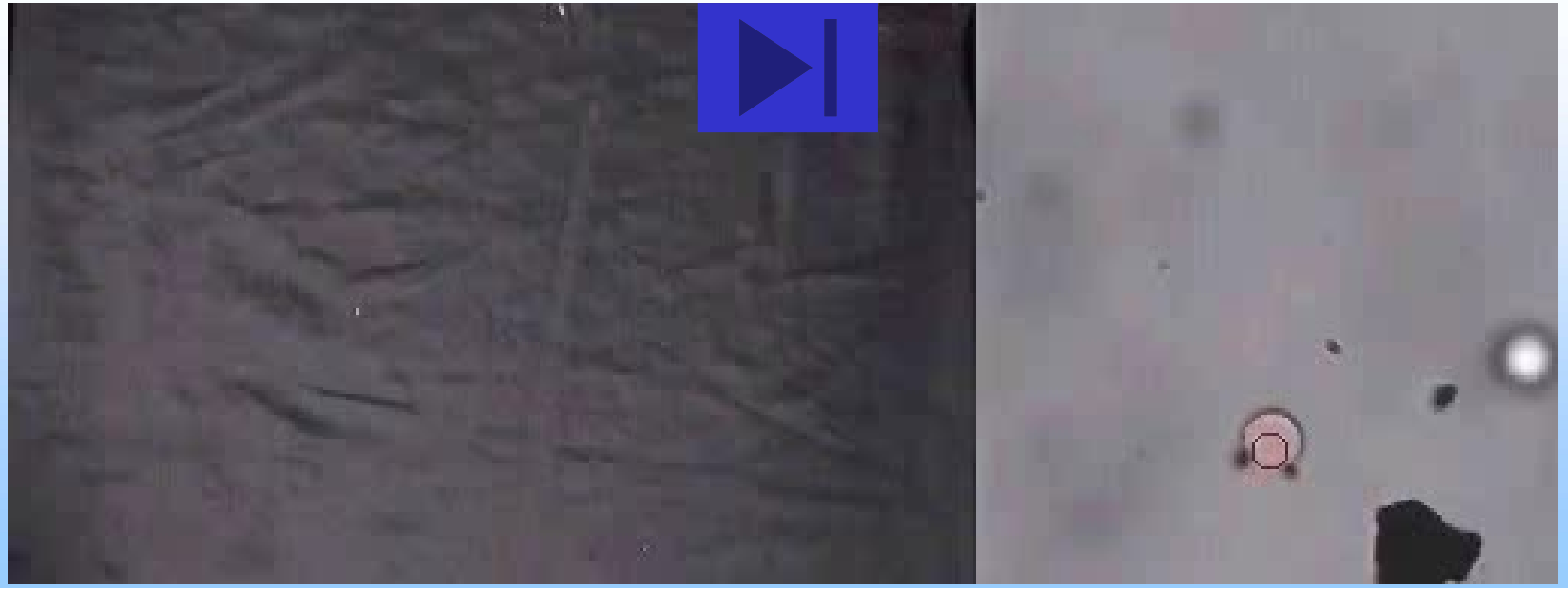
Scottisch dance

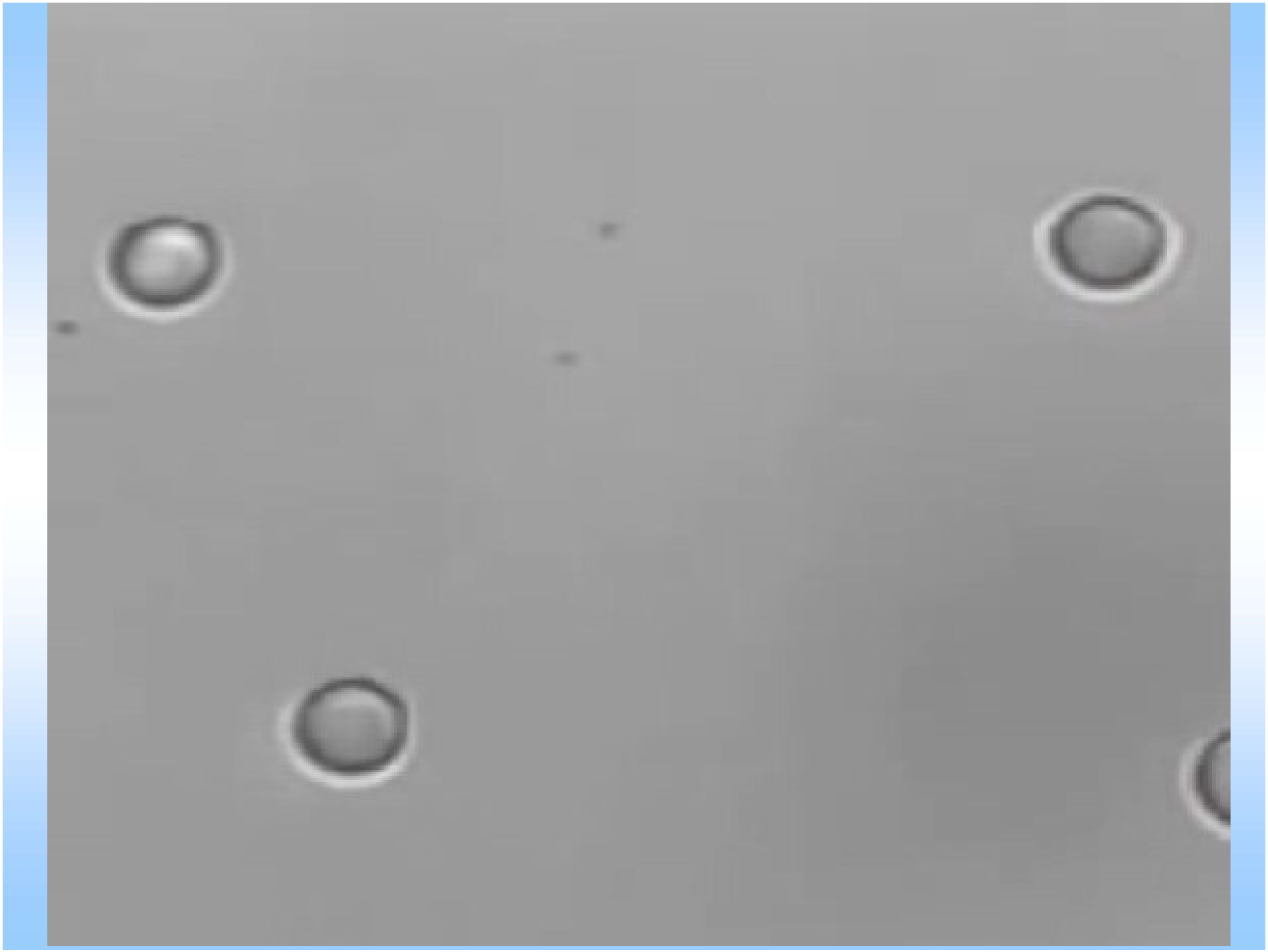
tetris

Traps movable by hands

by M. Padgett's group (Glasgow

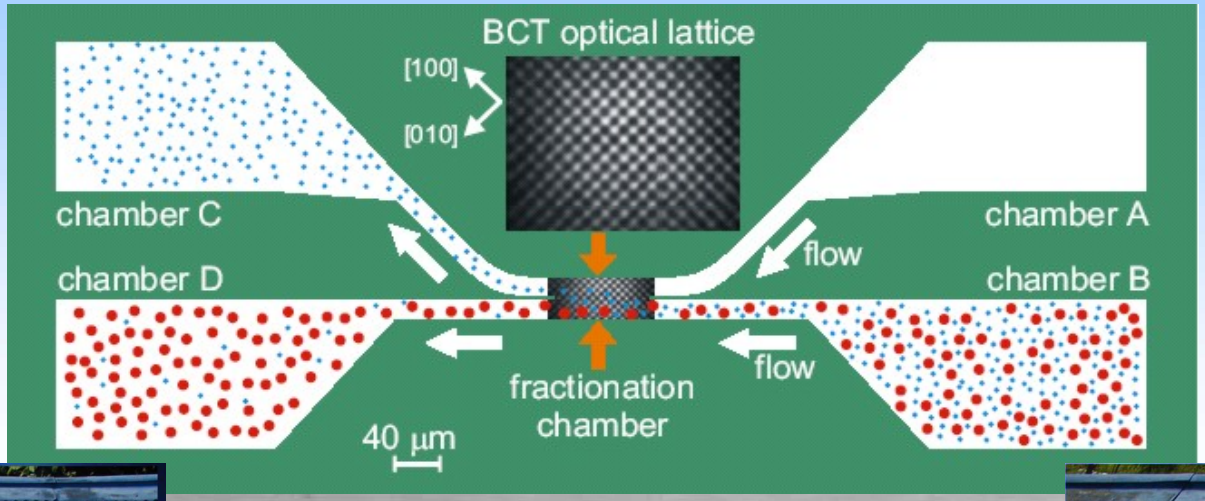


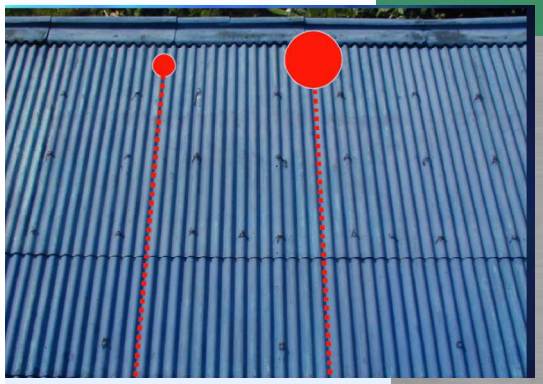


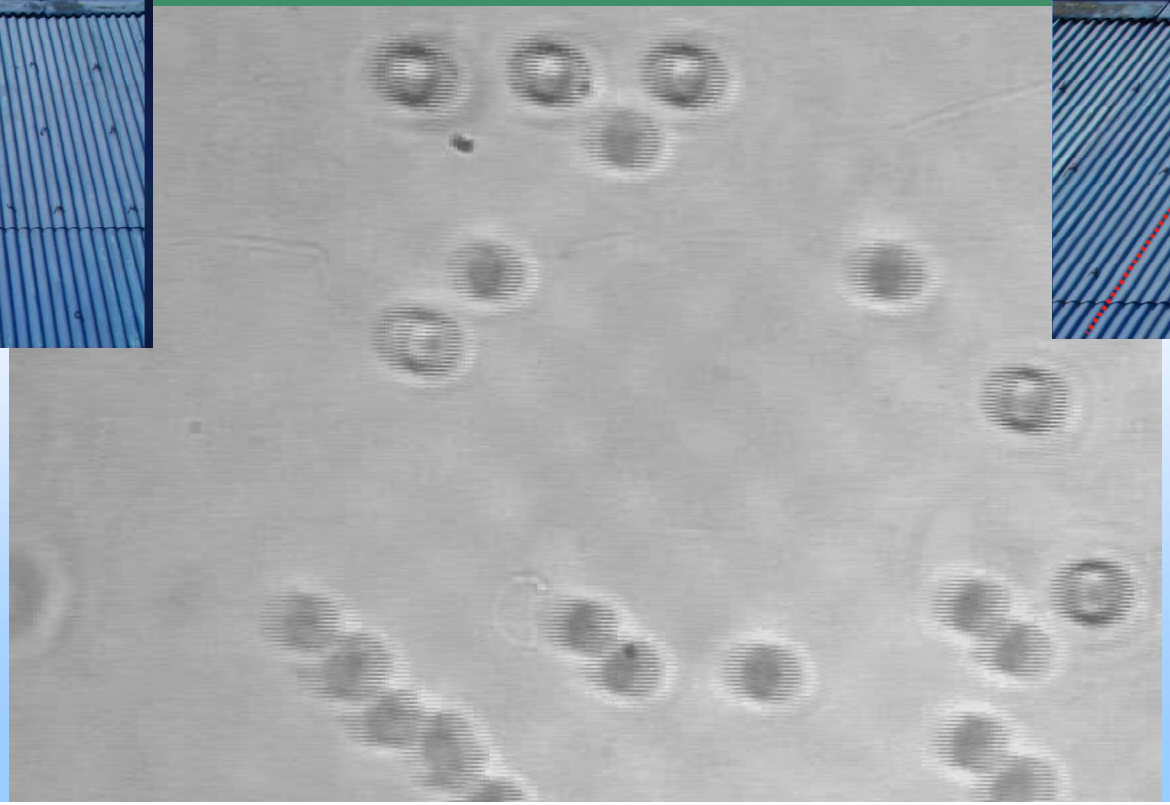


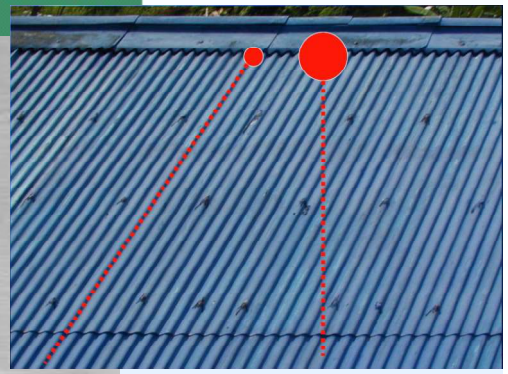
Sorting by optical traps

by K. Dholakia's group (St. Abdrews)

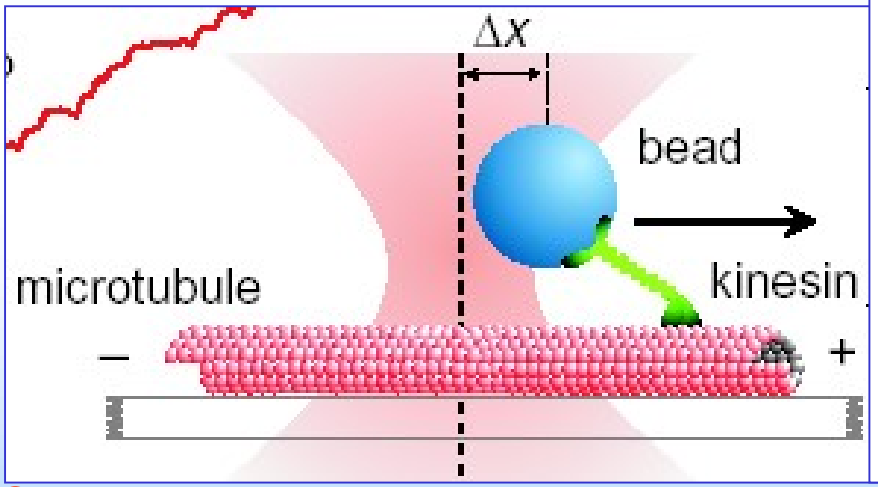


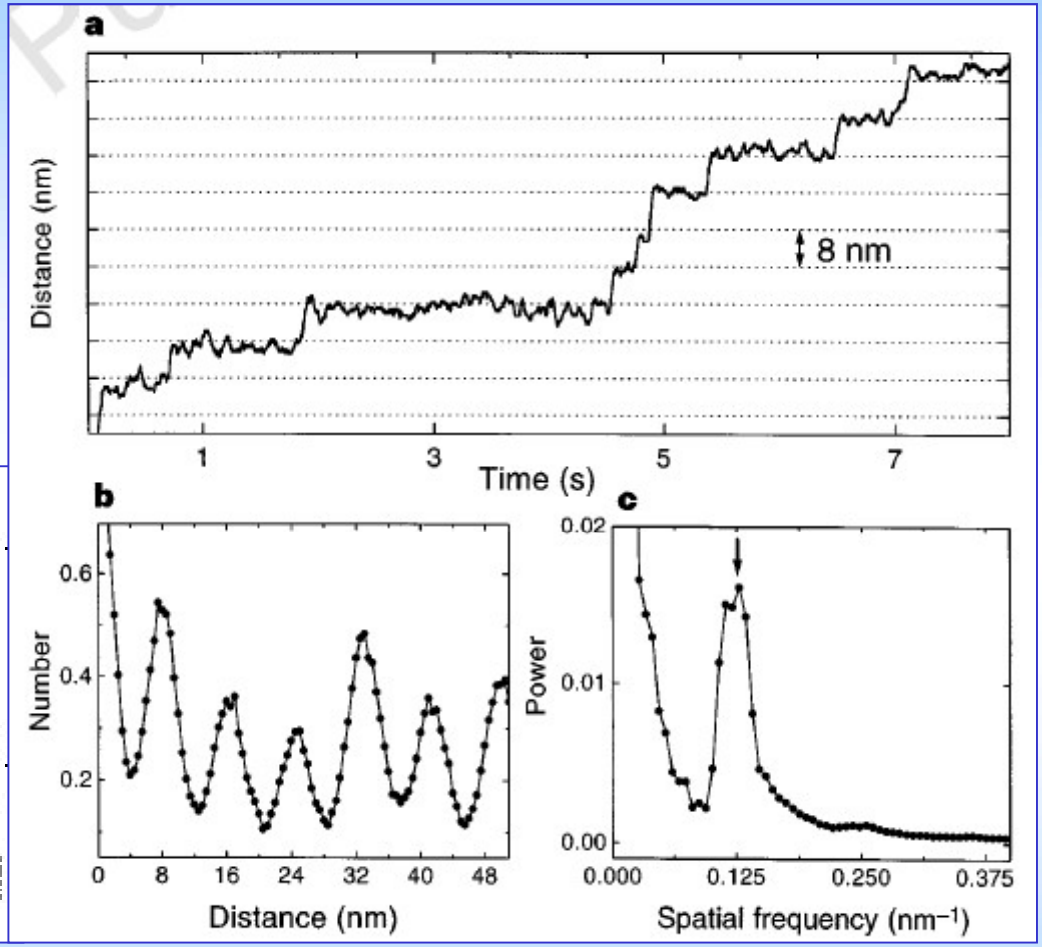






Molecular motors: KINESIN





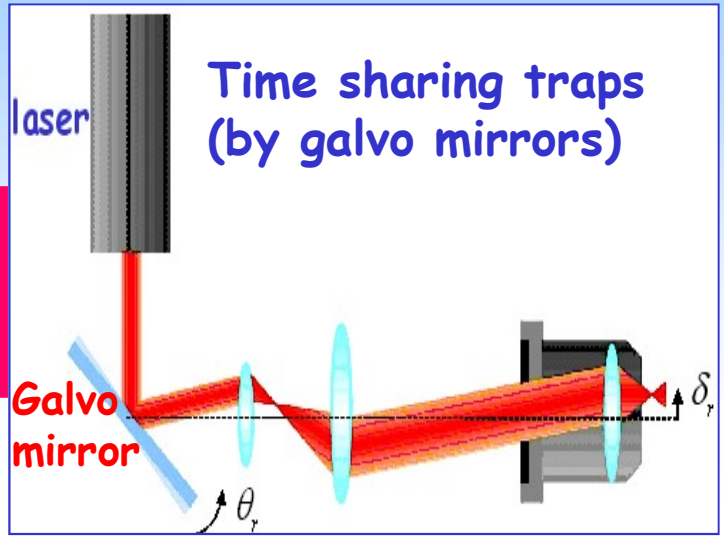
8 nm steps

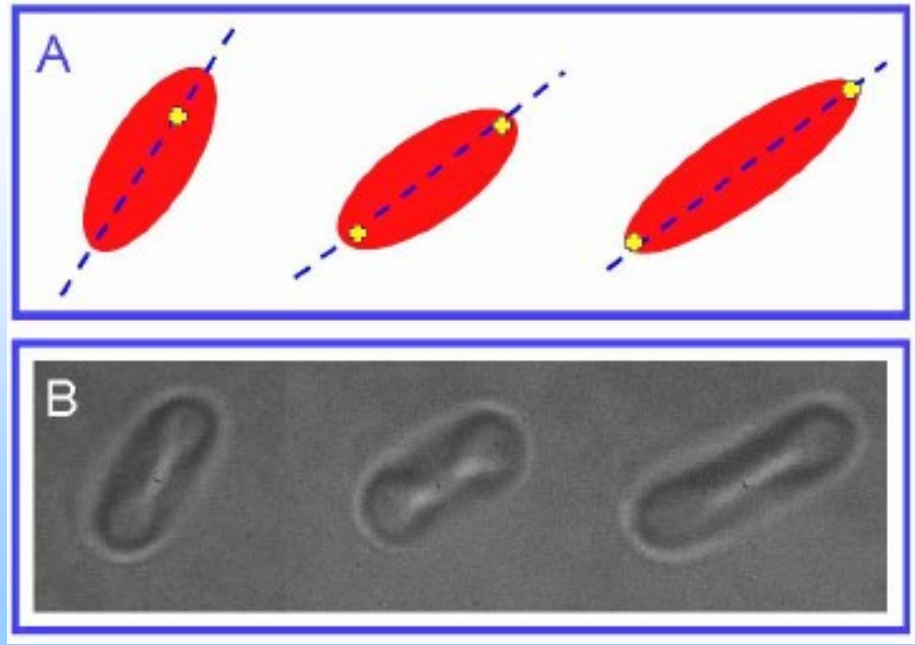
stall force ~6 pN

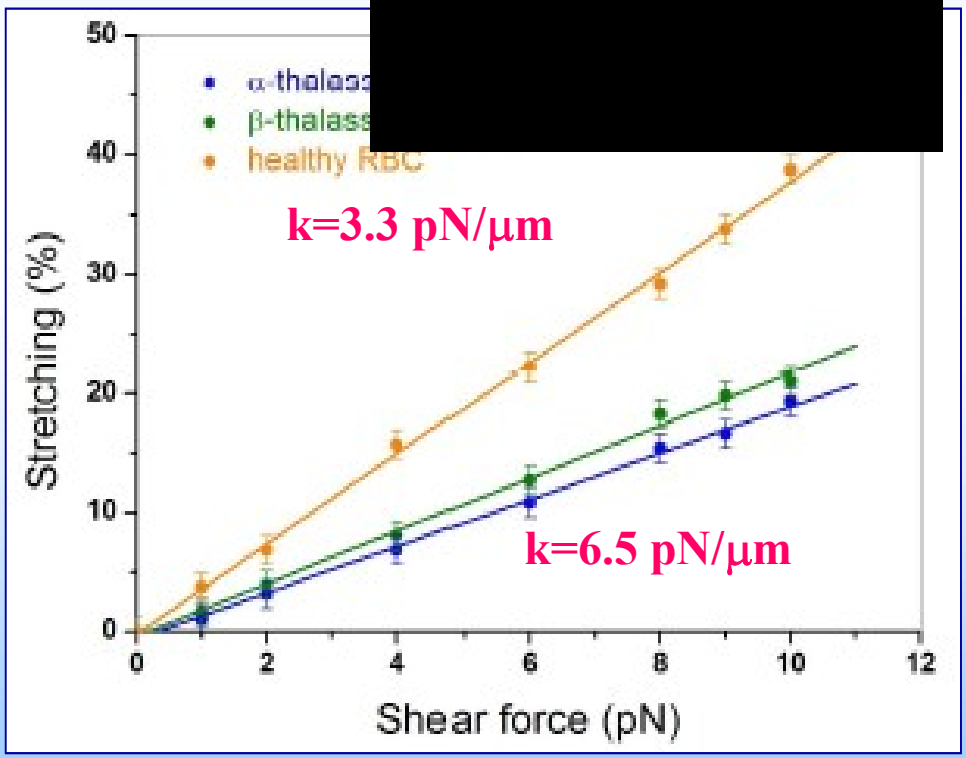
work=stepsize * maximal force = $48*10^{-21}$ J

~50% ATP

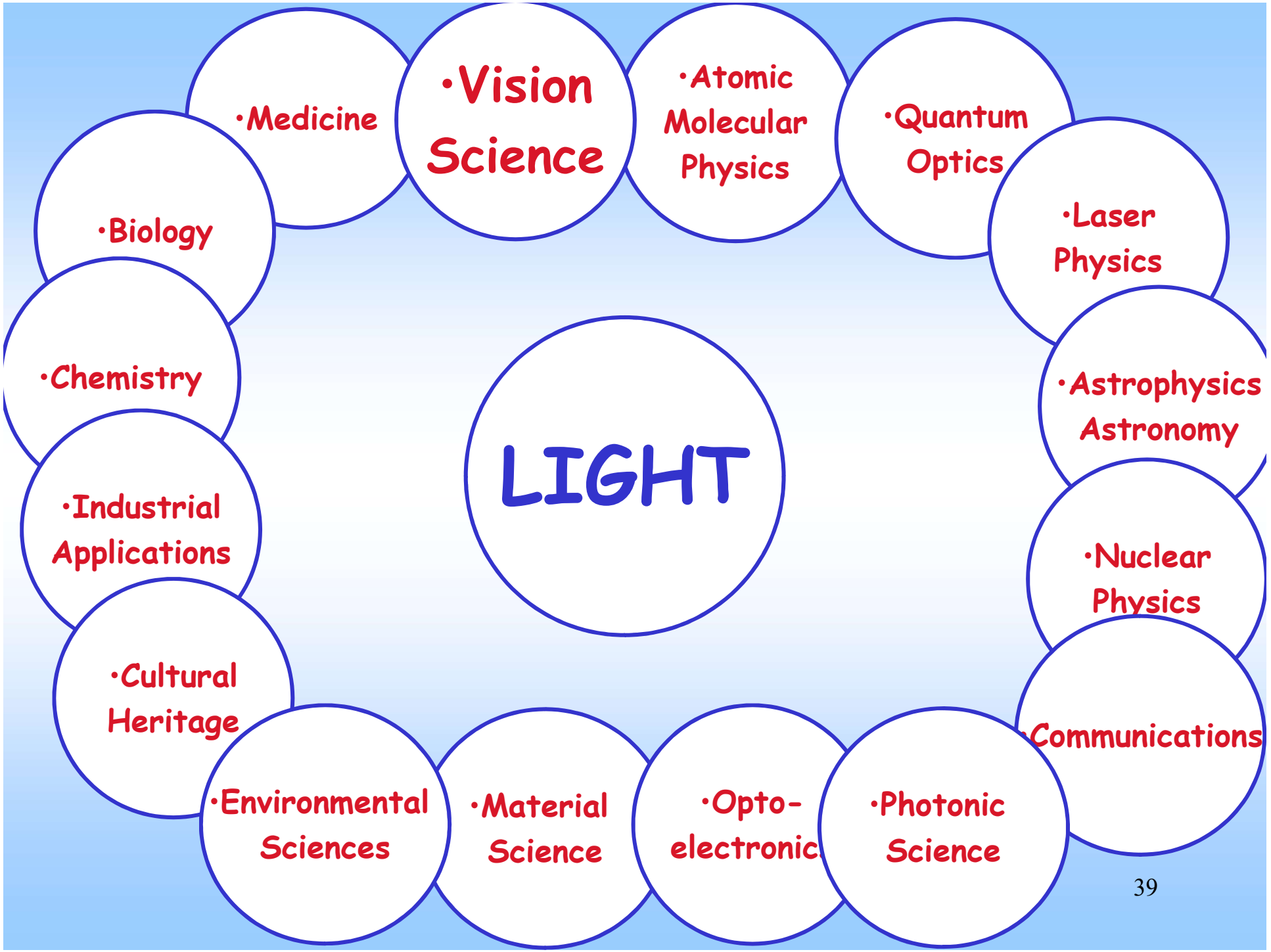
Pure optical Stretcher (red blood cells)







Rusciano et al, Biophy J submitted


LIGHT
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·Quantum Optics
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·Nuclear Physics
·Communications
·Photonic Science
·Opto-electronic
·Material Science
·Environmental Sciences
·Cultural Heritage
·Industrial Applications
·Chemistry
·Biology

All Nobel Laureates in Physics (1997-2017)

1997

S. Chu, C. Cohen-Tannoudji, William D. Phillips

"for development of methods to cool and trap atoms with laser light"

2001

Eric A. Cornell, Wolfgang Ketterle and Carl E. Wieman

"for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates"

2005

·R. J. Glauber, J.L. Hall, T.W. Hansch

"for his contribution to the quantum theory of optical coherence for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique"

2009

·C.C. Kao

"for groundbreaking achievements concerning the transmission of light in fibers for optical communication"

2012

S. Haroche, D.J.Wineland

"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems"

2014

I. Akasaki, H. Amano, S. Nakamura

"for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"

2014 (Chemistry)

E. Betzig, S.W. Hell, W.E. Moerner

"for the development of super-resolved fluorescence microscopy"

2017

R. Weiss, B. C. Barish and K. S. Thorne

"for decisive contributions to the LIGO detector and the observation of gravitational waves"

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Illuminate your planet.
WHAT WOULD BE DARKNESS WITHOUT LIGHT?
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LIGHT IS EVERYTHING WE SEE
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International Year of Light
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INTERNATIONAL YEAR OF LIGHT
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2015
international year of light
International Year of Light 2015
International Year of Light 2015
A Hug from our oldest friend
INTERNATIONAL YEAR OF LIGHT 2015
INTERNATIONAL YEAR OF LIGHT
2015