

4. Optics review

4.1 Ray Optics

Light travels in different optical media in accordance with a set of geometrical rules

4.2 Classical (Wave) Description

Light is an EM wave

4.3 Quantum (Particle) Description

Localized, massless quanta of energy – photons

4.4 Wave / Particle Duality

Appropriate description depends on experimental device examining light

4.3 Quantum Description of Light

1. Historical perspective

- **Max Planck (1858-1947)**

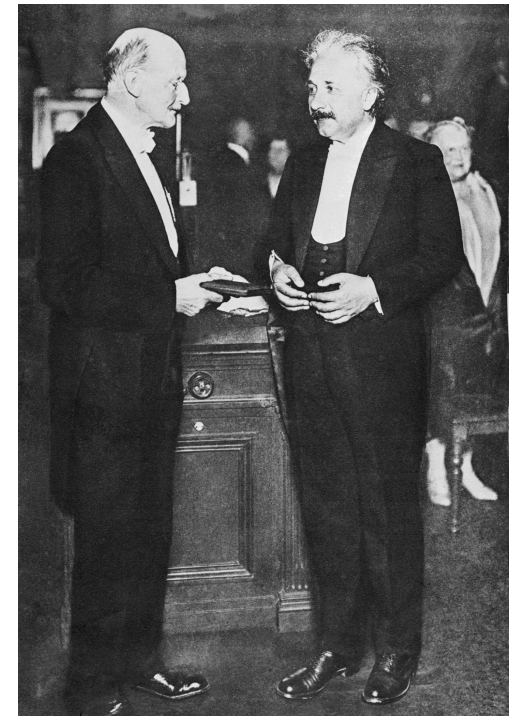
1900: Black-body radiation law

Central assumption:

Electromagnetic energy can only be emitted in quantized form (“quanta”), i.e. energy can only be a multiple of an elementary unit $E=h\nu$ with h = “Planck” constant, ν = frequency

- **Albert Einstein (1879-1955)**

1905: Proof of the particle-like behavior of light comes from the photoelectric effect experiment



Max Planck presents **Albert Einstein** with the Max-Planck medal, 1929

Quantum Description of Light

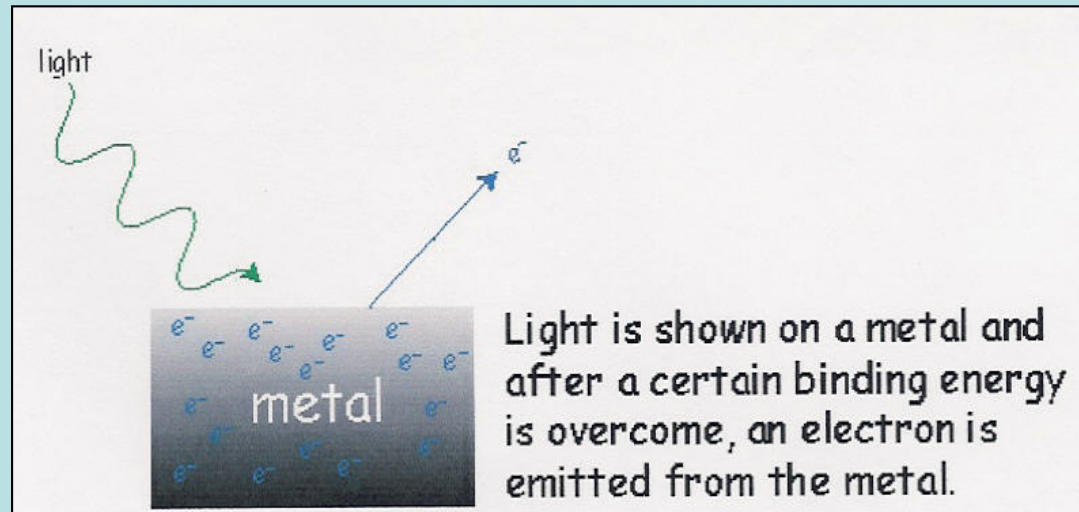
2. The Photoelectric effect

- *1888 Hallwachs and Hertz:*

Irradiation of negatively charged metal plate with UV light
=> emission of electrons leading electrical discharge

- *Most important feature of the photoelectric effect:*

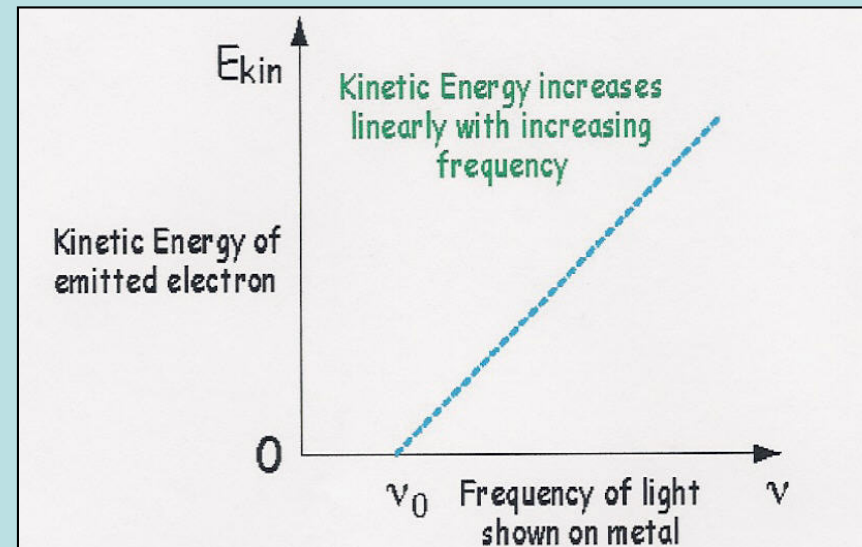
an electron is emitted
from the metal with
a specific kinetic energy
(speed)



Quantum Description of Light

2. The Photoelectric effect - Observations

- Kinetic energy do not change with light intensity but changes with the frequency of the incident light
- there is a critical frequency below which no electrons are emitted
- Slope of the line is Planck's constant



Quantum Description of Light

2. Photoelectric effect – Interpretation

- 1905 by A. Einstein (Nobelprize 1921)
- We can write an equation for the kinetic energy of the emitted electron, where h is the Planck constant:

Kinetic energy
of the electron
emitted from the metal $\Rightarrow E_{\text{kin}} = h\nu - h\nu_0$

Energy
of the photon $\nearrow$

Energy needed
to eject an electron
from the metal
("work function of a metal") $\nwarrow$

Quantum Description of Light

Photon Properties:

- Energy $E_{\text{ph}} = h \cdot \nu = \frac{h \cdot c}{\lambda}$

- Momentum: $p_{\text{ph}} = \frac{E}{c} = \frac{h}{\lambda}$

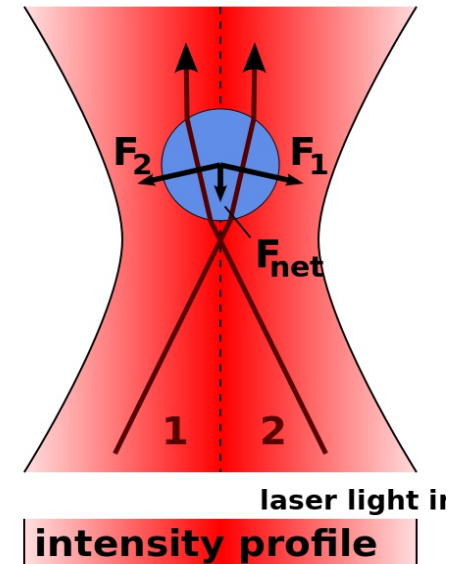
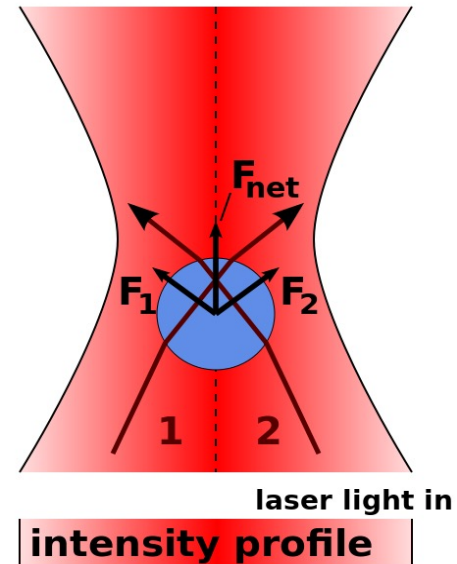
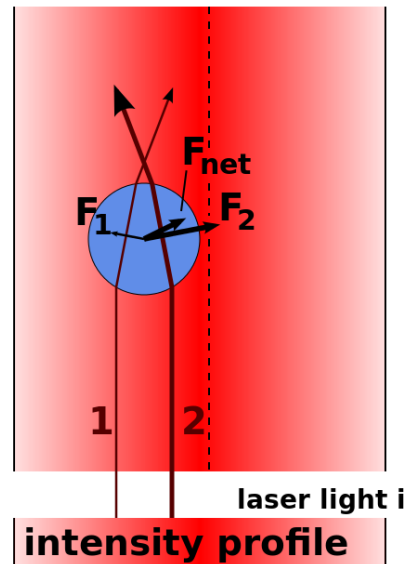
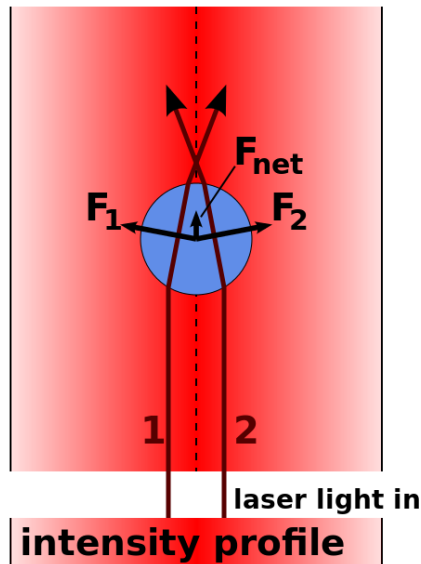
Derives from:

$$E^2 = p^2 c^2 + m^2 c^4$$

- Rest mass: $m_{0,\text{ph}} = 0$

with $h = 6.6261965 \times 10^{-34} \text{ Js}$, $c = 2.9979250 \times 10^8 \text{ m/s}$

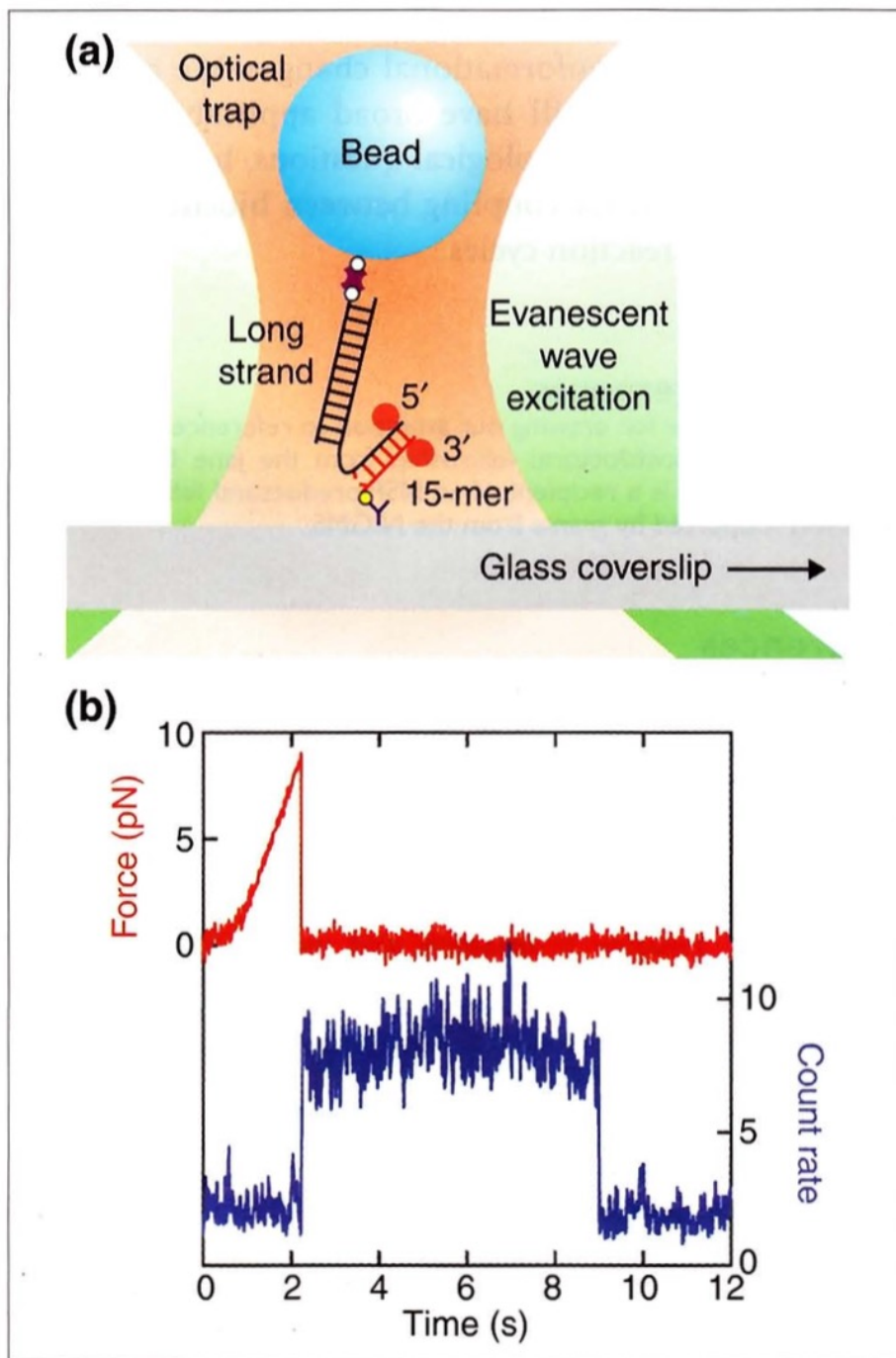
Optical tweezers



Source: R. Koebler

Lateral positioning

Longitudinal positioning



le) description of light

A combined optical trapping and fluorescence experiment to unzip DNA. **(a)** A cartoon of the simplified experimental geometry (not to scale). A bead was tethered by a digoxigenin-based linkage (blue and yellow) to the coverglass surface through a DNA molecule, consisting of a long segment (black) joined to a shorter 15 base-pair strand that forms a duplex region (red). The bead (blue) was captured by the optical trap and force was applied to unzip the short duplex. Tetramethylrhodamine (TAMRA) dyes attached at the ends of the DNA strands provide a fluorescence signal (red dots). **(b)** Simultaneous records of force (red trace) and fluorescence, measured as the photon count rate (blue trace). Rupture occurred at $t \approx 2$ sec at an unzipping force of 9 pN. The dye unquenched at the point of rupture, and later bleached at $t \approx 9$ sec. See text for further details.

Research article

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Combined optical trapping and single-molecule fluorescence

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