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

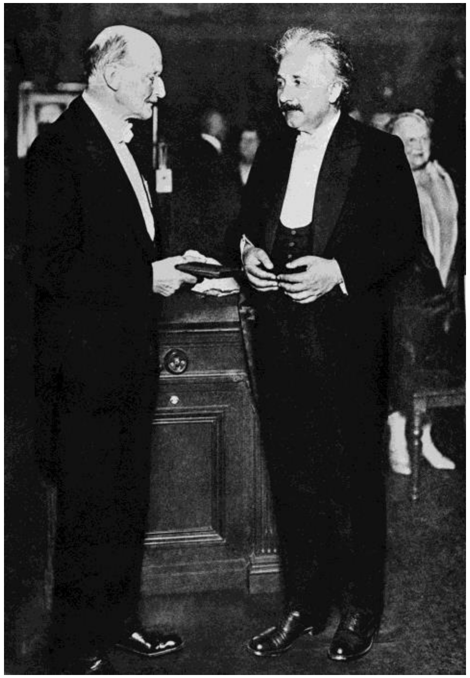
Appropriate description depends on experimental device examining light

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 cames from the photoelectric effect experiment

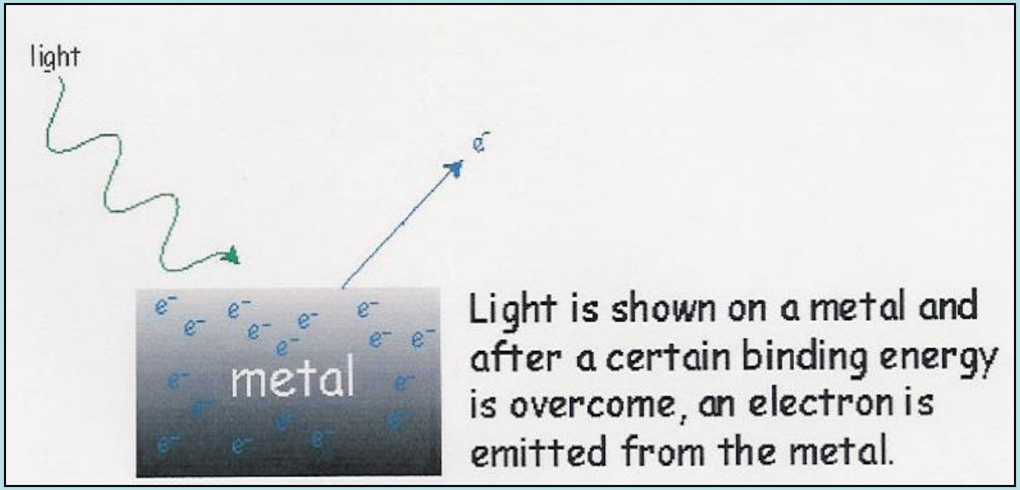


Max Planck presents **Albert Einstein** with the Max-Planck medal, 1929

Quantum Description of Light

2. The Photoelectric effect

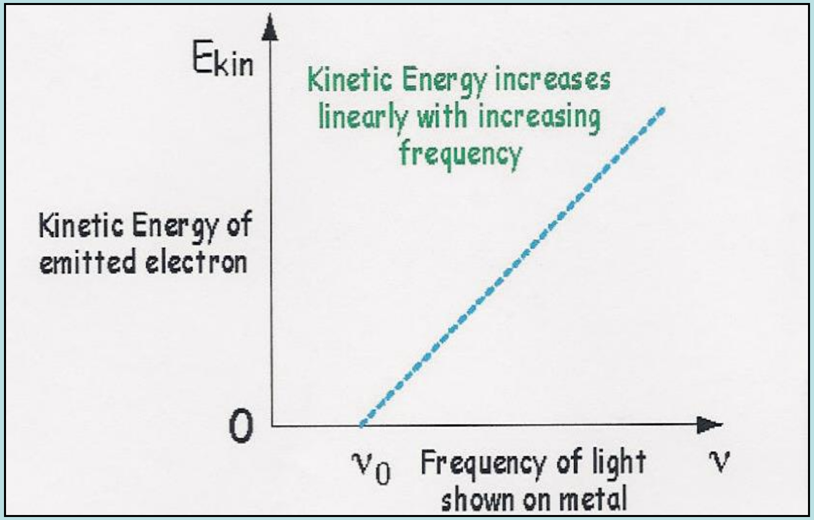
- *1888 Hallwachs and Hertz:*
  Irradiation of negatively charged metal plate with UV light
  => emission of electrons leading electrical discharge
- *Most important feature of the photoelectric effect:*
  an electron is emitted from the metal with a specific kinetic energy (speed)



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 ➡ $E_{kin} = h\nu - h\nu_0$

$h\nu$: Energy of the photon

$h\nu_0$: Energy needed to **eject** an electron from the metal ("work function of a metal")

Quantum Description of Light

Photon Properties:

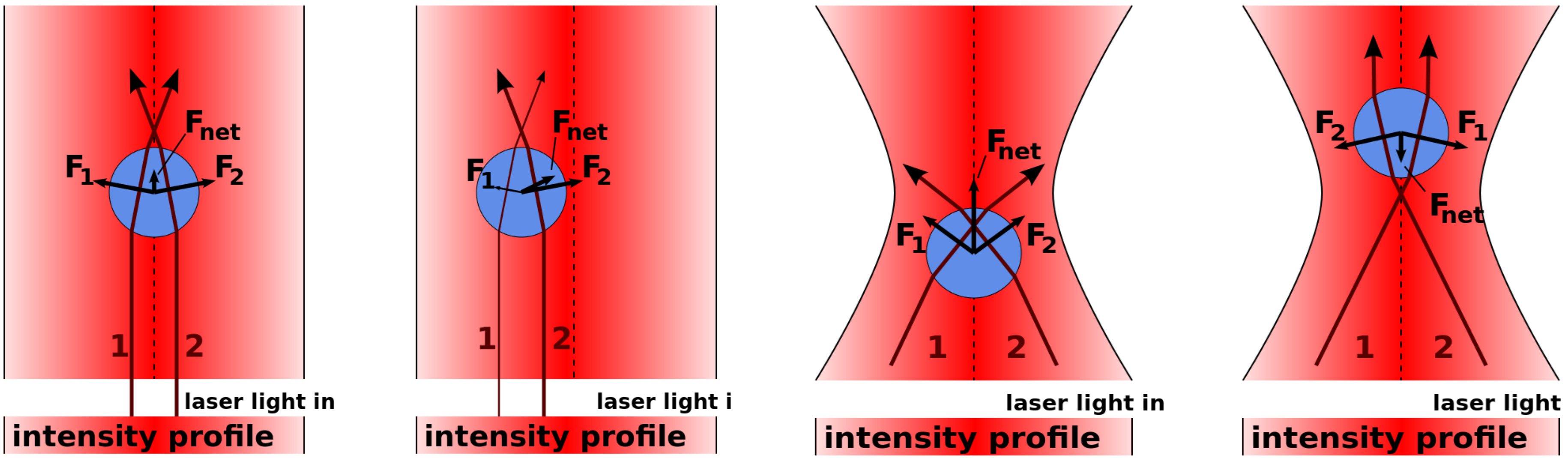
- Energy $E_{ph} = h \cdot \nu = \frac{h \cdot c}{\lambda}$
- Momentum: $p_{ph} = \frac{E}{c} = \frac{h}{\lambda}$
- Rest mass: $m_{0,ph} = 0$

Derives from:

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

with h = 6.6261965 x 10^{-34} Js, c = 2.9979250 x 10^{8} m/s

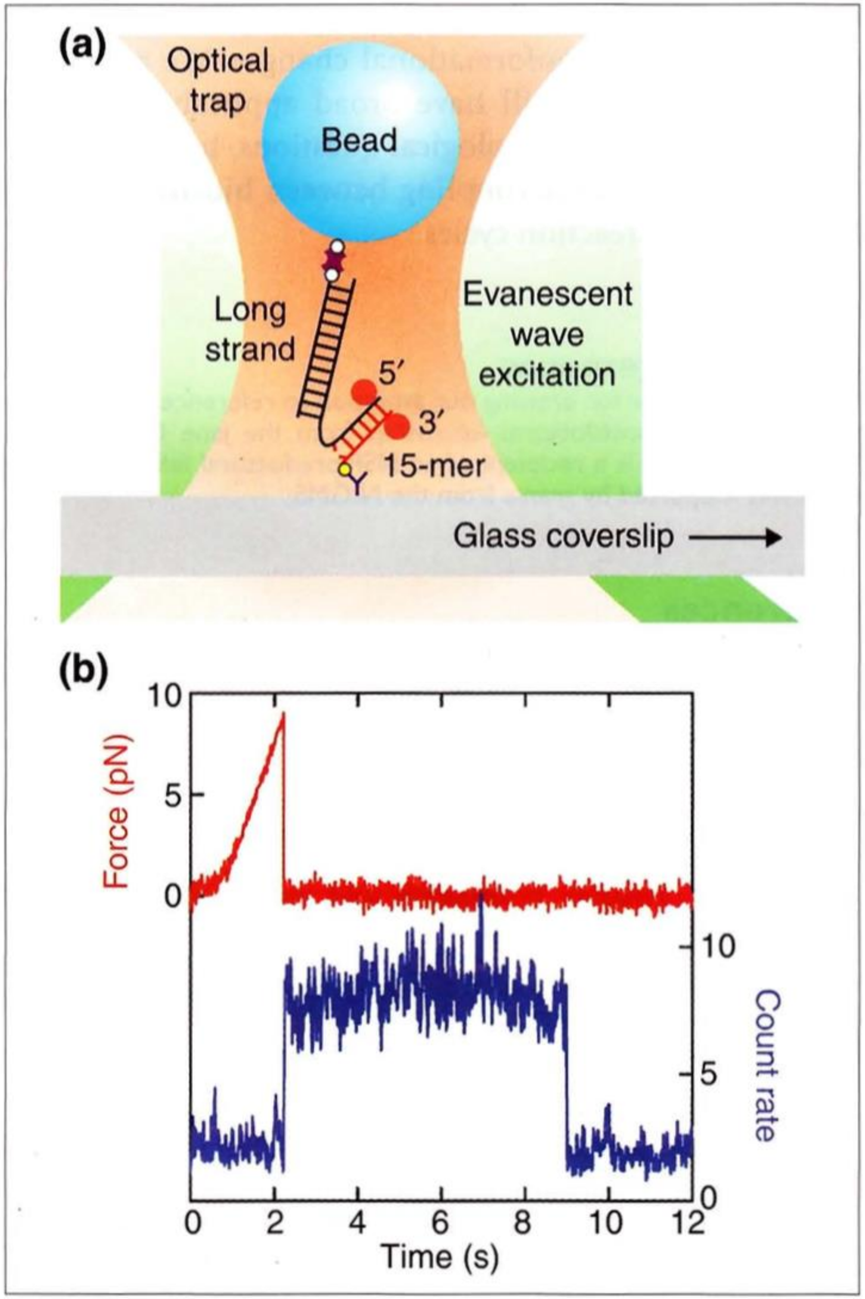
Optical tweezers



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 digoxygenin-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 **Open Access**

Combined optical trapping and single-molecule fluorescence

Matthew J Lang*†‡, Polly M Fordyce§ and Steven M Block*†

Addresses: *Department of Biological Sciences, †Department of Applied Physics, and §Department of Physics, Stanford University, Stanford, CA 94305-5020, USA. ‡Current address: Biological Engineering Division and Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

Correspondence: Steven M Block. E-mail: sblock@stanford.edu

Published: 24 February 2003

Journal of Biology 2003, **2:**6

Received: 24 December 2002
Revised: 3 February 2003
Accepted: 4 February 2003