Biophysics

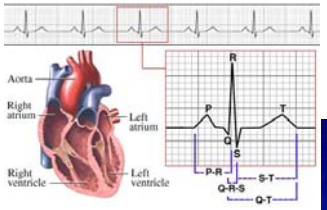
Gabriella Csik

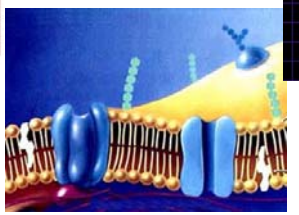
csik.gabriella@med.semmelweis-univ.hu

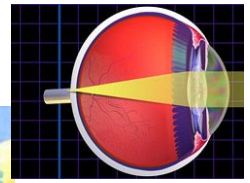
What is the subject of biophysics?

Physical aspects/background of biological processes

E.g., Electrophysiology of heart, structure and functioning of membranes, sensory function stb.



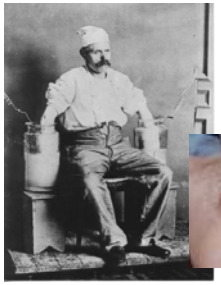


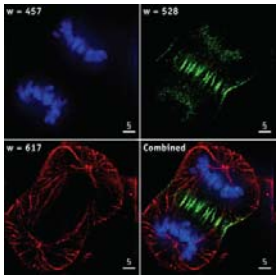


What is the subject of biophysics?

Physical methods in biology and medicine

E.g., ECG, X-ray diagnostics, microscopy….





Radiation

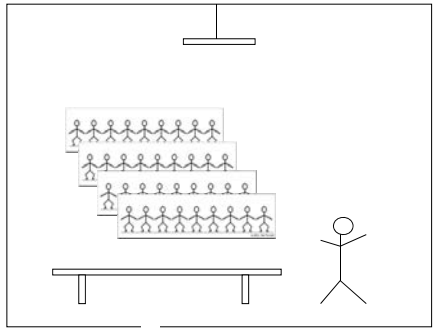
Examples around us

sound

light

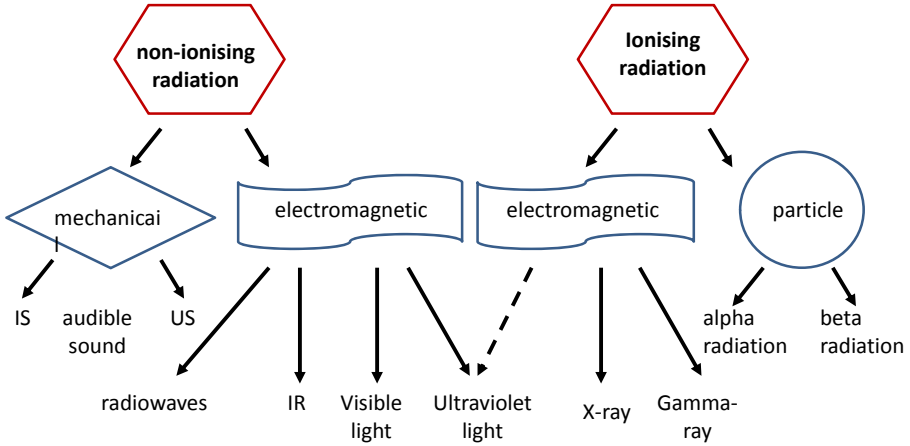
radiowaves

nuclear radiation



Radiation: emission and propagation of energy

Radiation



Nature of light

Wave?

Christiaan Huygens

(1629 - 1695)

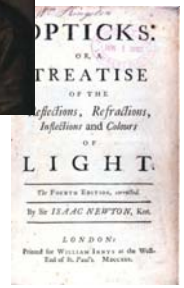
Traité de la lumière
1690

Particle?

Isaac Newton

(1642 - 1727)

Opticks
1704



Natur of waves

periodic disturbance in space and time, possibly transferring energy to or through a spacetime region.

Waves differ in
- type of energy
- amplitude
- mechanism of propagation

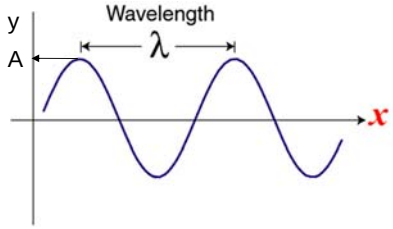
Characteristic values

Period in space– *wavelength*

λ [m] or [nm]

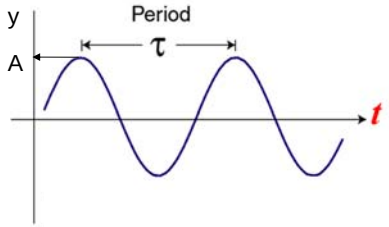
Highest displacement – *amplitude*

$$E \sim A^2$$

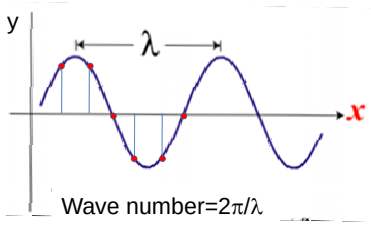


Period in time
- *period*
- *frequency*

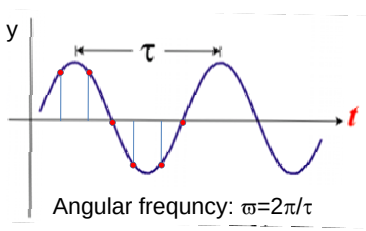
$$f = \frac{1}{\tau}\left[\frac{1}{s}\right]$$



Phase: the initial angle of a sinusoidal function at its origin



Wave number=$2\pi/\lambda$



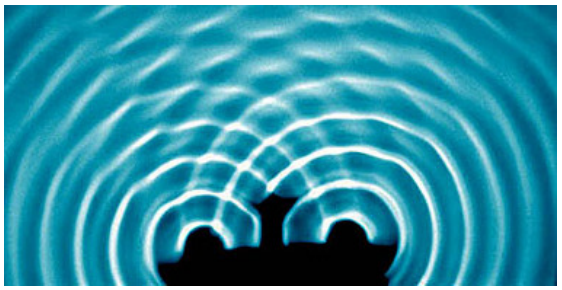
Angular frequncy: $\varpi=2\pi/\tau$

$\phi(x)=kx+\phi_o$ $\phi(t)=\varpi t+\phi_o$

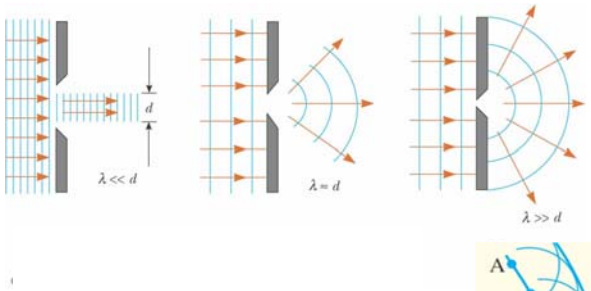
$\phi=\varpi t+kx+\phi_o$

Indication of wave nature

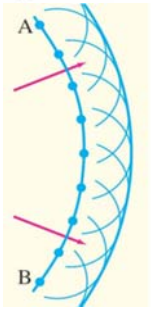
- diffraction
- superposition/interference
- polarization



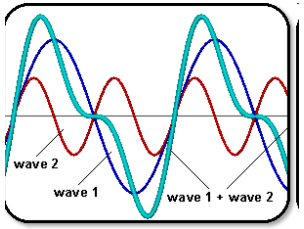
Diffraction



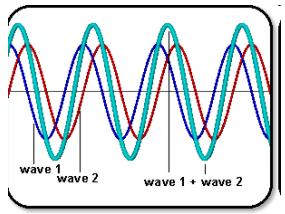
Huygens-principle: every point on a propagating wavefront serves as the source of spherical secondary wavelets, such that the wavefront at some later time is the envelope of these wavelets.



Superposition:

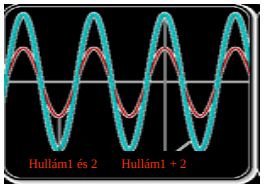


Un-equal frequencies



Equal frequencies

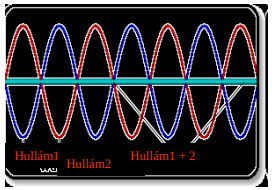
Interference: superposition of coherent waves



Similar phase

Constructive interference

$\Phi = 0^{\circ}$



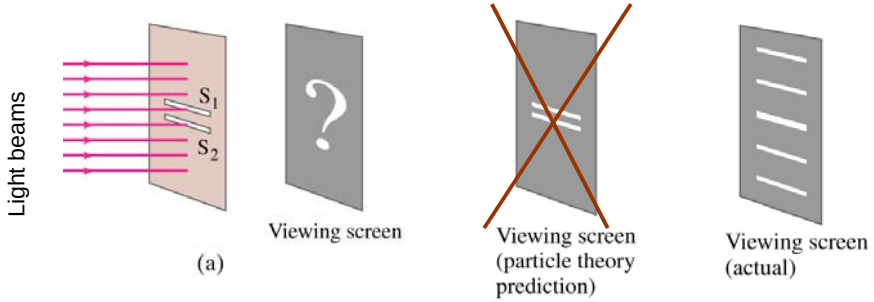
Opposite waves

Destructive interference

$\Phi = 180^{\circ}$

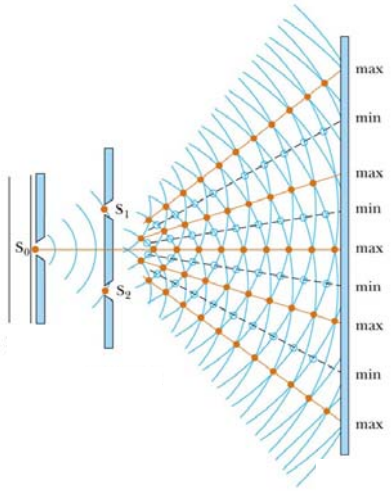
Thomas Young
(1773-1829)

Thomas Young's
double-slit experiment



Interpretation of Thomas Young's double-slit experiment

S_1 and S_2 slits are wave sources

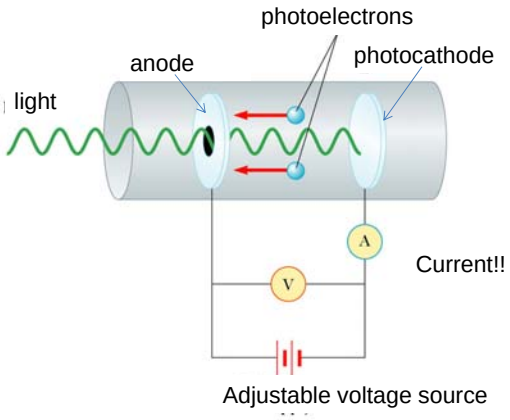


interference

Interference fringes on a screen

Photoelectric effect

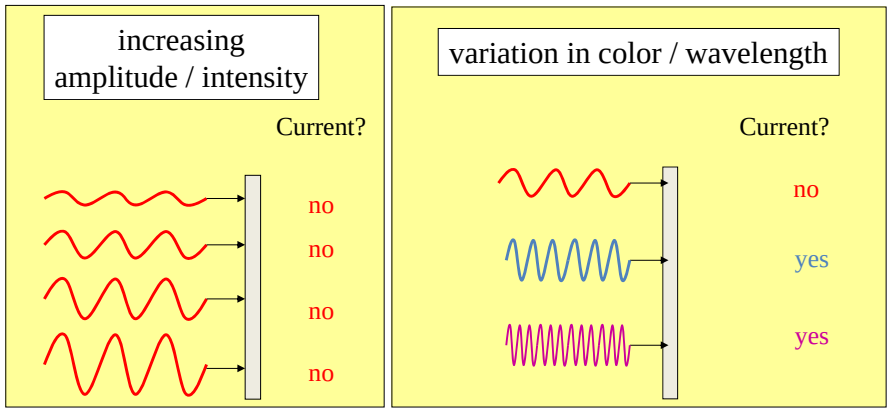
Heinrich Hertz
1887



Light irradiation

Similar color / wavelength

Similar amplitude



No current up to a critical value of frequency

Interpretation of photoelectric effect

- Based on the wave character it is not possible.

- Planck – foundation of quantum physics

$$E = hf$$

- Einstein's concept is based on the quantum theory

Max Planck

Albert Einstein

Nobel Prize in physics 1918

*"in recognition of the services he rendered to the advancement of Physics by his **discovery of energy quanta**".*

Nobel Prize in physics 1921

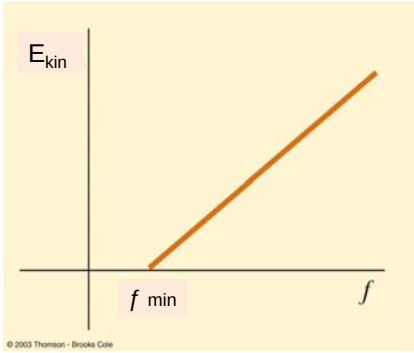
*for his services to Theoretical Physics, and especially for his **discovery of the law of the photoelectric effect**".*

Einstein interpretation

- Light consists of a finite number of energy quanta - photons
- The energy of photon: $E = hf$
- Photon can be absorbed or generated only as complete units.
- A photon transfer its energy to one electron if the photon energy is equal or higher than the work function (A).
- No interaction, if the photon energy is smaller than the work function.
- 1 photon– 1 electron interaction
- Kinetic energy of the electron: $E_{kin} = hf - A$

Einstein interpretation and the frequency limit

Kinetic energy of electron proportional to the frequency.



Intercept with the *x* axis is the smallest frequency inducing photoelectric effect

F_{min} depends on the cathode material:

$$A = hf_{min}$$

Dual nature of light

Particle – its energy is quantised; a photon is an elementary particle, the quantum of the electromagnetic interaction

Energy of photon: $E = hf = h\frac{c}{\lambda}$

Planck constant: $h = 6.62 \cdot 10^{-34}\ Joule \cdot s$

It has no resting mass

Propagates in vacuum

Calculation of photon energy

$$E = h \times \frac{c}{\lambda}$$

If λ=400 nm

$$E = 6.6\times10^{-34}\ Js \times \frac{3\times10^{8}\ \frac{m}{s}}{4\times10^{-7}\ m} = 4.95\times10^{-19}\ J$$

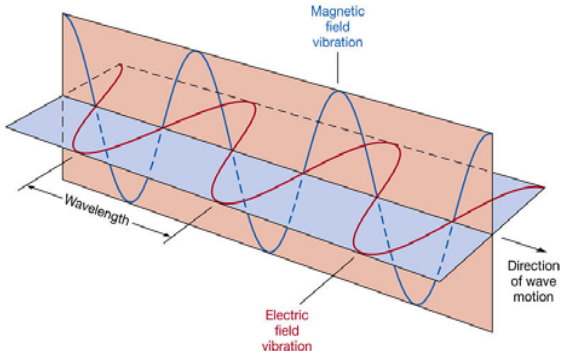
$$E = \frac{4.95\times10^{-19}\ J}{1.6\times10^{-19}} = 3.1eV$$

E_{VIS}= 1.6 – 3.1 *eV*

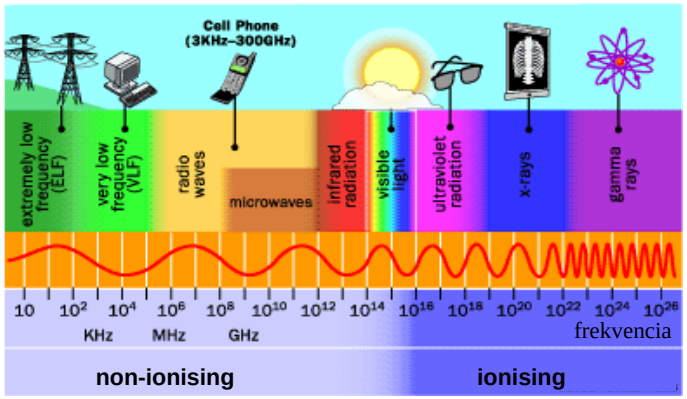
Dual nature of light

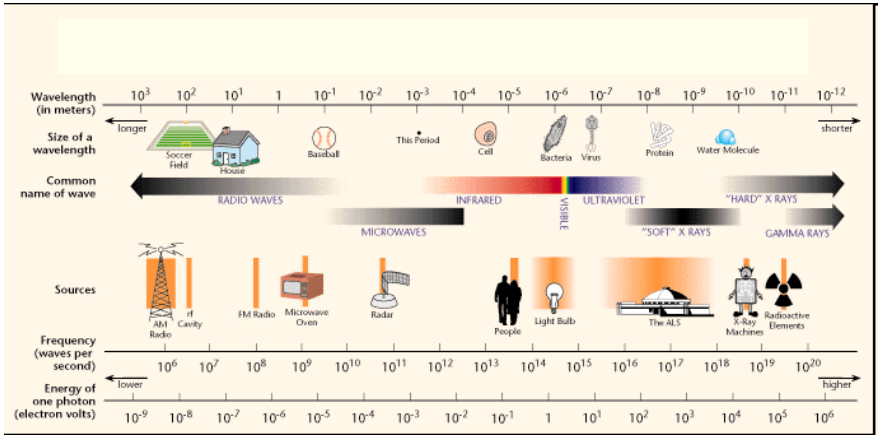
Wave – electric and magnetic fields vary sinusoidally

Electromagnetic radiation



Ranges of electromagnetic radiation





Optical range