

Biophysics

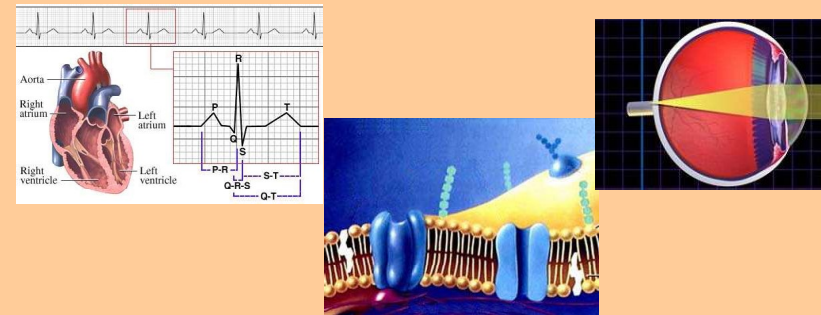
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What is the subject of biophysics?

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

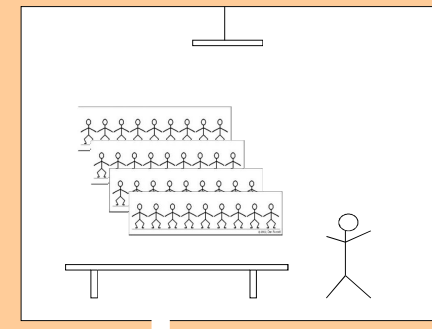
E.g., ECG, X-ray diagnostics, microscopy....



Radiation

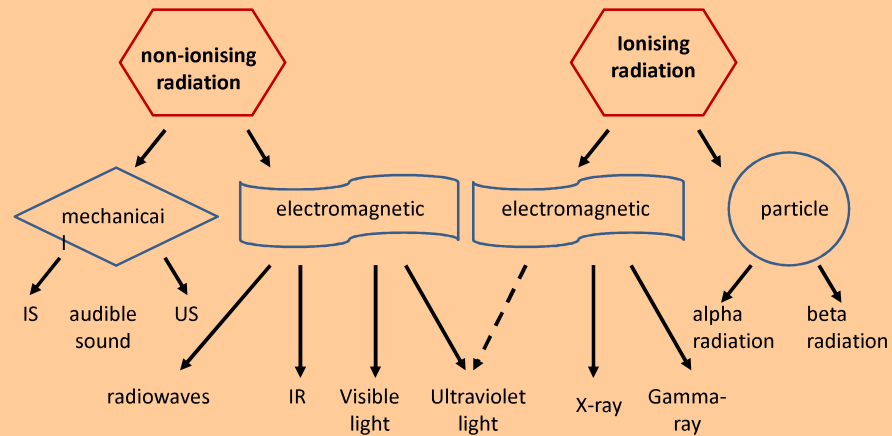
Examples around us

sound
light
radiowaves
nuclear radiation



Radiation: emission and propagation of energy

Radiation



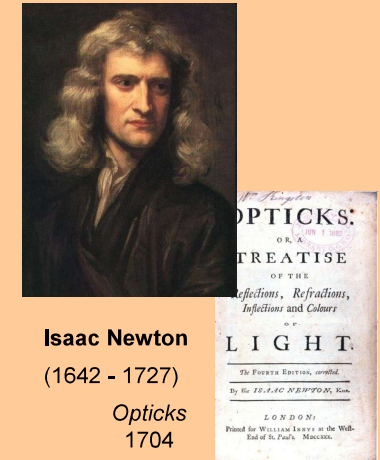
Nature of light

Wave?



Christiaan Huygens
(1629 - 1695)
Traité de la lumière
1690

Particle?



Isaac Newton
(1642 - 1727)
Opticks
1704

Nature 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]

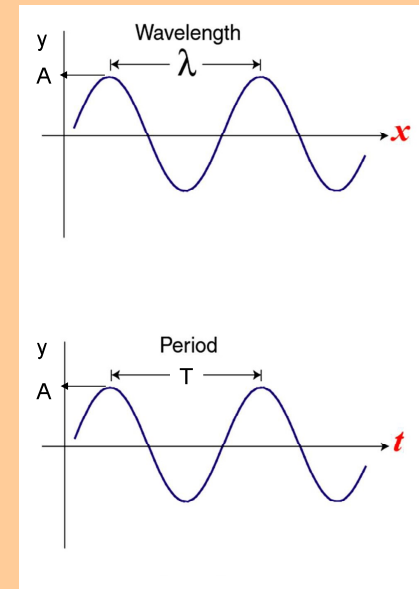
Highest displacement — *amplitude*

$$E \sim A^2$$

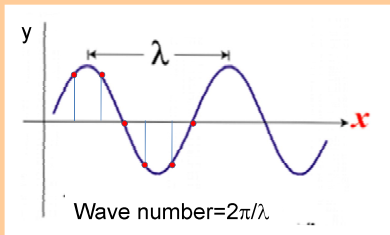
Period in time

— *period*
— *frequency*

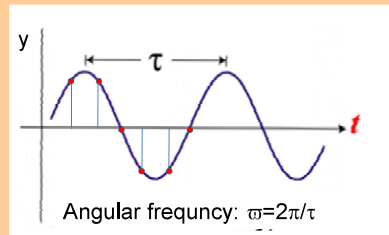
$$f = \frac{1}{T} \left[\frac{1}{s} \right]$$



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



$$\phi(x) = kx + \phi_0$$



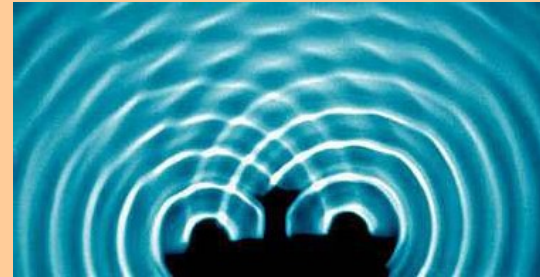
$$\phi(t) = \omega t + \phi_0$$

$$\phi = \omega t + kx + \phi_0$$

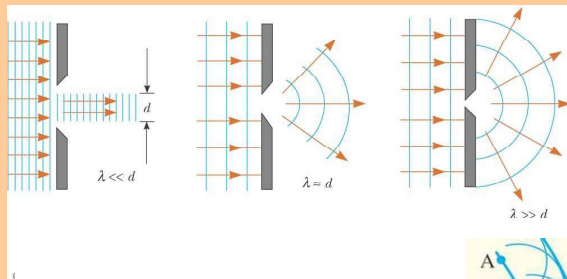
- fraction of the **wave** cycle that has elapsed relative to the origin.
- the *phase* difference is the fraction of a period between peaks.

Indication of wave nature

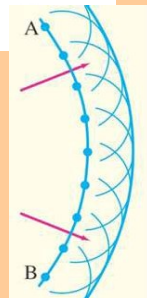
- diffraction
- superposition/interference
- polarization



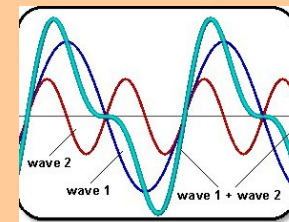
Diffraction



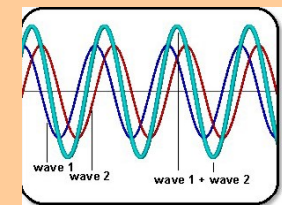
Huygens-principle: every point on a propagating wavefront serves as the source of spherical secondary wavelets, such that the wavefront at some later time is the envelope of these wavelets.



Superposition: The principle of superposition may be applied to waves whenever two (or more) waves traveling through the same medium at the same time. The net displacement of the medium at any point in space or time, is simply the sum of the individual wave displacements.

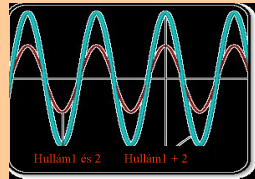


Un-equal frequencies



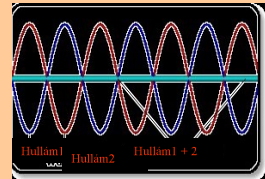
Equal frequencies

Interference: superposition of coherent waves



Similar phase
Constructive interference

$$\Phi = 0^\circ$$



Opposite waves
Destructive interference

$$\Phi = 180^\circ$$

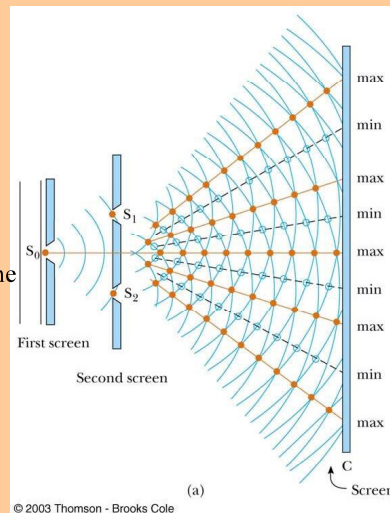
Interpretation of Thomas Young's double-slit experiment

S_1 and S_2 slits are wave sources

Two waves from S_1 and S_2 originates from the same wave front that is they are in the same phase.



interference



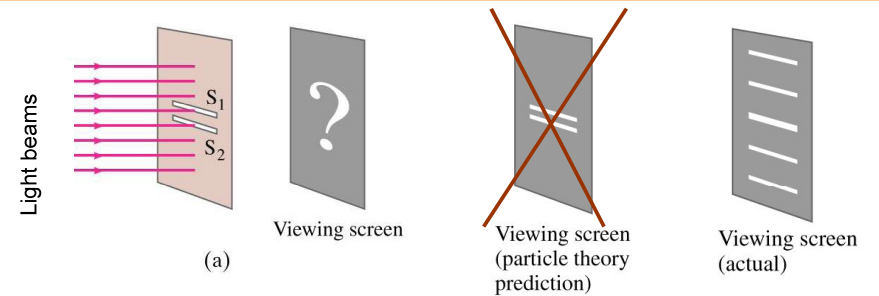
Interference fringes on a screen



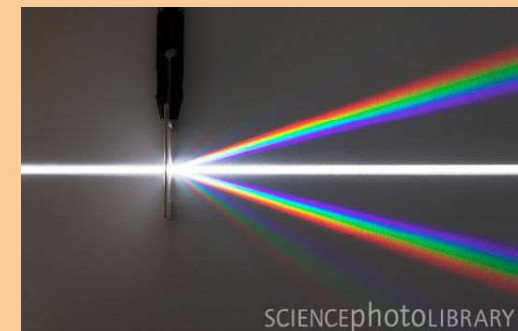
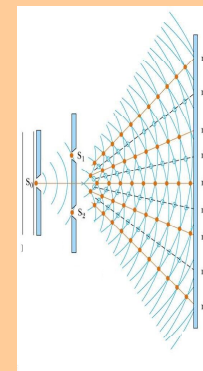
Thomas Young
(1773-1829)

Wave or particle?

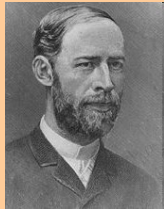
1. Thomas Young's double-slit experiment



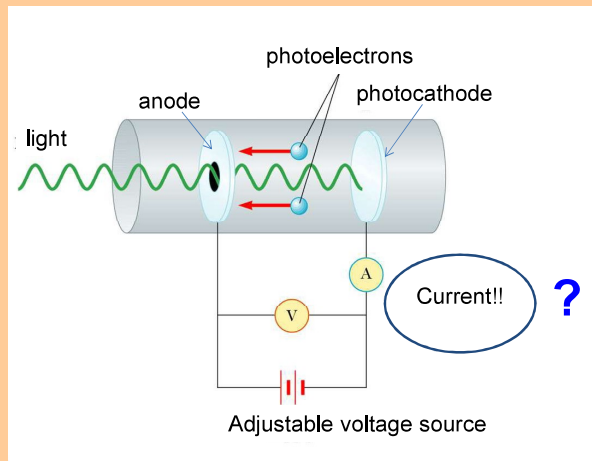
Dispersion of light by diffraction grating



2. Hertz's experiment



Heinrich Hertz
1887



Photoelectric effect

Interpretation of photoelectric effect

- Based on the wave character it is not possible.

- Planck – foundation of quantum physics

$$E = hf$$

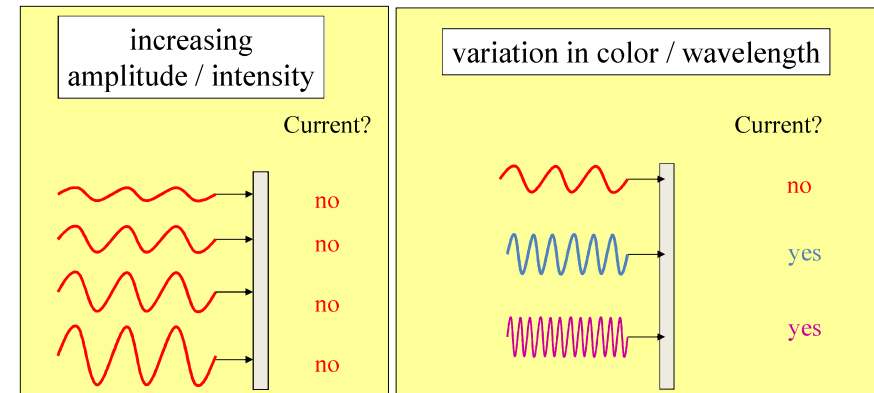
- Einstein's concept is based on the quantum theory

Current ?

Light irradiation

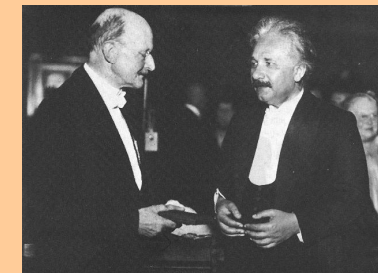
Similar color / wavelength

Similar amplitude



No current up to a critical value of frequency

Max Planck



Albert Einstein

Nobel Prize in physics 1918

Nobel Prize in physics 1921

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

*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: $E_{kin} = hf - A$

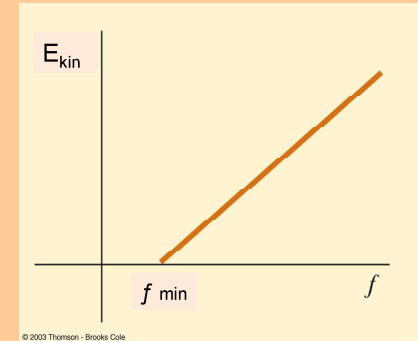
Einstein interpretation and the frequency limit

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

It has no resting mass

Propagates in vacuum

Calculation of photon energy

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

If $\lambda = 400 \text{ nm}$

$$E = 6.6 \times 10^{-34} \text{ Js} \times \frac{3 \times 10^8 \frac{\text{m}}{\text{s}}}{4 \times 10^{-7} \text{ m}} = 4.95 \times 10^{-19} \text{ J}$$

$$E = \frac{4.95 \times 10^{-19} \text{ J}}{1.6 \times 10^{-19}} = 3.1 \text{ eV}$$

$$E_{VIS} = 1.6 - 3.1 \text{ eV}$$

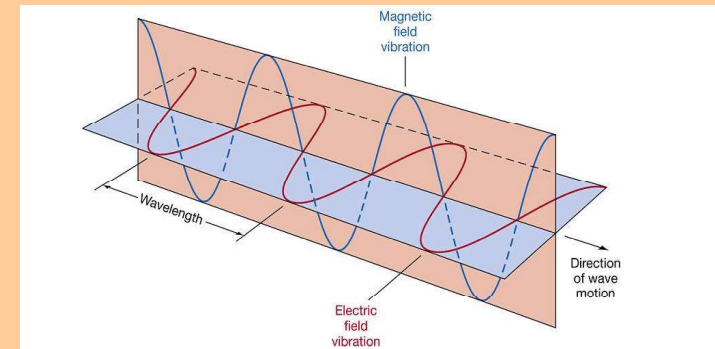
How much

- 1 TeV: kinetic energy of a fly
- 200 MeV: energy released during nuclear decay of ^{235}U atom
- 13.6 eV: ionizing energy of H atom
- 2.5 eV: energy of bluish light photon
- **1/40 eV: kT energy at room temperature**

Dual nature of light

Wave – electric and magnetic fields vary sinusoidally

Electromagnetic radiation

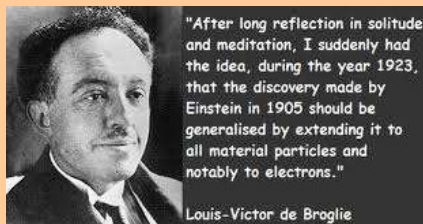


Why only light could have dual nature?

De Broglie concept: the wave–particle duality

All particles exhibit both **wave** and **particle** properties

Momentum of the electron: $p = m_e v$

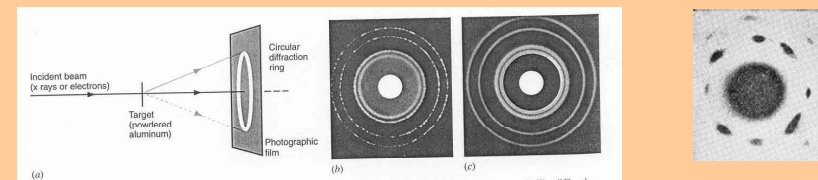


Louis-Victor de Broglie

$$\lambda = h / p$$

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

Particles ARE Waves!



Electrons indeed behave exactly as if they were waves.



Clinton Joseph Davisson

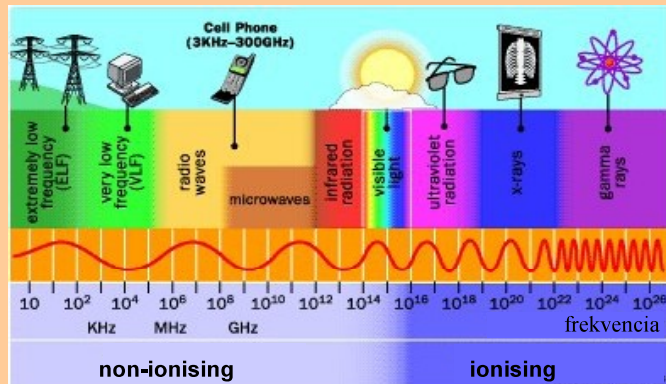


George Paget Thomson

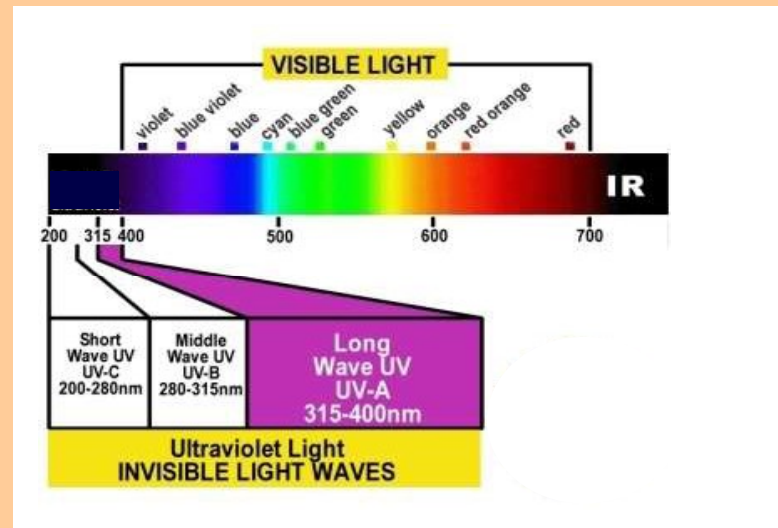
Nobel Prize in Physics 1937

"for their experimental discovery of the diffraction of electrons by crystals"

Ranges of electromagnetic radiation



Optical range



Checklist

- What are the parameters of waves?
- What does the dual nature of light mean?
- How can one prove the wave nature of light?
- How can one prove the corpuscular nature of light?
- How can we give the energy of the photon?
- What is the matter wave?

Measures and units

- wavelength
- frequency
- energy
- power
- intensity
- momentum

Related chapters

Damjanovich, Fidy, Szöllősi: Medical Biophysics

II. 2. 1.

- 2.1.1
- 2.1.2
- 2.1.3
- 2.1.4
- 2.1.5
- 2.1.8