Biophysics

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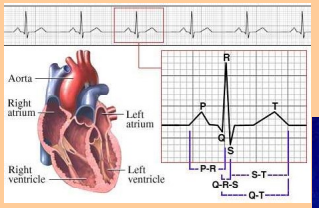
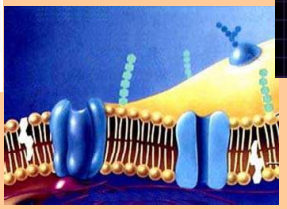
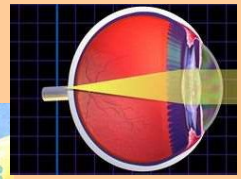
What is the subject of biophysics?

Physical aspects/background of biological processes

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



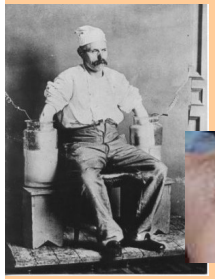


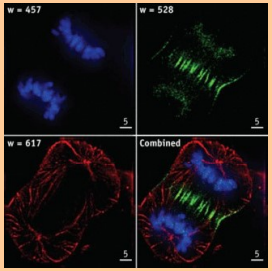


What is the subject of biophysics?

Physical methods in biology and medicine

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





Radiation

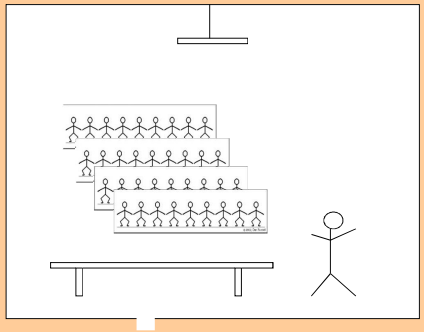
Examples around us

sound

light

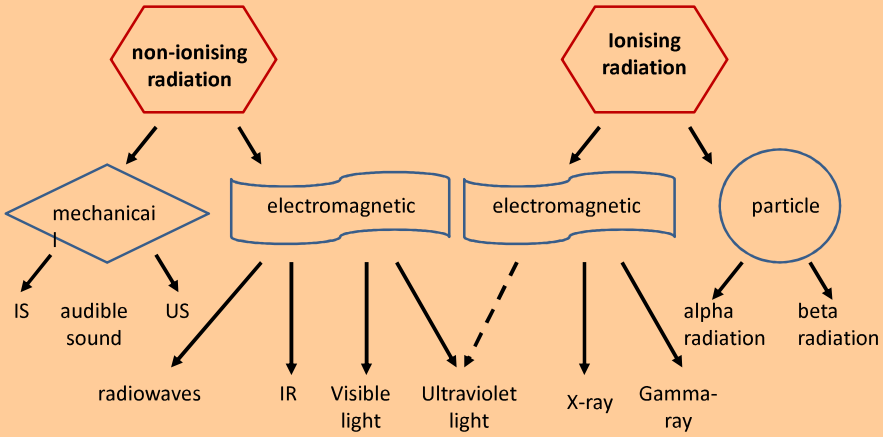
radiowaves

nuclear radiation



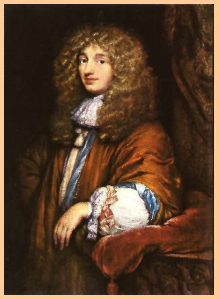
Radiation: emission and propagation of energy

Radiation



Nature of light

Wave?

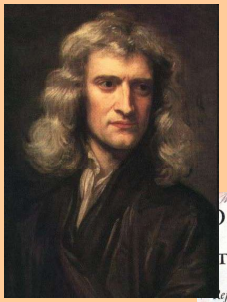


Christiaan Huygens

(1629 - 1695)

Traité de la lumière
1690

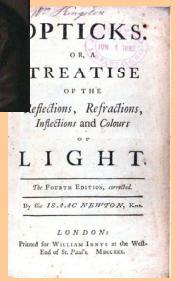
Particle?



Isaac Newton

(1642 - 1727)

Opticks
1704


OPTICKS:
OR, A
TREATISE
OF THE
Reflections, Refractions,
Inflections and Colours
OF
LIGHT.
The Fourth Edition, corrected.
By Sir ISAAC NEWTON, Knt.
LONDON:

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*

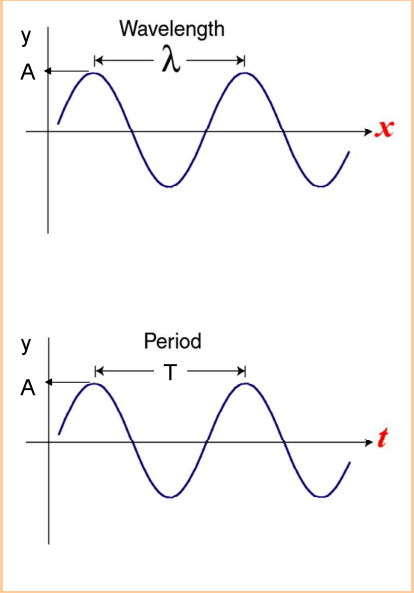
λ [m] or [nm]

Highest displacement – *amplitude*

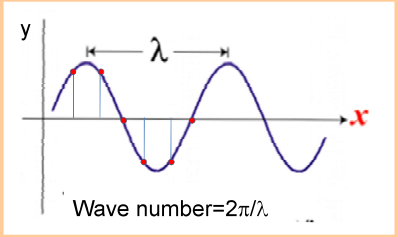
$$E \sim A^2$$

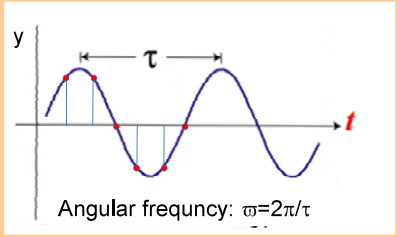
Period in time
- *period*
- *frequency*

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



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





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

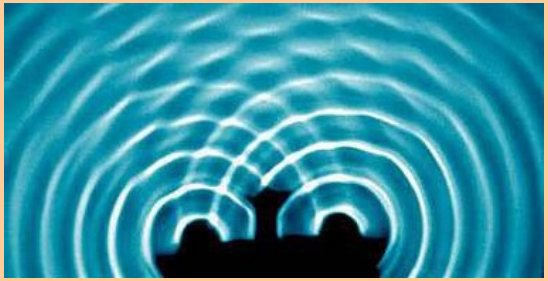
$\phi(t)=\varpi t+\phi_o$

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

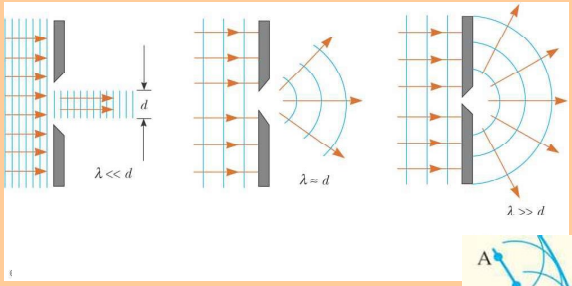
- fraction of the **wave** cycle that has elapsed relative to the origin.
- the *phase* difference is the fraction of a period between peaks.

Indication of wave nature

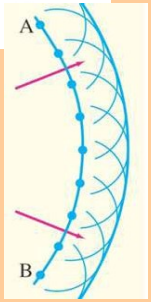
- diffraction
- superposition/interference
- polarization



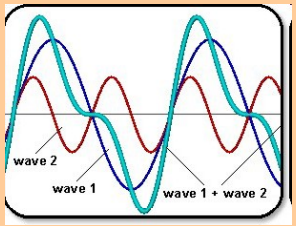
Diffraction



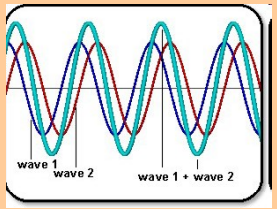
Huygens-principle: every point on a propagating wavefront serves as the source of spherical secondary wavelets, such that the wavefront at some later time is the envelope of these wavelets.



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.

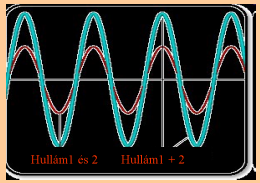


Un-equal frequencies



Equal frequencies

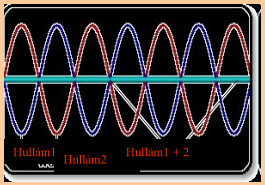
Interference: superposition of coherent waves



Similar phase

Constructive interference

$\Phi = 0^\circ$



Opposite waves

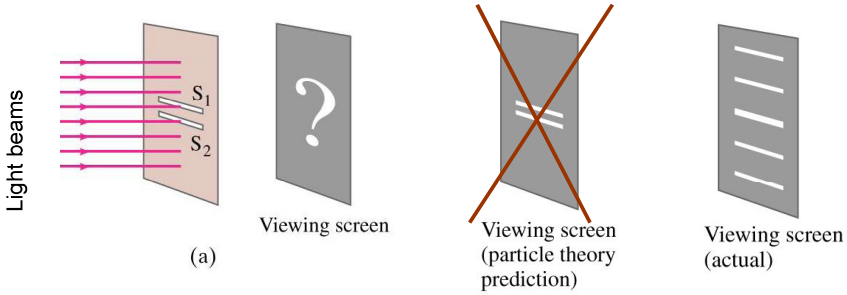
Destructive interference

$\Phi = 180^\circ$

Thomas Young
(1773-1829)

Wave or particle?

1. Thomas Young's double-slit experiment

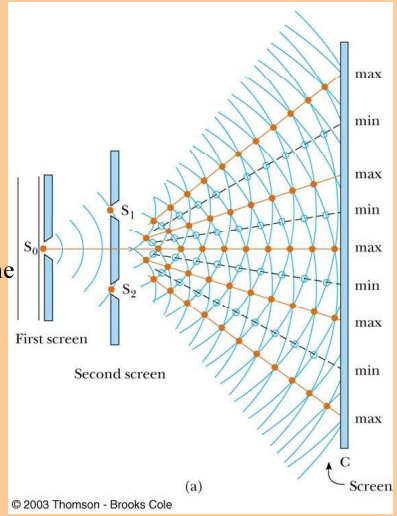


Interpretation of Thomas Young's double-slit experiment

S_1 and S_2 slits are wave sources

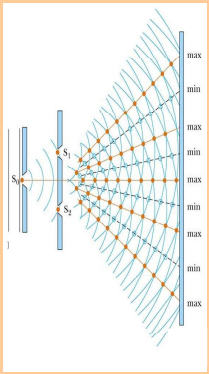
Two waves from S_1 and S_2 originates from the same wave front that is they are in the same phase.

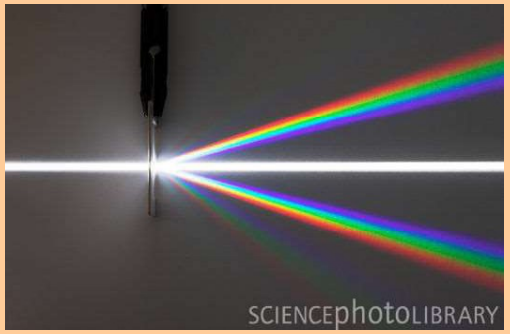
interference



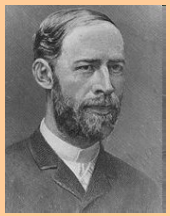
Interference fringes on a screen

Dispersion of light by diffraction grating

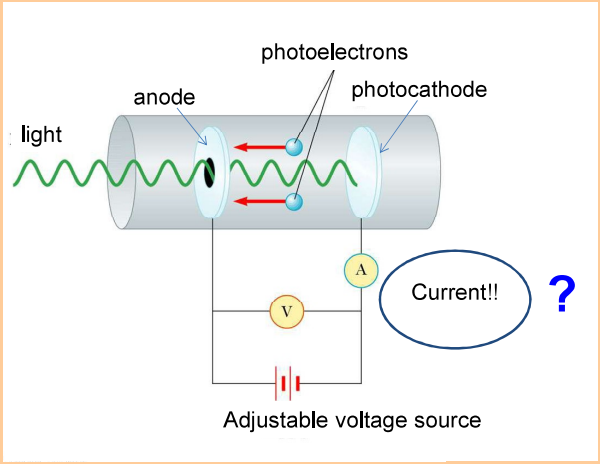




2. Hertz's experiment



Heinrich Hertz
1887



Photoelectric effect

¿ Current ?

Light irradiation

Similar color / wavelength

increasing amplitude / intensity

Current?

no
no
no
no

Similar amplitude

variation in color / wavelength

Current?

no
yes
yes

No current up to a critical value of frequency

Interpretation of photoelectric effect

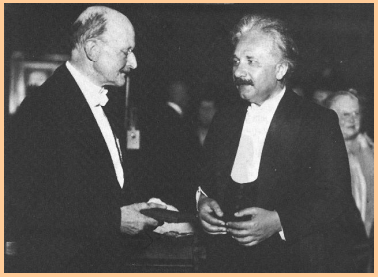
- Based on the wave character it is not possible.

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

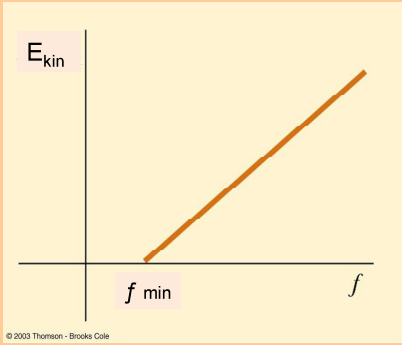
Einstein interpretation and the frequency limit

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

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

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

E_{VIS}= 1.6 – 3.1 *eV*

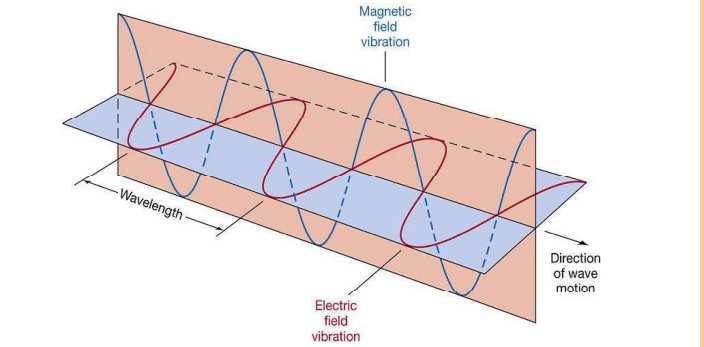
How much ……?

- 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

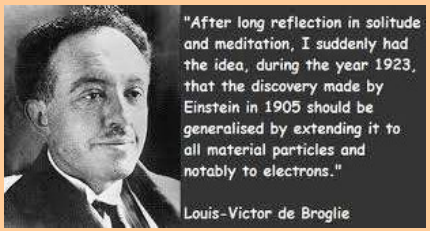


Why only light could have dual nature?

De Broglie concept: the wave–particle duality

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

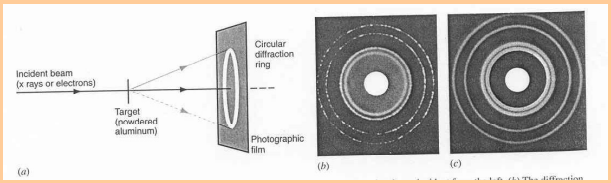
Momentum of the electron: $p = m_e v$

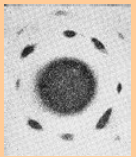


$$\lambda = h / p$$

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

Particles ARE Waves!





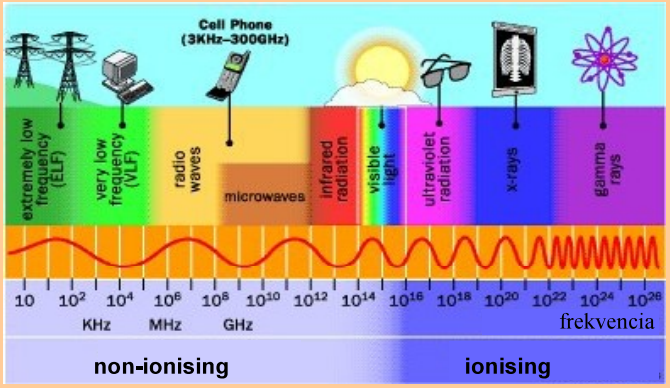
Electrons indeed behave exactly as if they were waves.

Clinton Joseph Davisson **George Paget Thomson**

Nobel Prize in Physics 1937

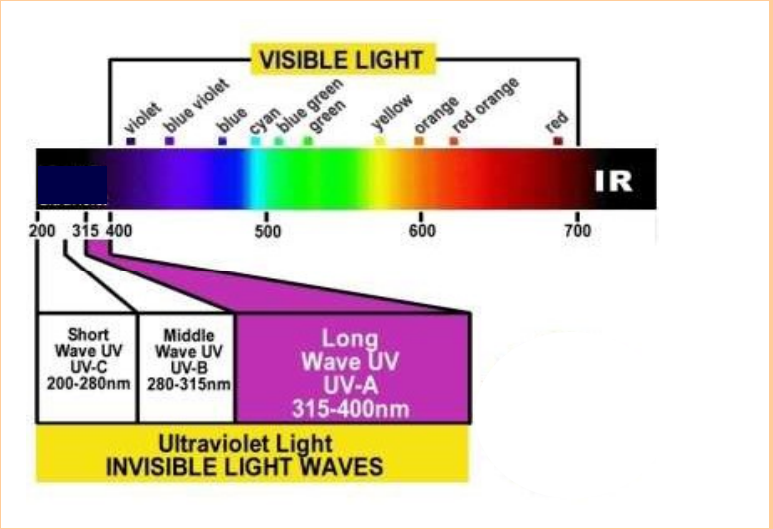
"for their experimental discovery of the diffraction of electrons by crystals"

Ranges of electromagnetic radiation



Amalgam is an alloy of mercury with other metals and it is used as a dental filling. The smallest work function in a given amalgam is about 703 kJ/mol. Are the photons of white light able to induce release of electrons from this material?

Optical range



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