Biophysics

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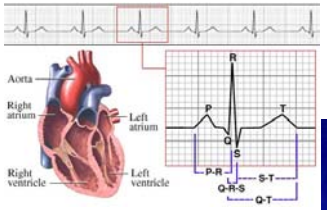
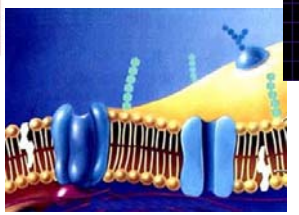
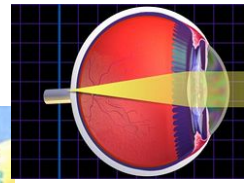
What is the subject of biophysics?

Physical aspects/background of biological processes

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



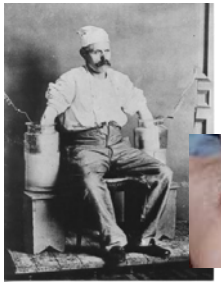


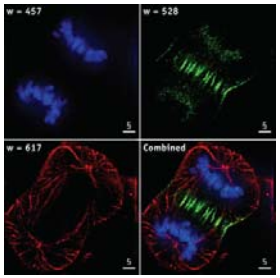


What is the subject of biophysics?

Physical methods in biology and medicine

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





Radiation

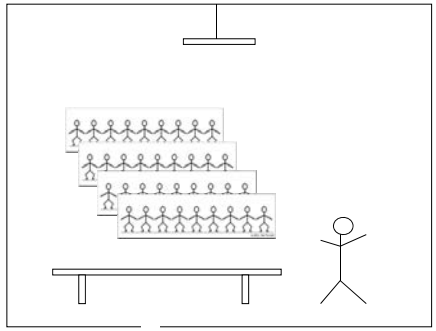
Examples around us

sound

light

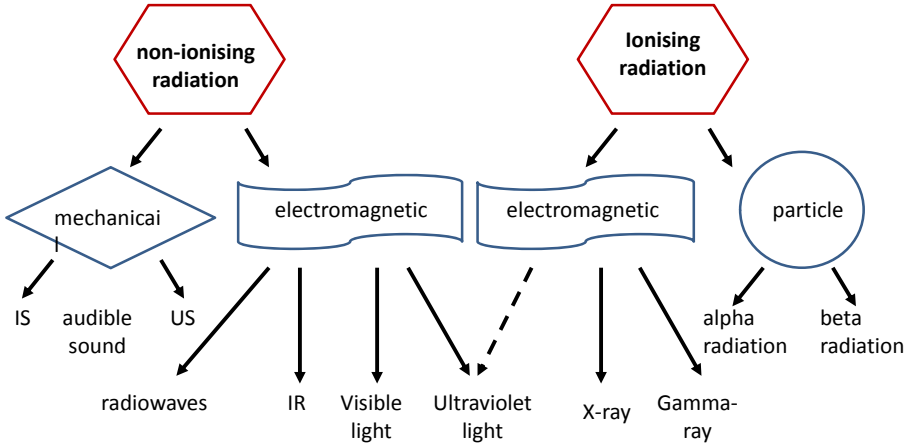
radiowaves

nuclear radiation



Radiation: emission and propagation of energy

Radiation



Nature of light

Wave?

Christiaan Huygens

(1629 - 1695)

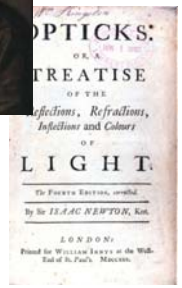
Traité de la lumière
1690

Particle?

Isaac Newton

(1642 - 1727)

Opticks
1704



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

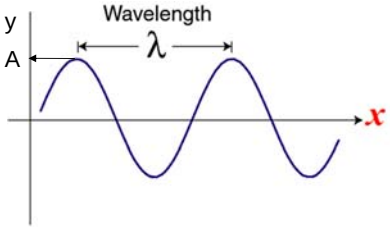
Characteristic values

Period in space– *wavelength*

λ [m] or [nm]

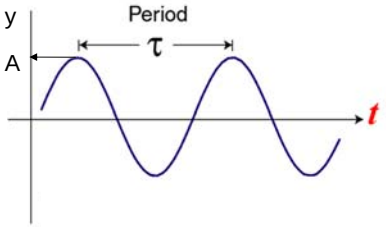
Highest displacement – *amplitude*

$$E \sim A^2$$

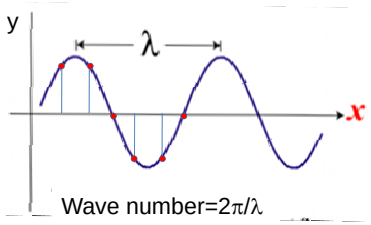


Period in time
- *period*
- *frequency*

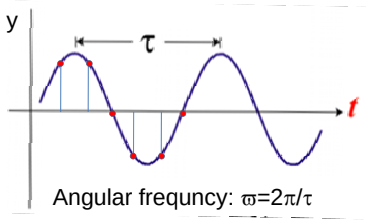
$$f = \frac{1}{\tau}\left[\frac{1}{s}\right]$$



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



Wave number=$2\pi/\lambda$



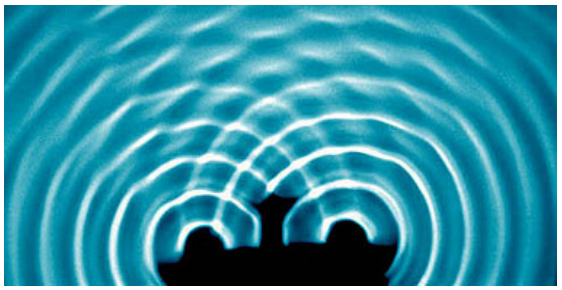
Angular frequncy: $\varpi=2\pi/\tau$

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

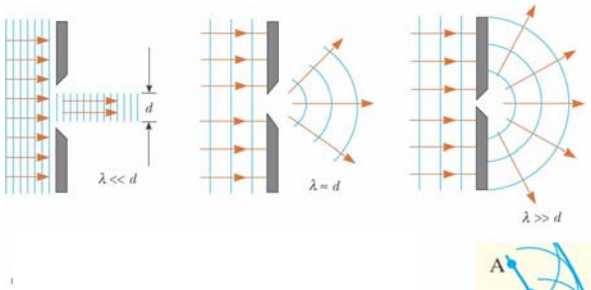
$\phi=\varpi t+kx+\phi_o$

Indication of wave nature

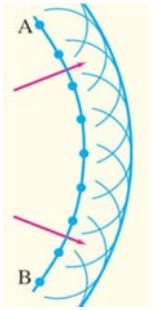
- diffraction
- superposition/interference
- polarization



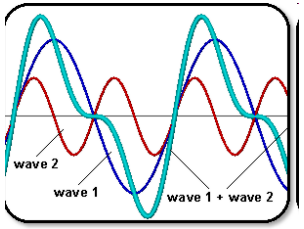
Diffraction



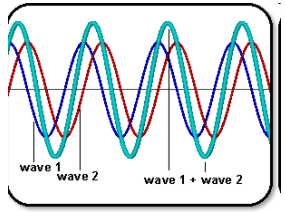
Huygens-principle: every point on a propagating wavefront serves as the source of spherical secondary wavelets, such that the wavefront at some later time is the envelope of these wavelets.



Superposition: The principle of superposition may be applied to waves whenever two (or more) waves travelling 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.

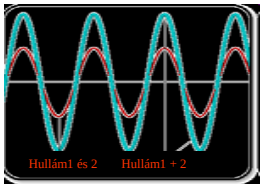


Un-equal frequencies



Equal frequencies

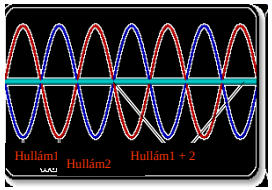
Interference: superposition of coherent waves



Similar phase

Constructive interference

$\Phi = 0^{\circ}$



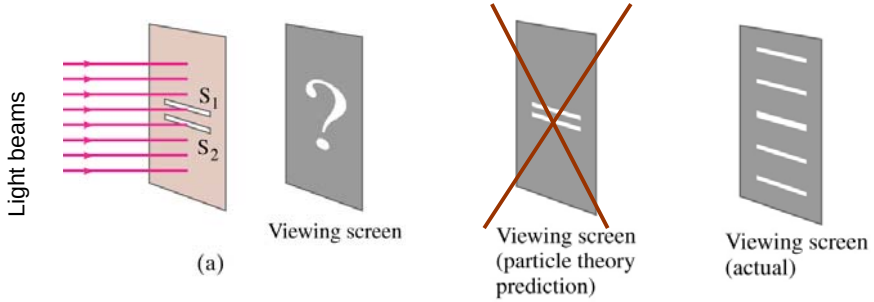
Opposite waves

Destructive interference

$\Phi = 180^{\circ}$

Thomas Young
(1773-1829)

Thomas Young's
double-slit experiment

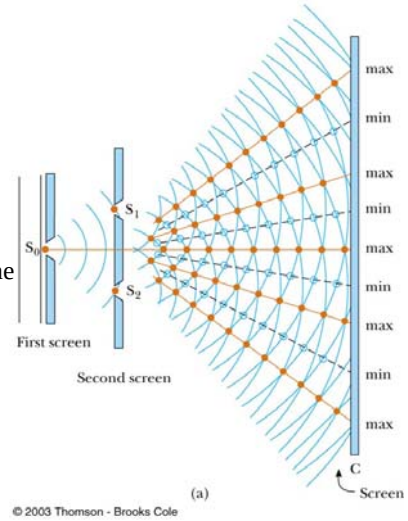


Interpretation of Thomas Young's double-slit experiment

S_1 and S_2 slits are wave sources

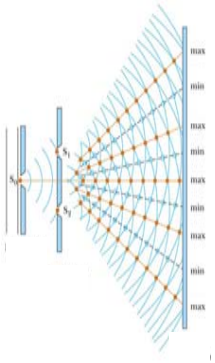
Two waves from S_1 and S_2 originates from the same wave front that is they are in the same phase.

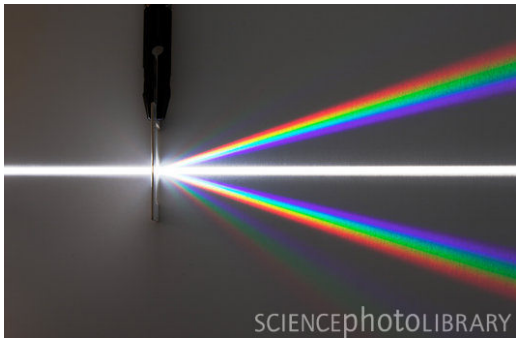
interference



Interference fringes on a screen

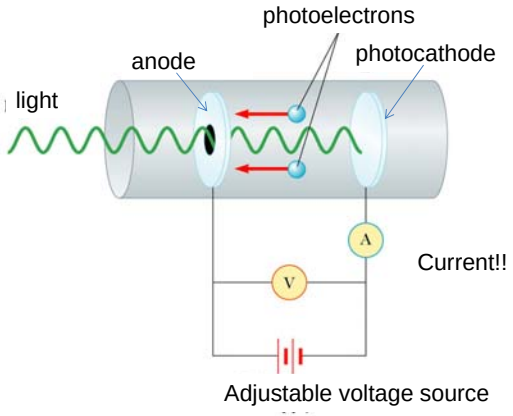
Dispersion of light by diffraction grating





Photoelectric effect

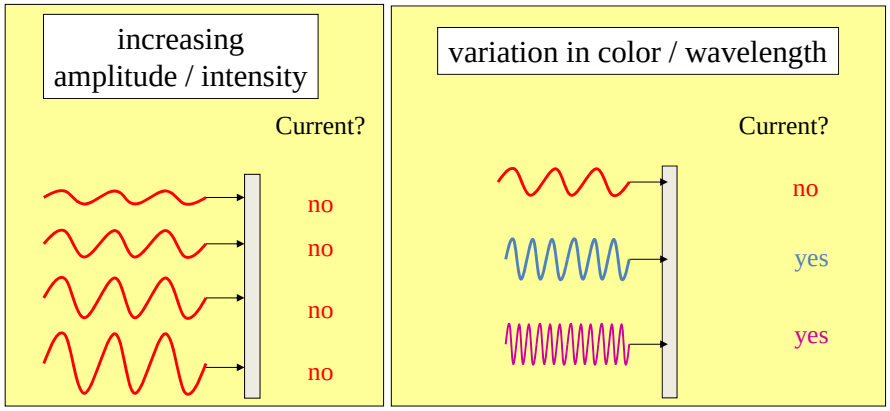
Heinrich Hertz
1887



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**".*

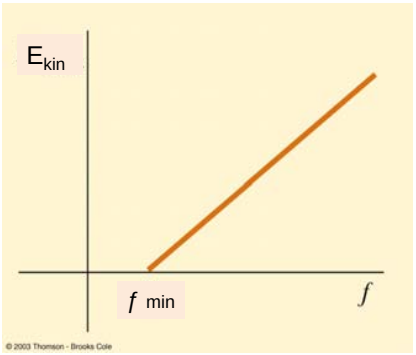
Einstein interpretation

- 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

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

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

E_{VIS}= 1.6 – 3.1 *eV*

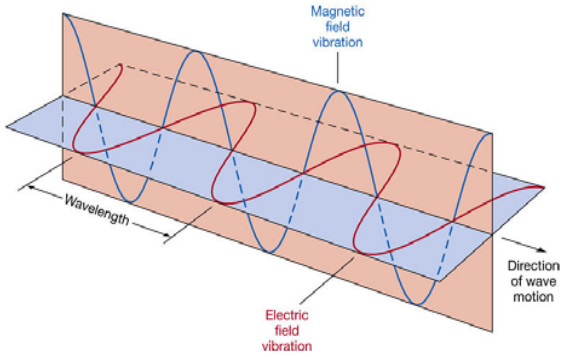
How much ……?

- 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

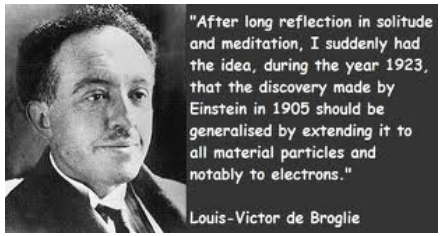


Why only light could have dual nature?

De Broglie concept: the wave–particle duality

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

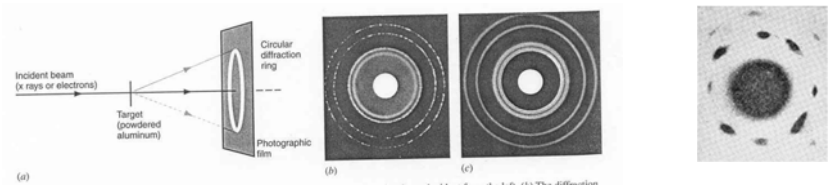
Momentum of the electron: $p = m_e v$



$$\lambda = h / p$$

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

Particles ARE Waves!



Electrons indeed behave exactly as if they were waves.

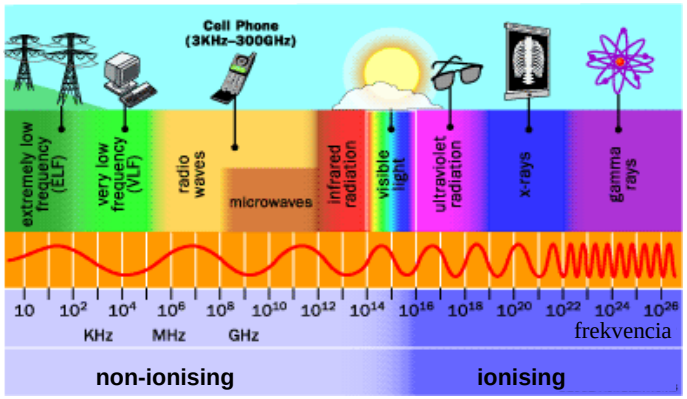
Clinton Joseph Davisson

George Paget Thomson

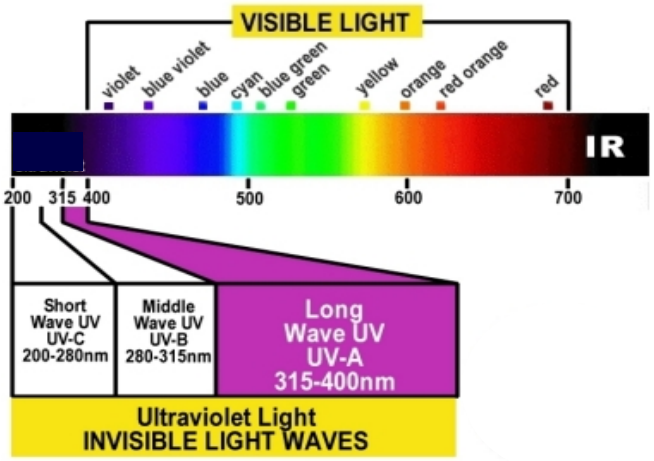
Nobel Prize in Physics 1937

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

Ranges of electromagnetic radiation



Optical range



Question: Which object can have similar size as the wavelength of microwaves, visible light or soft X-ray?

Typical values of photon-energies

10^{-5} eV – microwave

2 eV – visible light

100 eV – X-ray

Related chapters

Damjanovich, Fidy, Szöllősi: Medical Biophysics

II. 2. 1.

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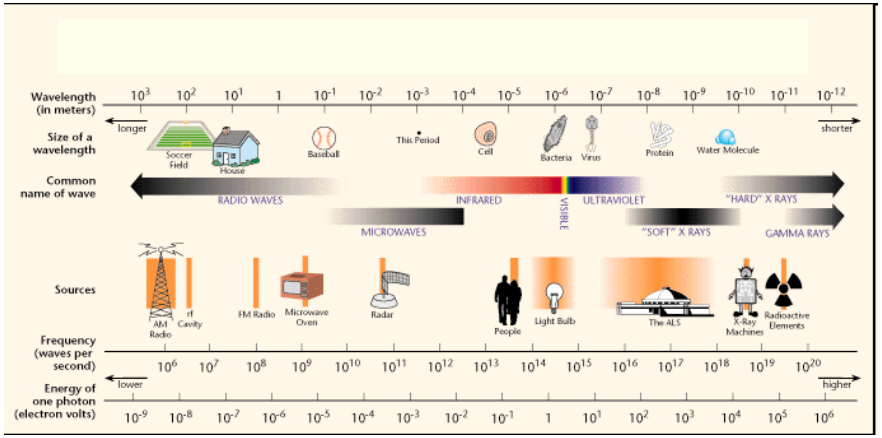
2.1.2
2.1.3
2.1.4
2.1.5
2.1.8


Wavelength (in meters)
10^{3} 10^{2} 10^{1} 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}
lower
higher
Energy of one photon (electron volts)
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6}