

# Biophysics

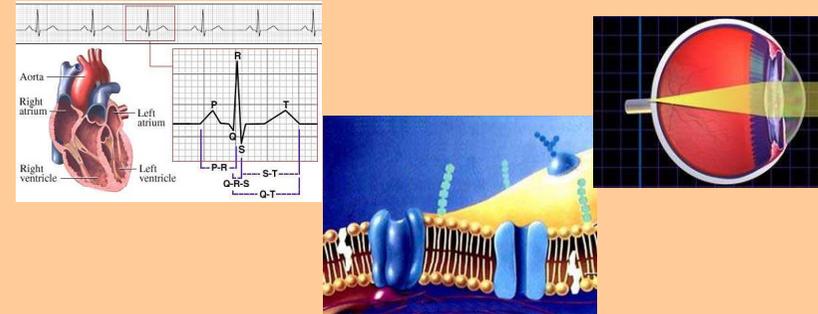
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## What is the subject of biophysics?

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

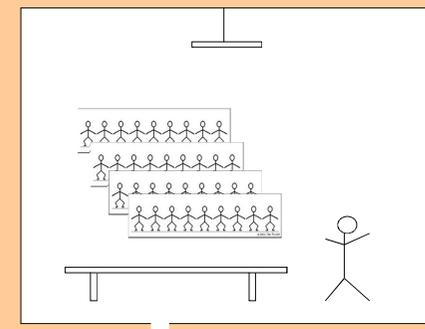
E.g., ECG, X-ray diagnostics, microscopy....



## Radiation

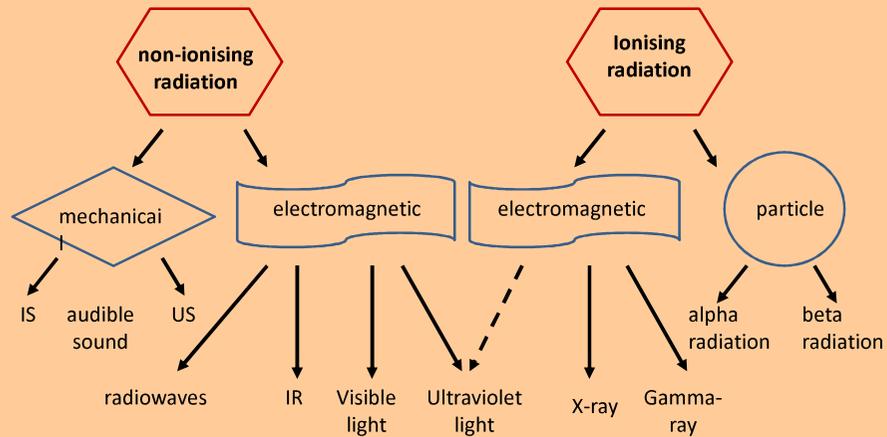
Examples around us

- sound
- light
- radiowaves
- nuclear radiation



Radiation: emission and propagation of energy

# Radiation



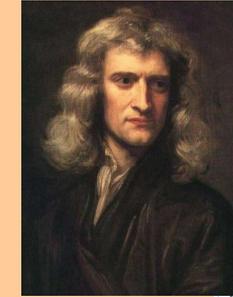
# Nature of light

Wave?

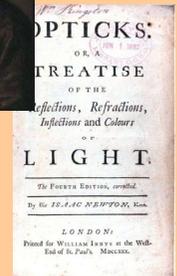


**Christiaan Huygens**  
(1629 - 1695)  
*Traité de la lumière*  
1690

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*

$$\lambda \text{ [m] or [nm]}$$

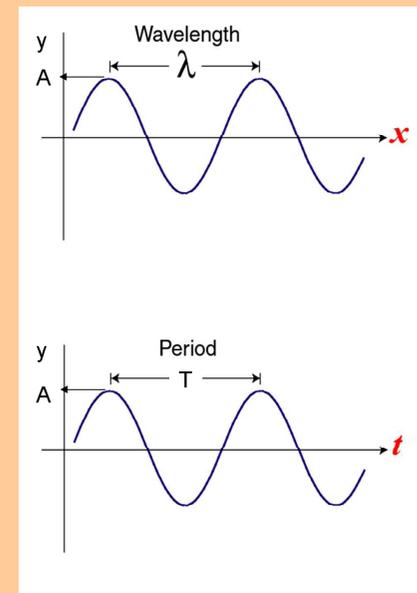
Highest displacement – *amplitude*

$$E \sim A^2$$

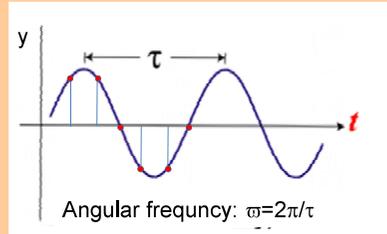
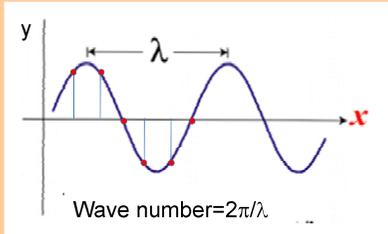
Period in time

– *period*  
– *frequency*

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



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



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

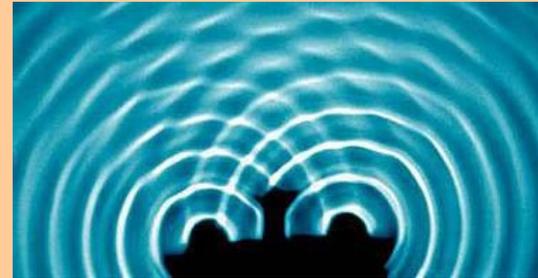
$$\phi(t) = \omega t + \phi_0$$

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

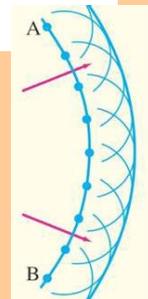
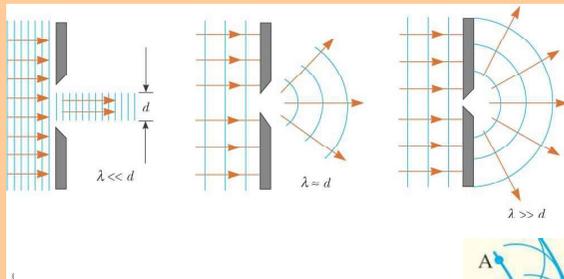
- fraction of the **wave** cycle that has elapsed relative to the origin.
- the *phase* difference is the fraction of a period between peaks.

### Indication of wave nature

- diffraction
- superposition/interference
- polarization

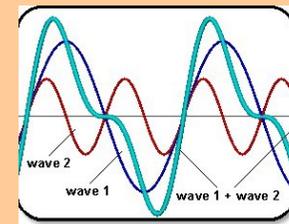


### Diffraction

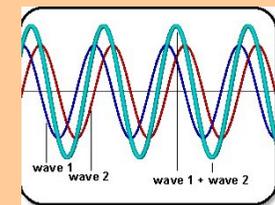


Huygens-principle: every point on a propagating wavefront serves as the source of spherical secondary wavelets, such that the wavefront at some later time is the envelope of these wavelets.

*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.

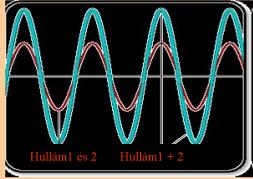


Un-equal frequencies



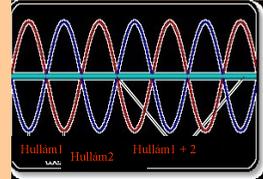
Equal frequencies

*Interference:* superposition of coherent waves



Similar phase  
Constructive interference

$$\Phi = 0^\circ$$



Opposite waves  
Destructive interference

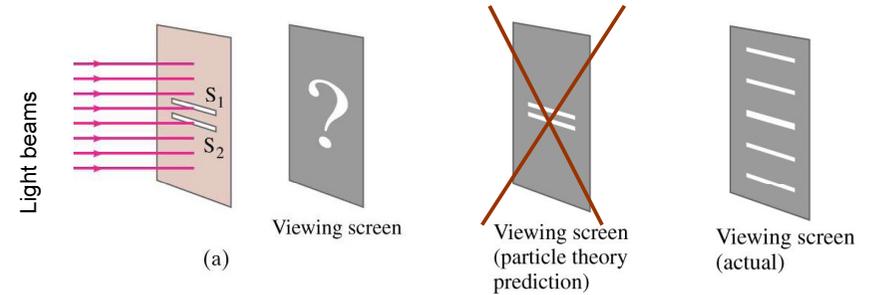
$$\Phi = 180^\circ$$



**Thomas Young**  
(1773-1829)

## Wave or particle?

### 1. Thomas Young's double-slit experiment



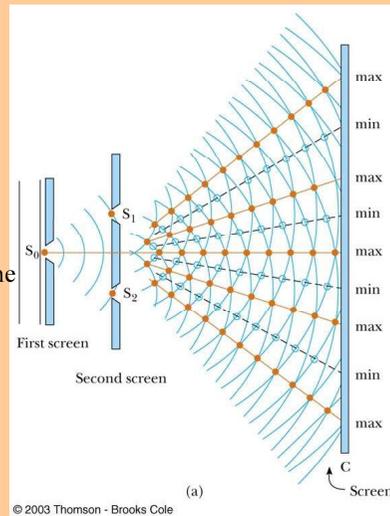
### Interpretation of Thomas Young's double-slit experiment

$S_1$  and  $S_2$  slits are wave sources

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

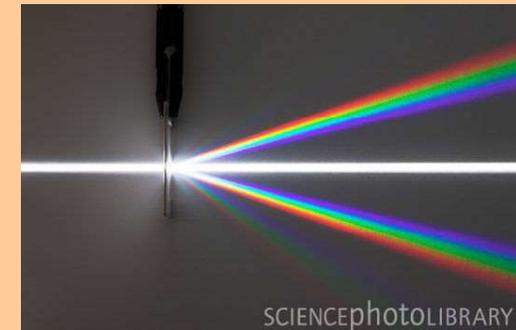
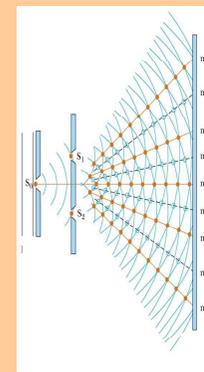


**interference**



Interference fringes on a screen

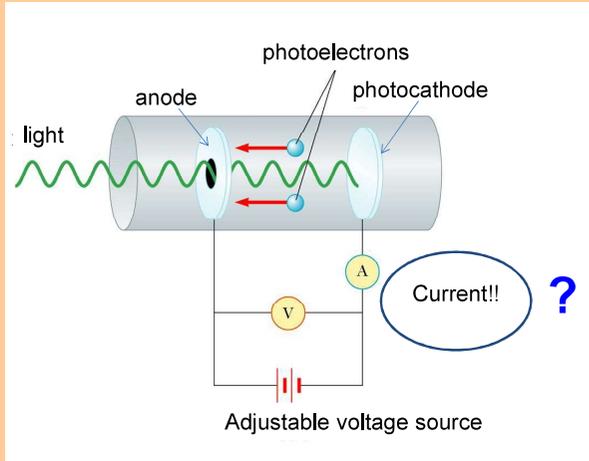
### Dispersion of light by diffraction grating



## 2. Hertz's experiment



Heinrich Hertz  
1887



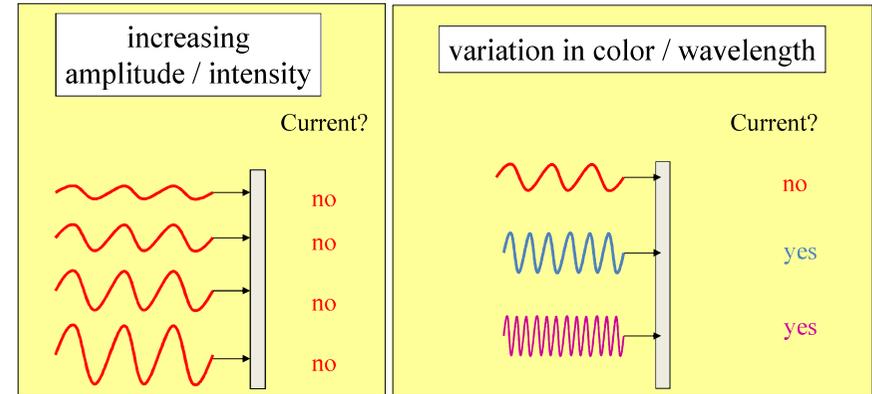
## Photoelectric effect

Current ?

Light irradiation

Similar color / wavelength

Similar amplitude



No current up to a critical value of frequency

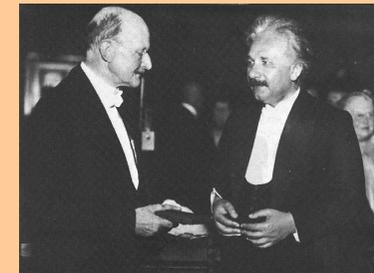
## Interpretation of photoelectric effect

- 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

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**".

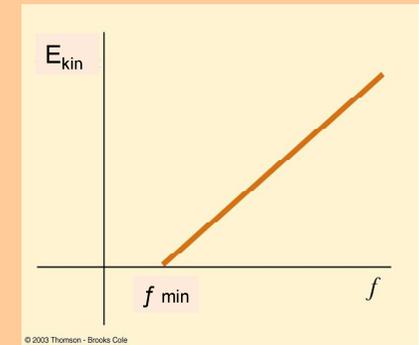
### Einstein interpretation

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

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

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

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

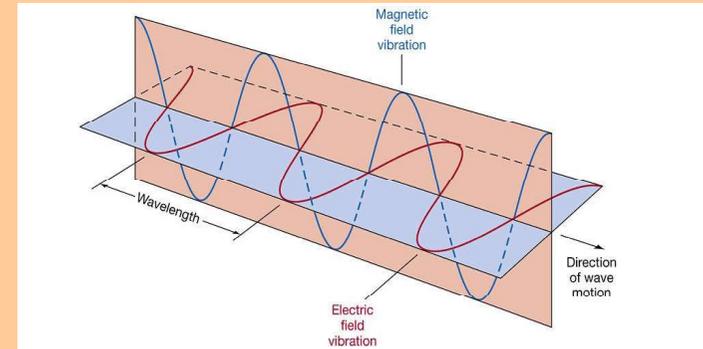
How much .....

- 1 TeV: kinetic energy of a fly
- 200 MeV: energy released during nuclear decay of  $^{235}\text{U}$  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

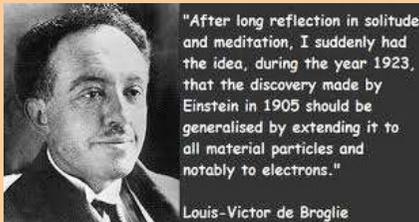


## Why only light could have dual nature?

De Broglie concept: the wave-particle duality

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

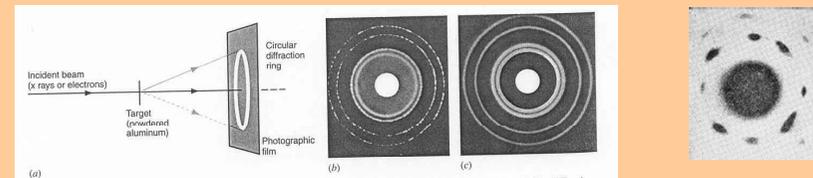
Momentum of the electron:  $p = m_e v$



$$\lambda = h / p$$

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

## Particles ARE Waves!



Electrons indeed behave exactly as if they were waves.

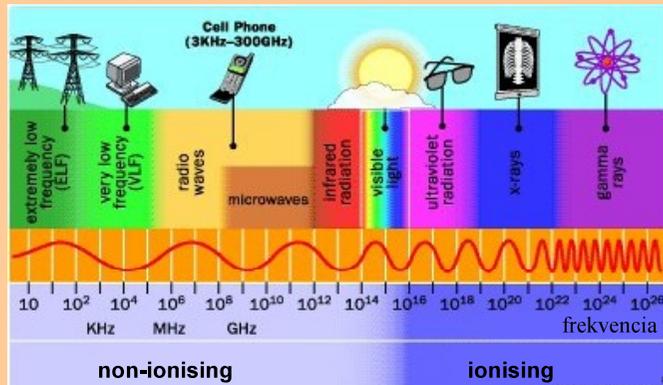


**Nobel Prize in Physics 1937**

Clinton Joseph Davison  
George Paget Thomson

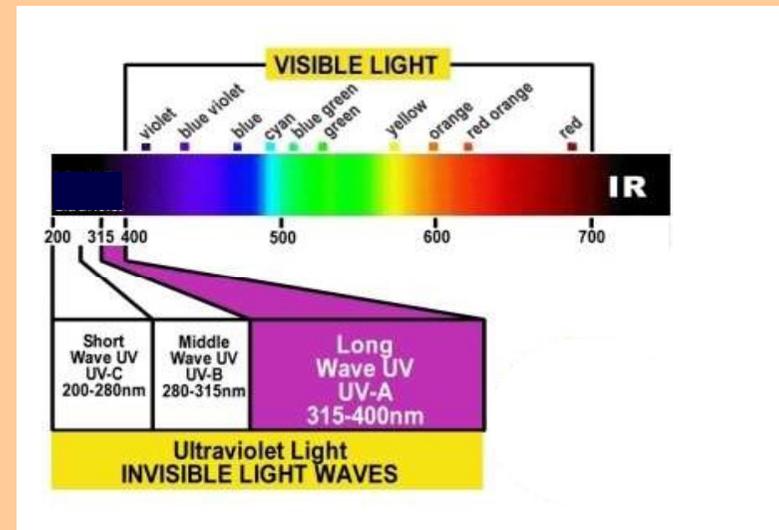
"for their experimental discovery of the diffraction of electrons by crystals"

## 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