Biophysics 1

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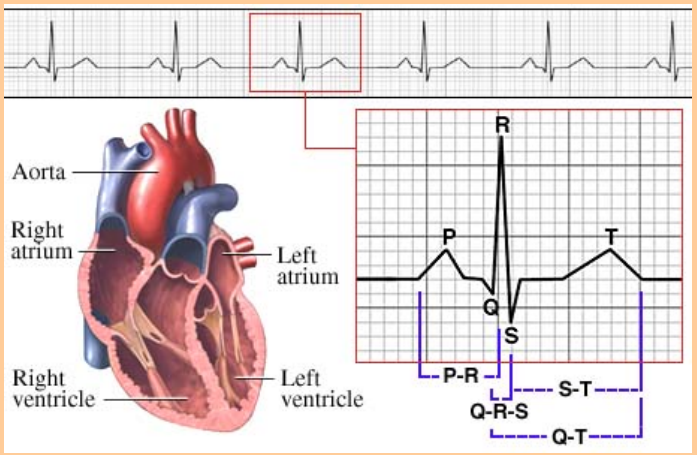
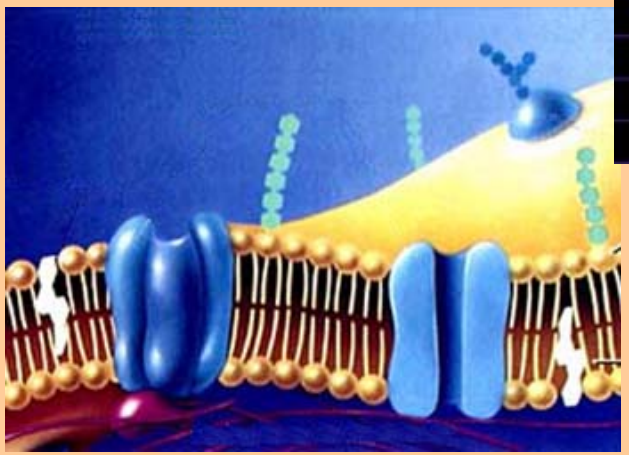
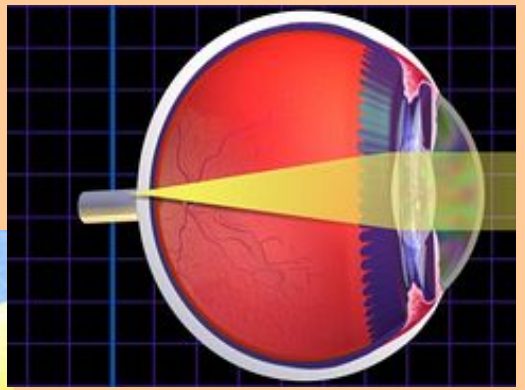
What is the subject of biophysics?

Physical aspects/background of biological processes

E.g.: electrophysiology of heart, structure and functioning of membranes, sensory functions,...



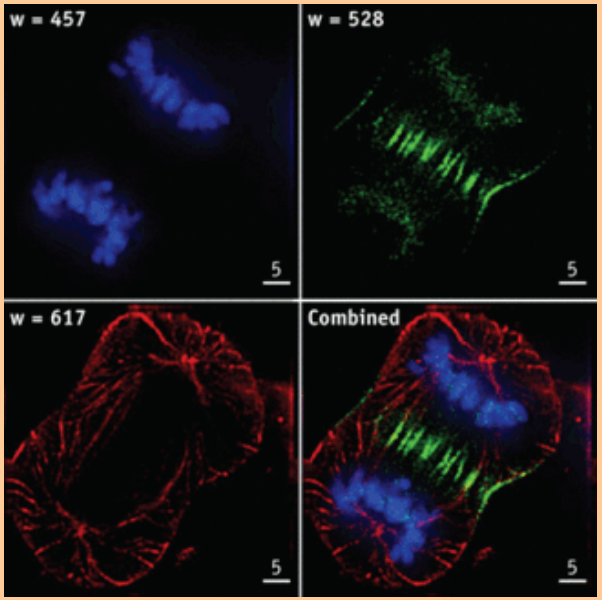




What is the subject of biophysics?

Physical methods in biology and medicine

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



Topic list of semester1

3 Radiation: characteristic parameters; classification, electromagnetic spectrum; dual nature of light, diffraction, interference, monochromators, matter wave.

4 Interaction of light I. refraction, lenses, light microscope, electron microscopes.

5 Interactions of light II.reflection, scattering, absorption, law of attenuation of intensity, medical applications; color of the objects,

6 Thermal radiation characteristics and description; emission of the human body, medical applications, infra-diagnostics

7 Luminescence: description, characteristics, light sources, medical applications

8 Lasers: working principle, types of lasers; fields of medical application

9 Special microscopic techniques: fluorescent microscope, confocal microscope, super resolution microscopes

10 Biological effects of light, medical applications.

11 X-radiation 1: production, spectrum, interaction with matter

12 X-radiation 2: physical bases of X-ray diagnostic methods; dental X-ray, principle of CAT-scan

13 Nuclear radiation: types, characteristics of them, principles of tracing with radioisotopes

14 Nuclear radiation in the clinical practice: isotope diagnostics: bases of radioisotope diagnostic methods, gamma-camera, SPECT, PET; radiotherapy

Radiation

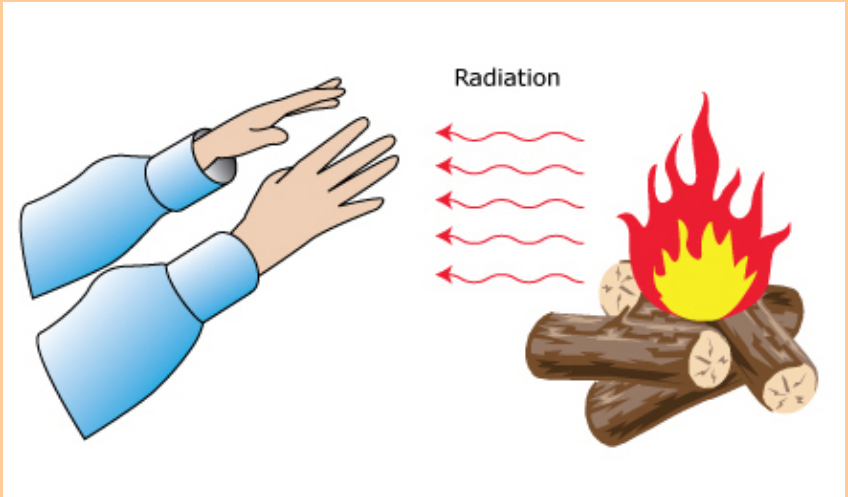
In physics, radiation is the emission and propagation of **energy** in the form of waves or particles through space or through a material medium.

Examples:

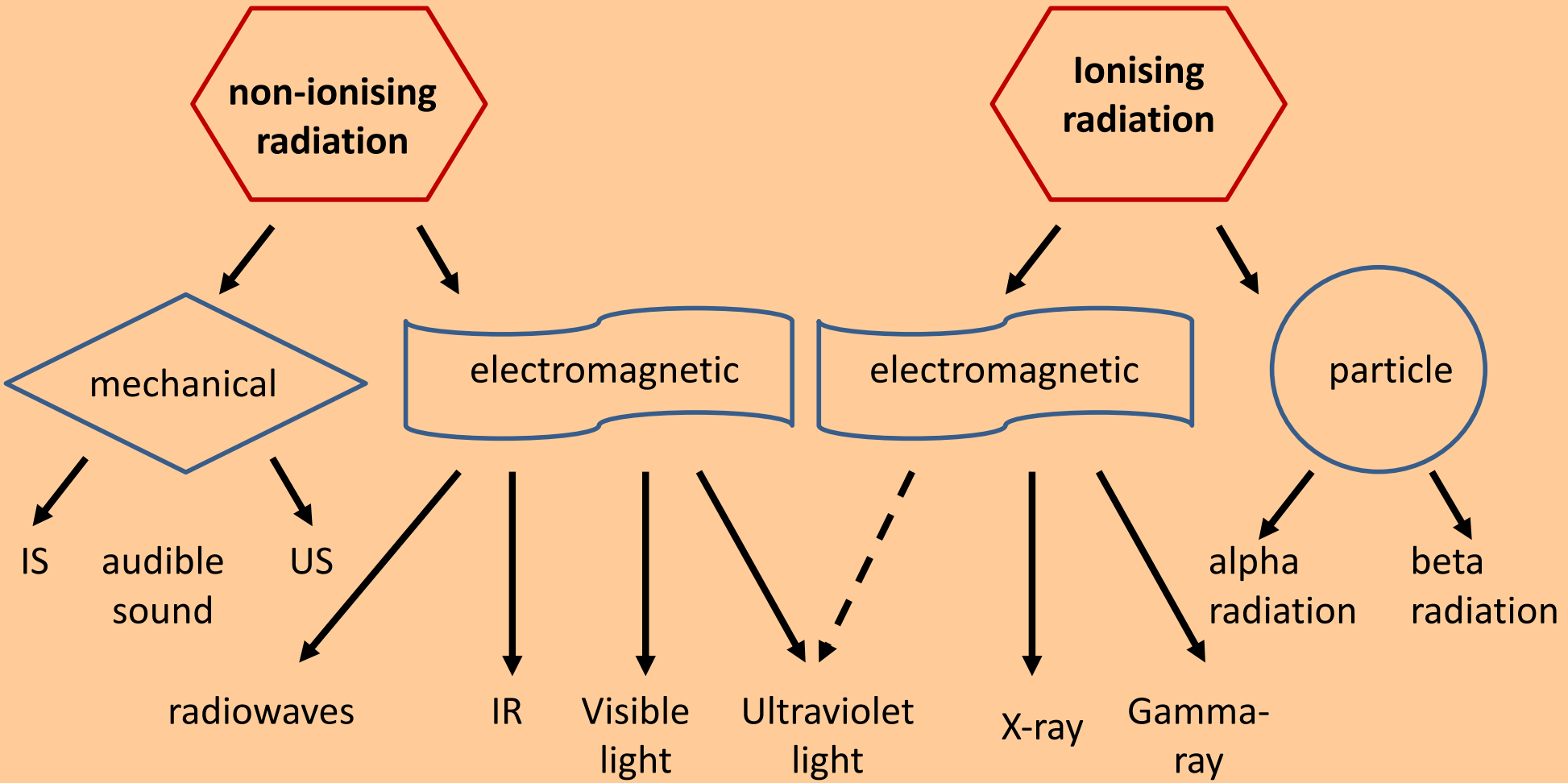
sound, light

radiowaves, X-ray

nuclear radiations



Radiation


non-ionising radiation
Ionising radiation
mechanical
electromagnetic
electromagnetic
particle
IS
audible sound
US
radiowaves
IR
Visible light
Ultraviolet light
X-ray
Gamma-ray
alpha radiation
beta radiation

Natur of waves

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

Waves differ in

- type of energy
- its intensity
- mechanism of propagation

Characteristic values

Period in space – *wavelength*

λ [m] or [nm]

displacement – *amplitude*

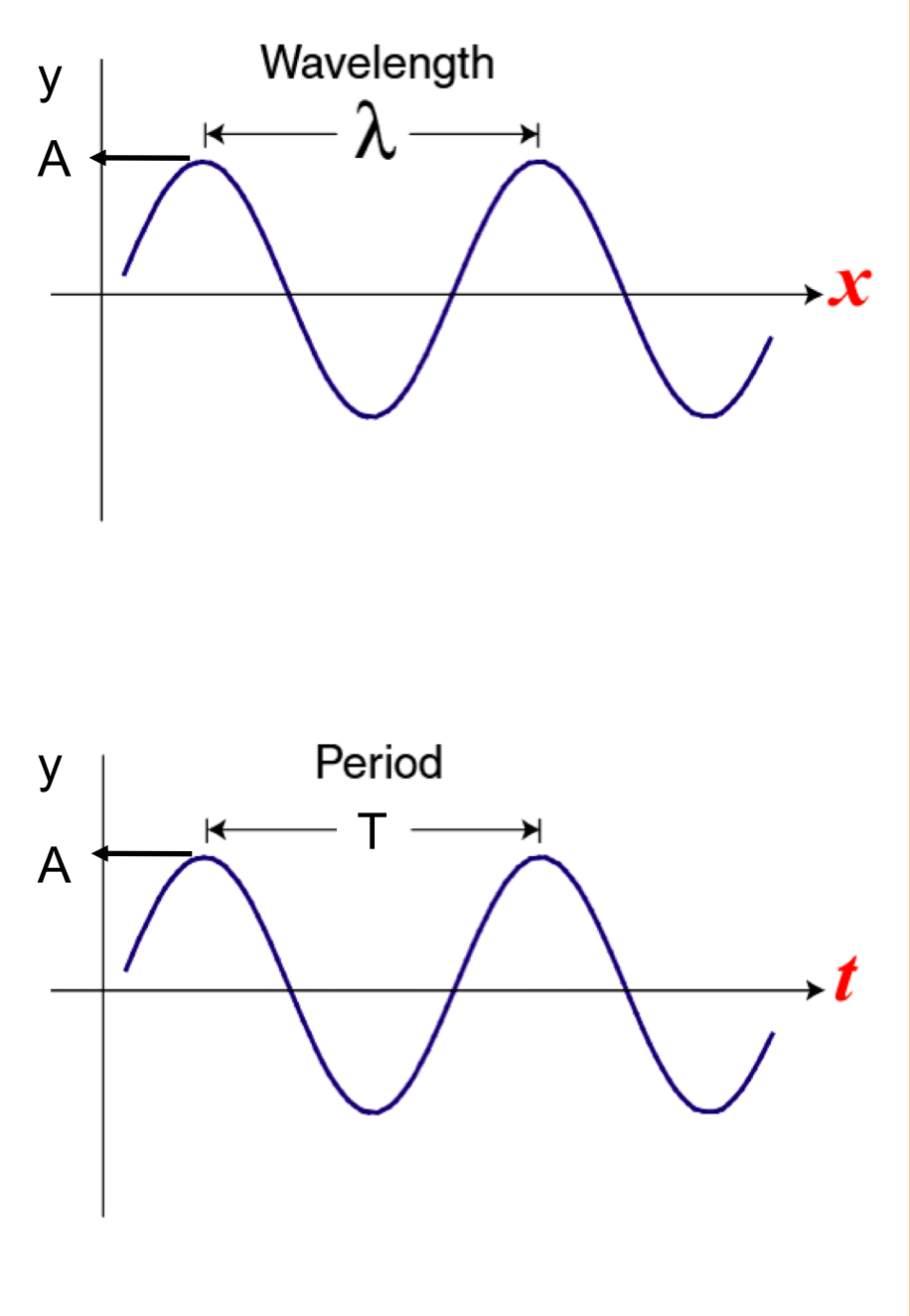
$$E \sim A^2$$

Period in time – *period, T*

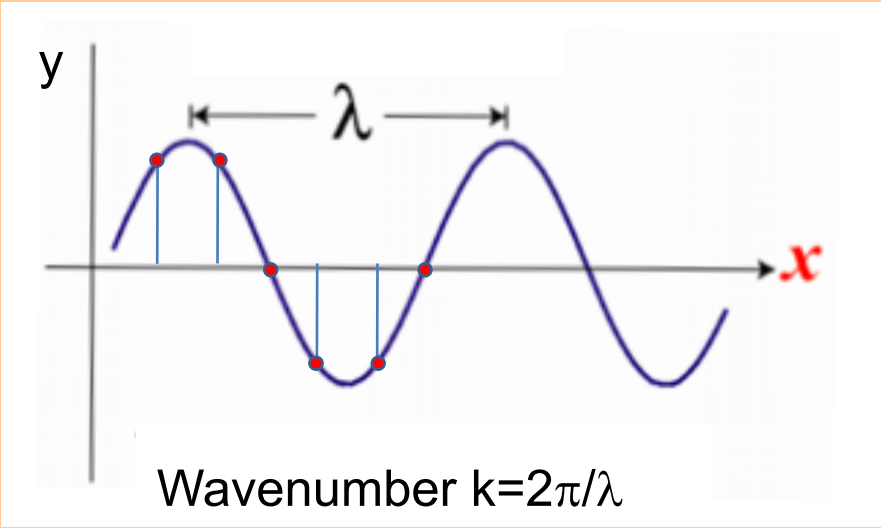
– *frequency, f*

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

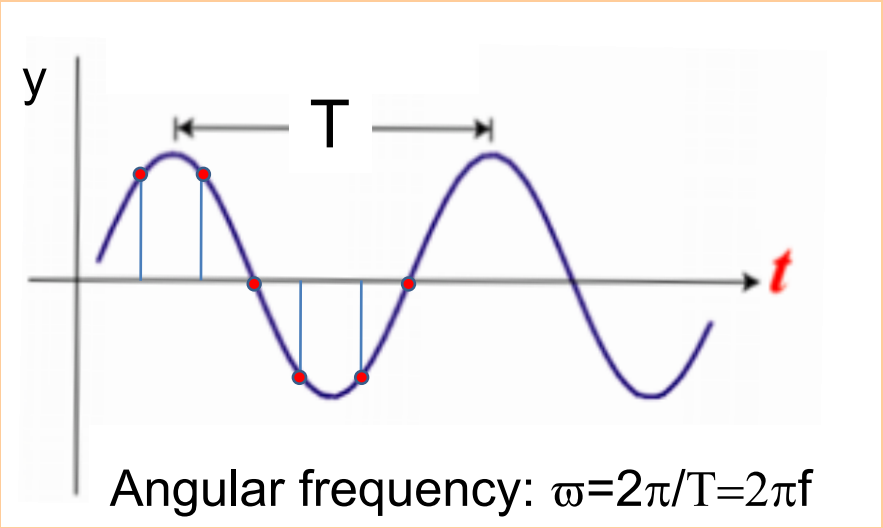
velocity of wave: c = λ/T = λf



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



Wavenumber $k=2\pi/\lambda$



Angular frequency: $\omega=2\pi/T=2\pi f$

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

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

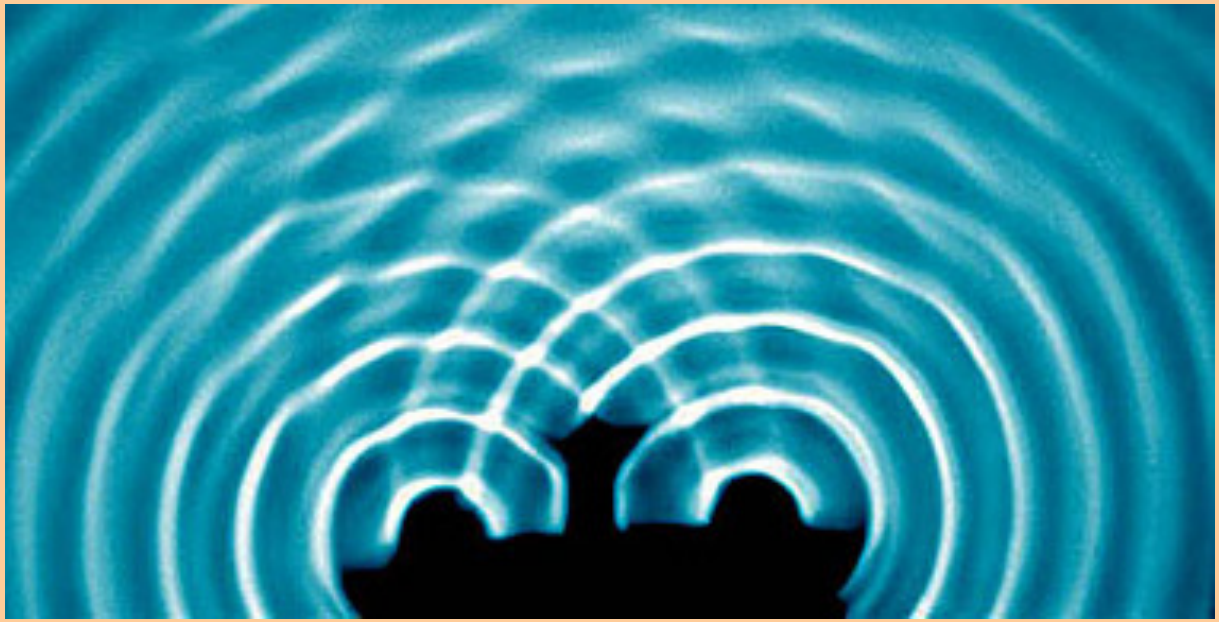
$$\phi=\omega t+kx+\phi_o$$

- fraction of the **wave** cycle that has elapsed relative to the origin.

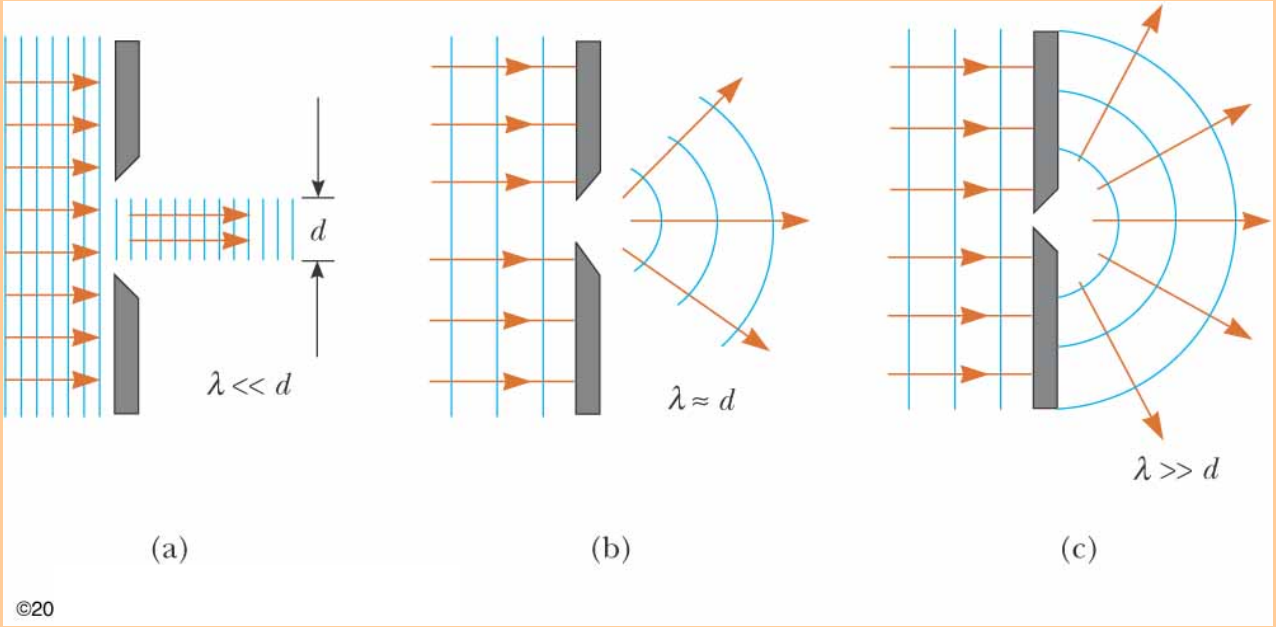
- the *phase* difference is the fraction of a period between peaks.

Indications of wave nature:

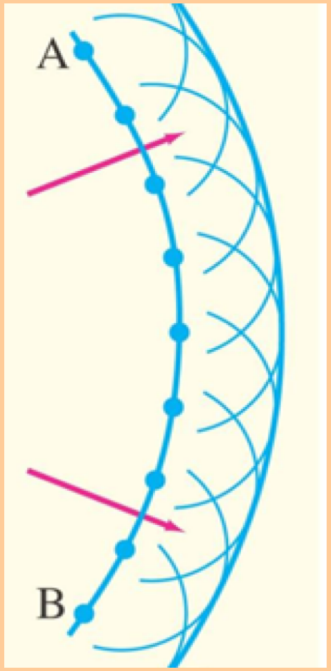
- diffraction
- superposition / interference
- polarization



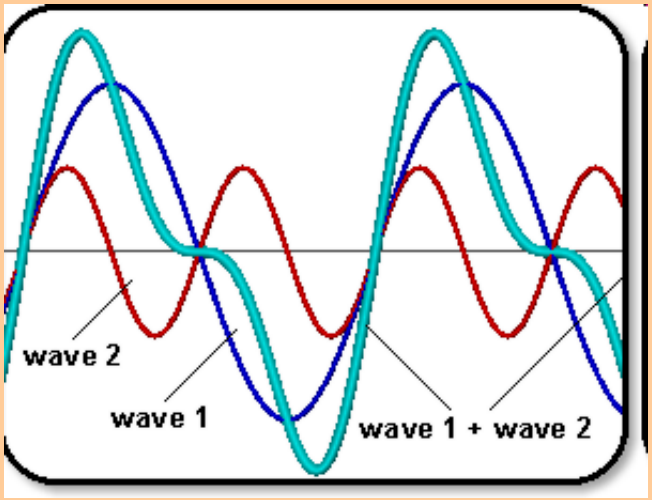
Diffraction



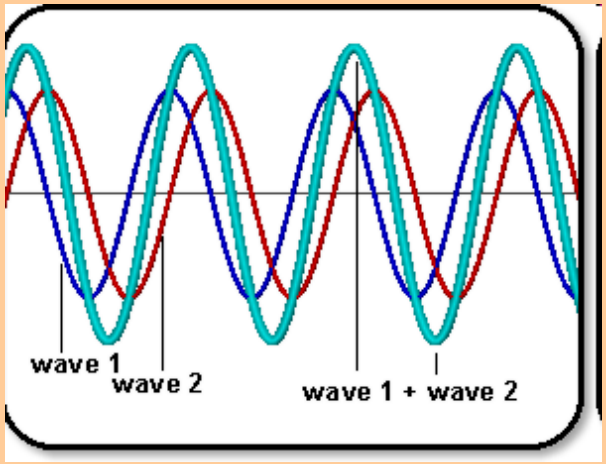
Huygens' principle: every point on a propagating wavefront serves as the source of spherical secondary wavelets, such that the wavefront at some later time is the envelope of these wavelets.



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 amplitude of the waves at any point in space or time, is simply the sum of the individual wave amplitudes.

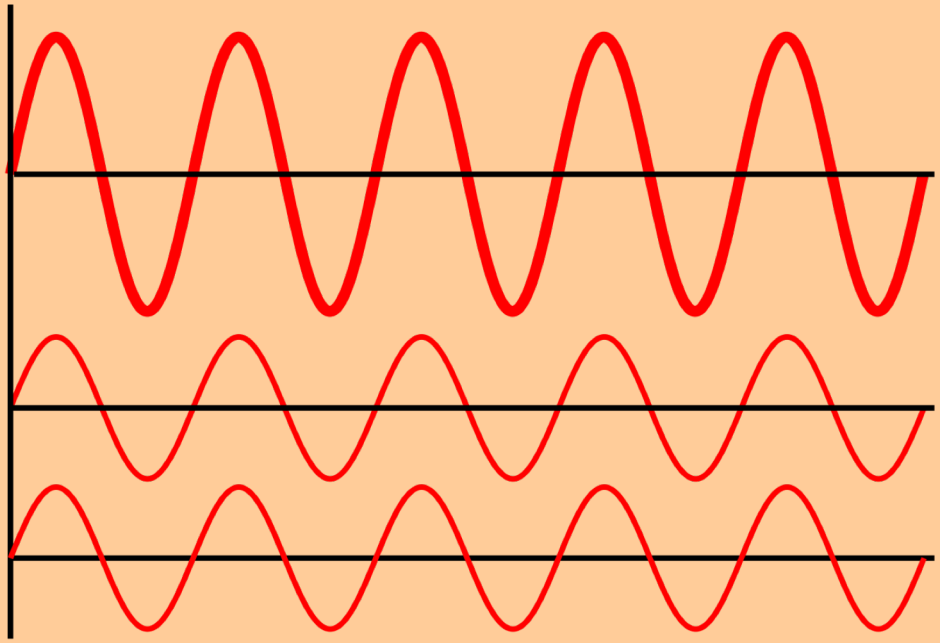


Un-equal frequencies



Equal frequencies

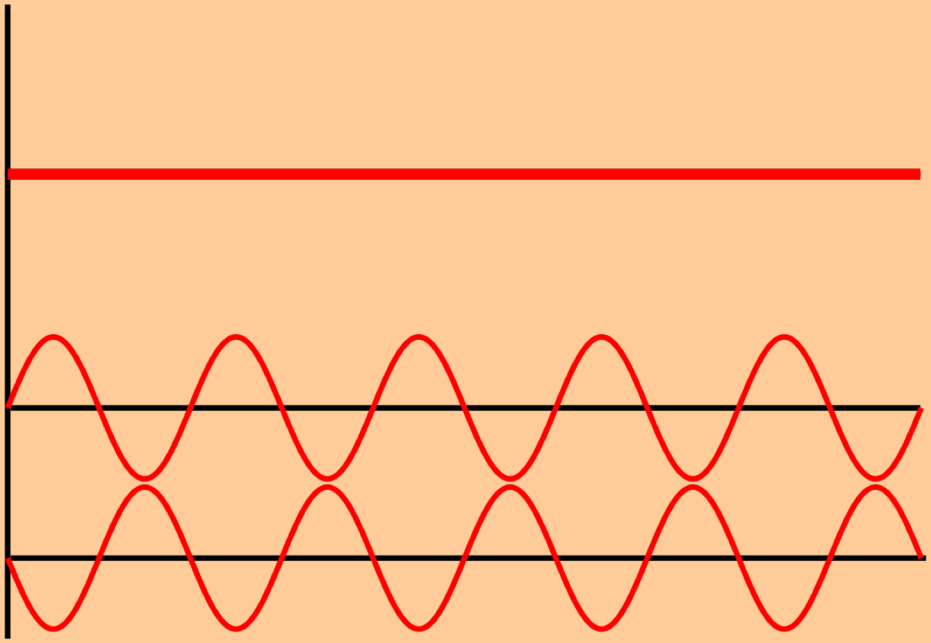
Interference: superposition of coherent waves



Similar phases

Constructive interference

$\Delta\Phi = 0^\circ$



Opposite phases

Destructive interference

$\Delta\Phi = 180^\circ$

Nature of light

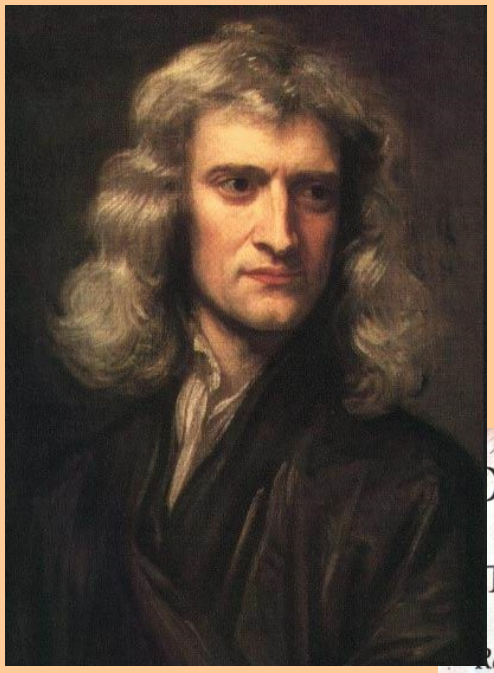
Wave?

Christiaan Huygens

(1629 - 1695)

Traité de la lumière
1690

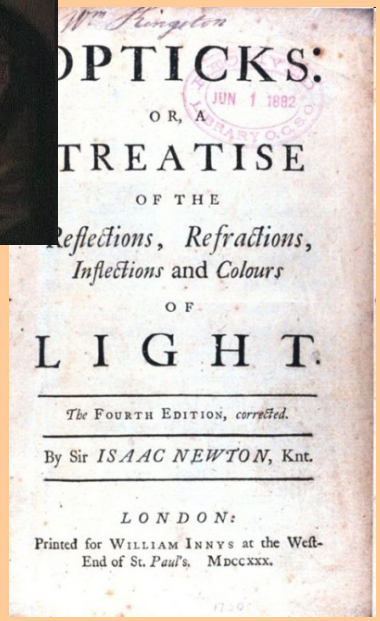
Particle?



Isaac Newton

(1642 - 1727)

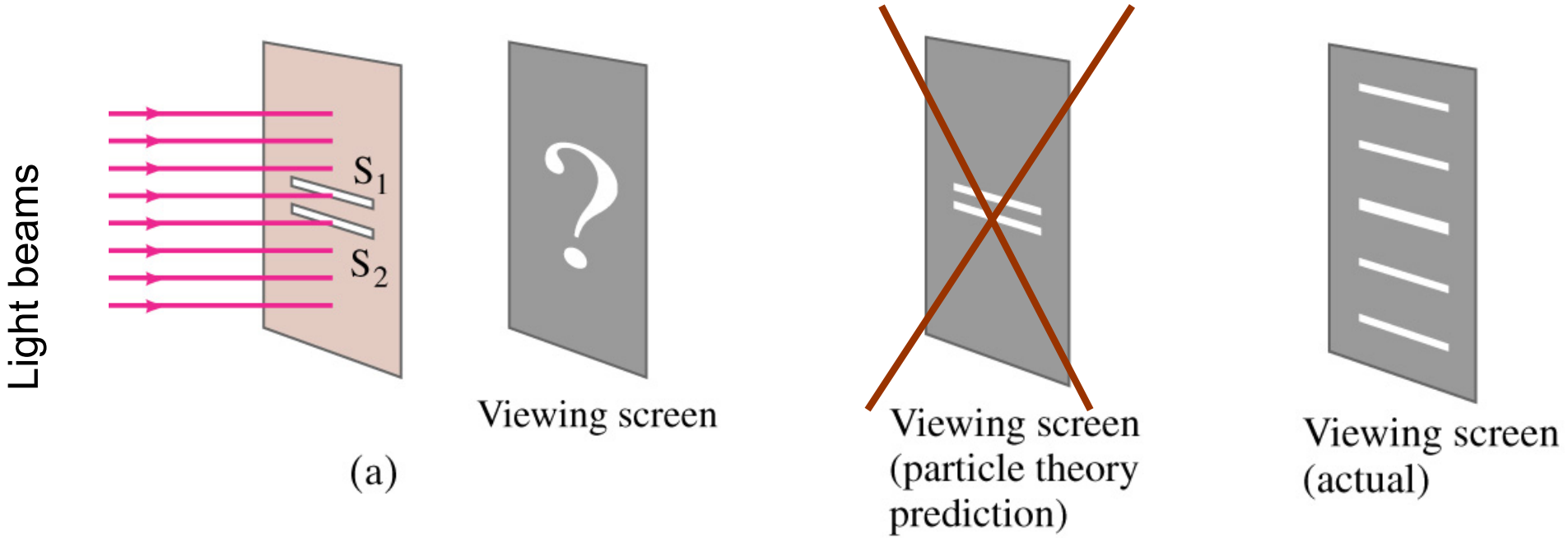
Opticks
1704


OPTICKS:
OR, A
TREATISE
OF THE
Reflections, Refractions, Inflections and *Colours*
OF
LIGHT.
The FOURTH EDITION, *corrected.*
By Sir *ISAAC NEWTON*, Knt.
LONDON:
Printed for WILLIAM INNYS at the West-End of St. *Paul's.* MDCCXXX.

Thomas Young
(1773-1829)

Wave or particle?

1. Thomas Young's double-slit experiment



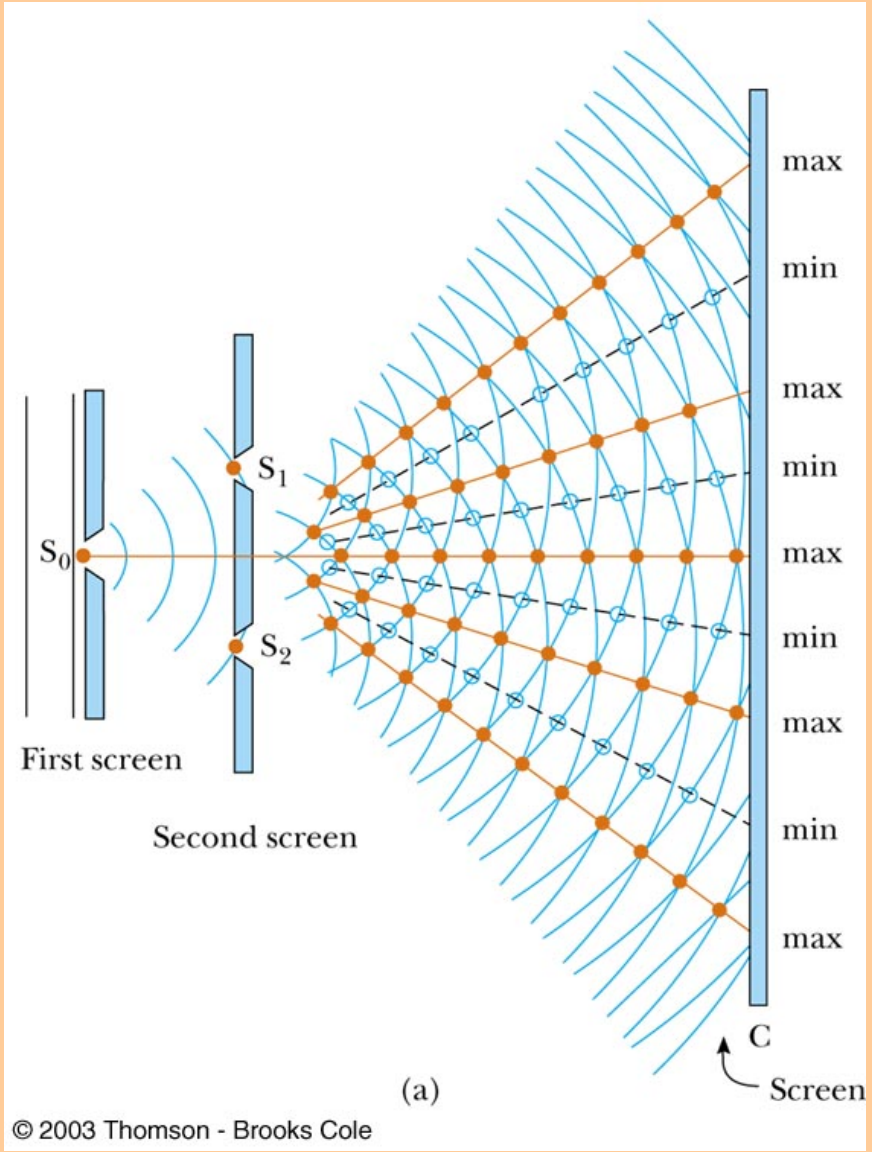
Interpretation of Thomas Young's double-slit experiment

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.

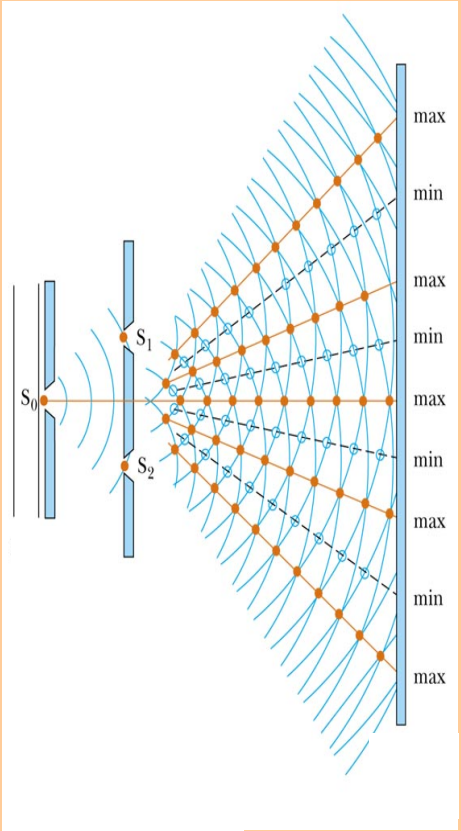
⇓⇓

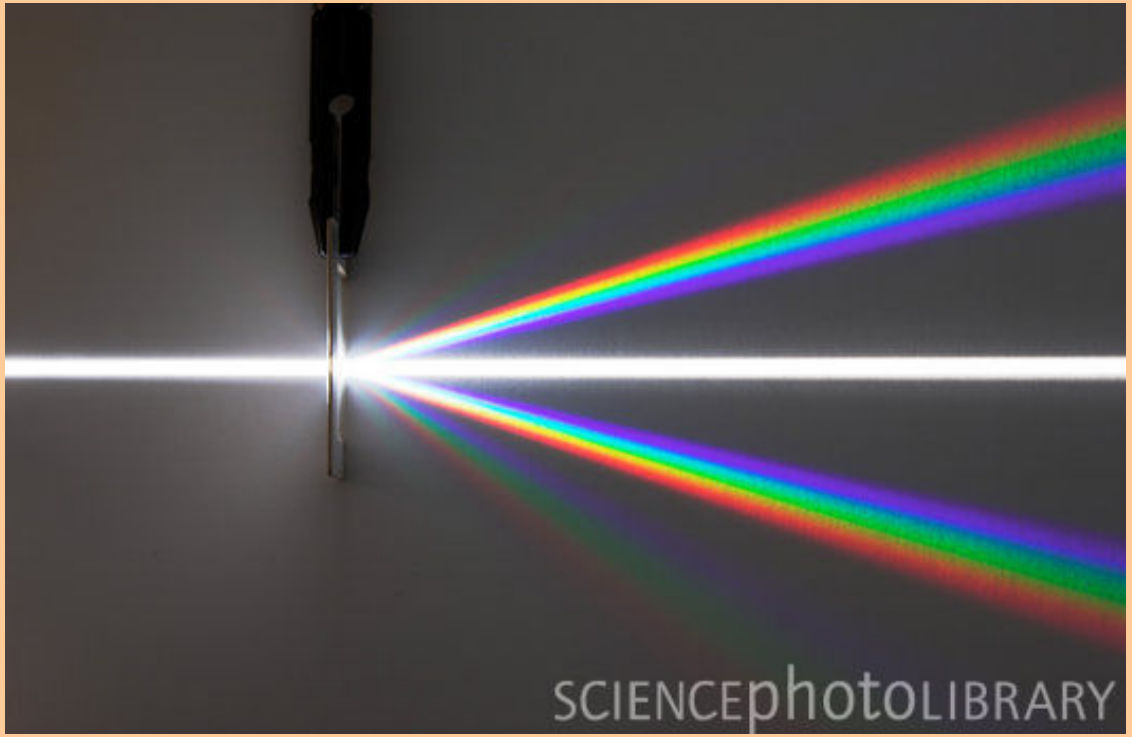
interference



Interference fringes on a screen

Dispersion of light by a diffraction grating

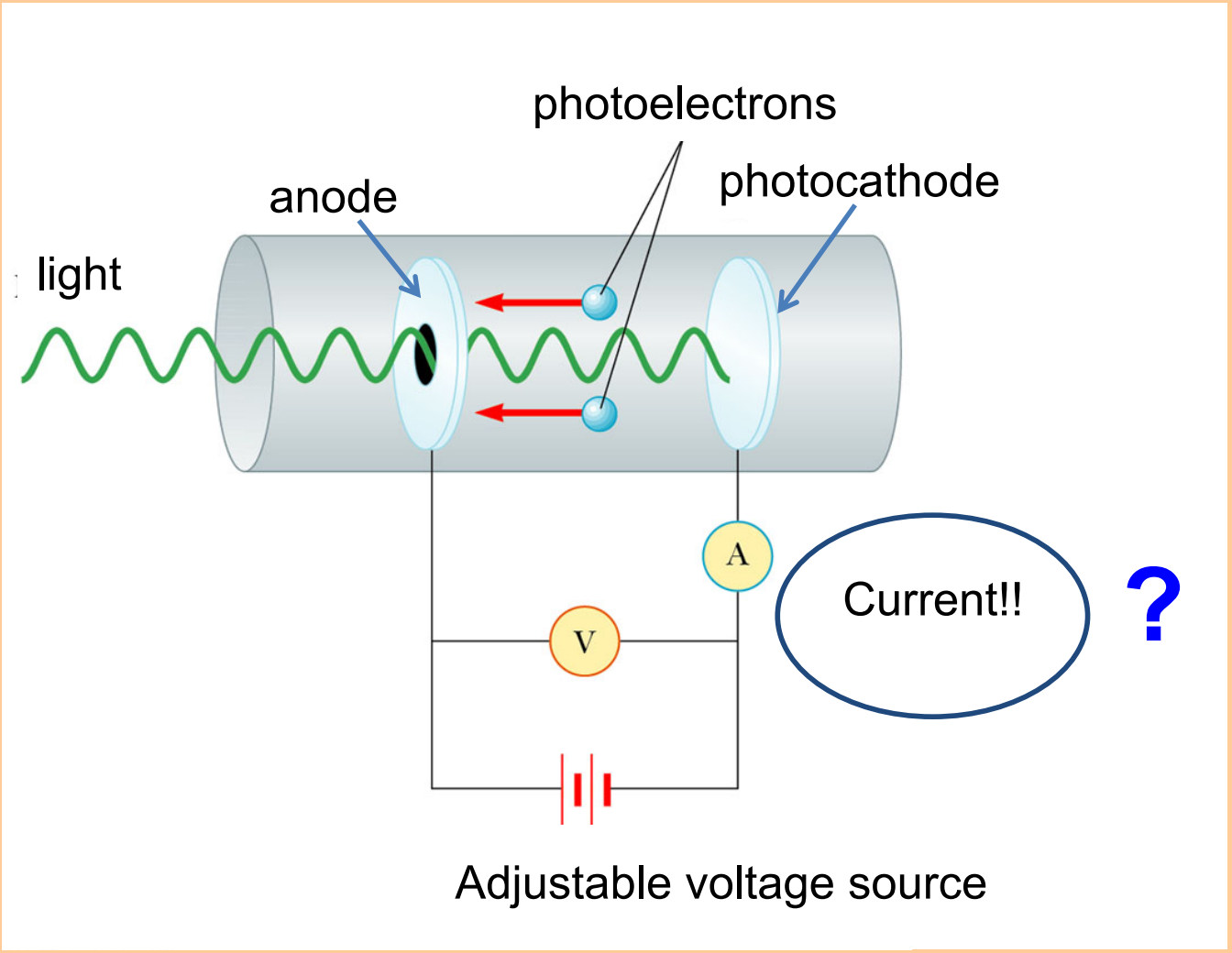




Wave or particle?

2. Hertz's experiment

Heinrich Hertz
1887



Photoelectric effect

Current ?

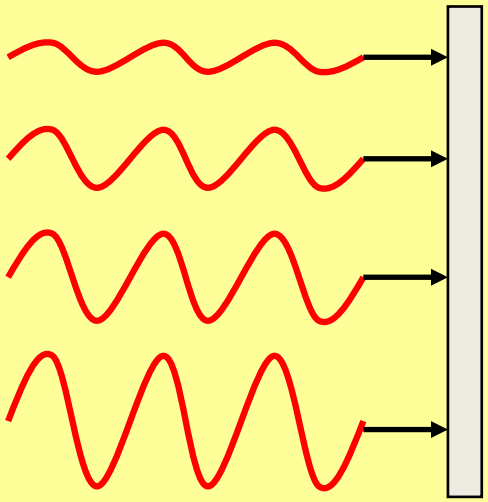
Light irradiation

Similar color / wavelength

Similar amplitude

increasing amplitude / intensity

Current?



no

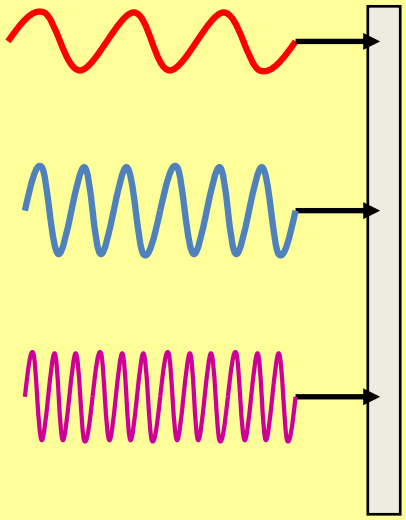
no

no

no

variation in color / wavelength

Current?



no

yes

yes

No current up to a critical value of frequency!

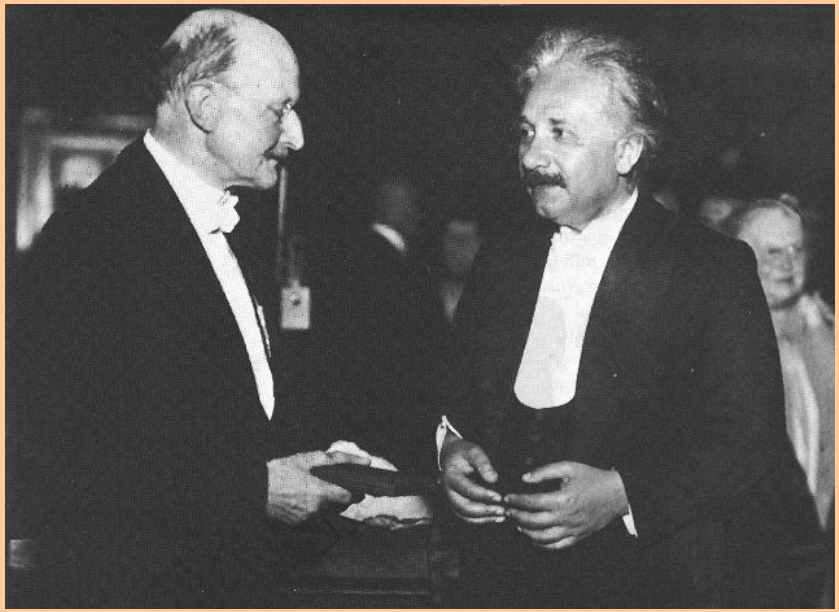
Interpretation of photoelectric effect

- Based on the wave character it is not possible.

- Planck – foundation of quantum physics: $E = hf$ (1900)

- Einstein's concept is based on the quantum theory (1905)

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's interpretation

- Light consists of a finite number of energy quanta - photons
- The energy of a photon: $E = hf$
- Photon can be absorbed or generated only as complete units
- A photon transfers 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: $E_{kin} = hf - A$

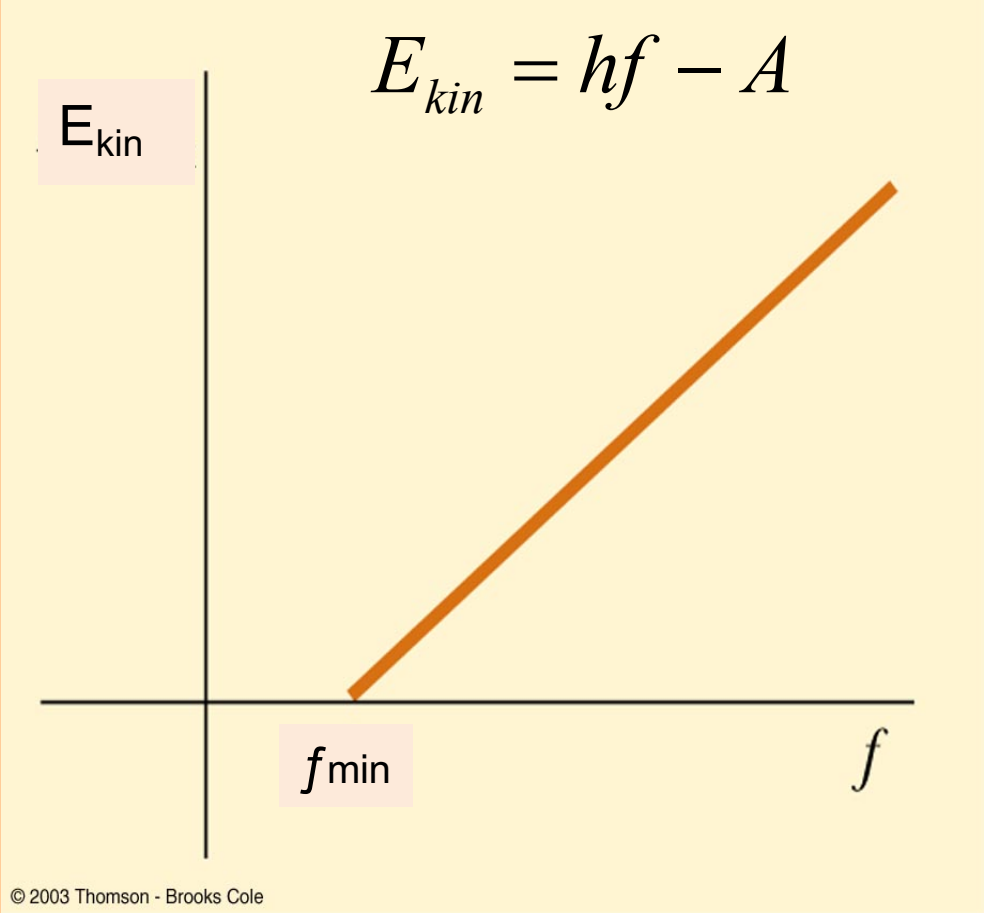
Einstein's interpretation and the frequency limit

Kinetic energy of the emitted electron is 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: $h = 6.62 \cdot 10^{-34}\, Joule \cdot s$

Photons have no resting mass and propagate in vacuum

Calculation of photon energy for light

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

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*

800 nm – 400 nm

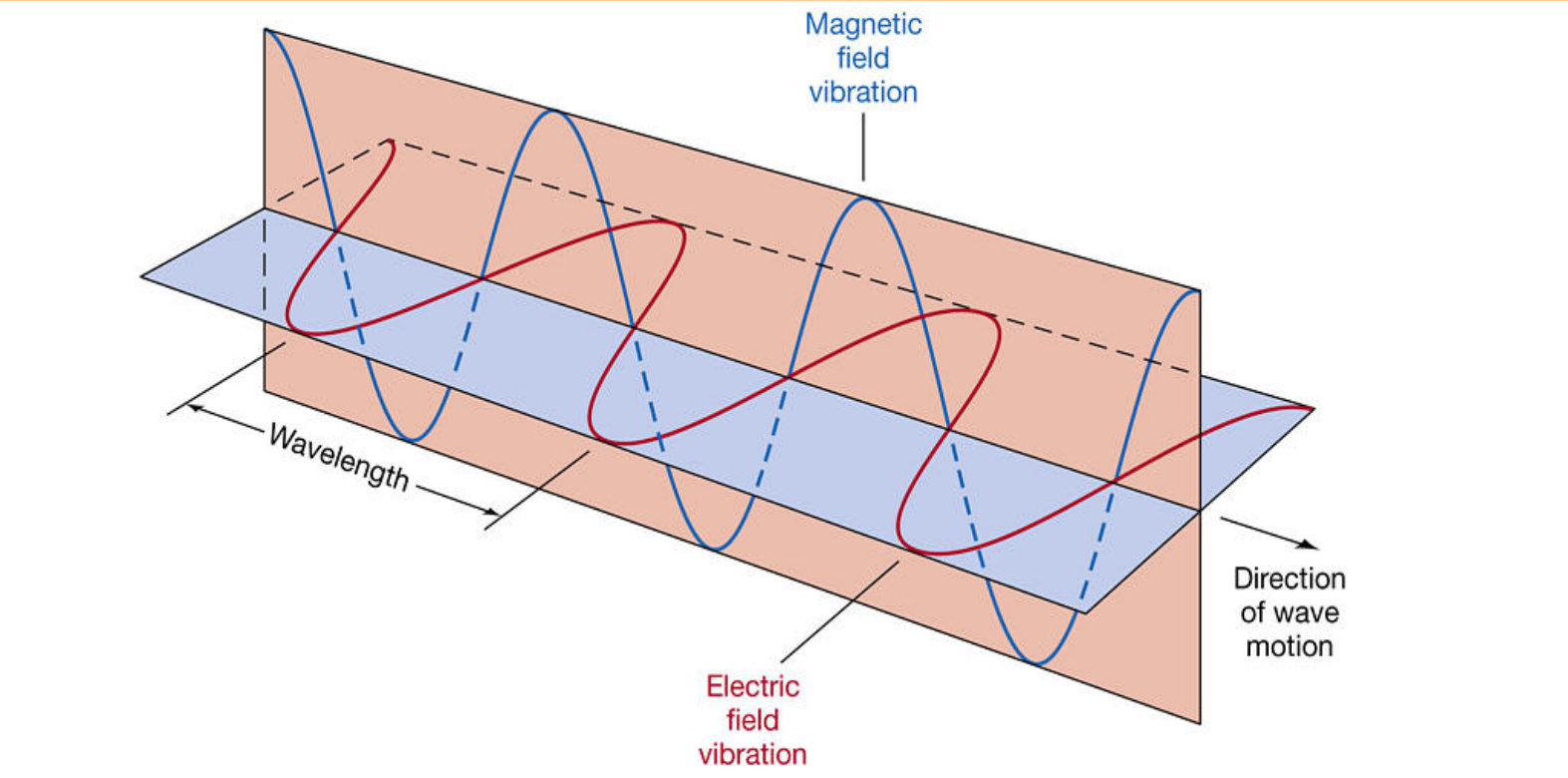
How much ……?

- 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 cyan light photon
- 1/40 eV: kT energy at room temperature

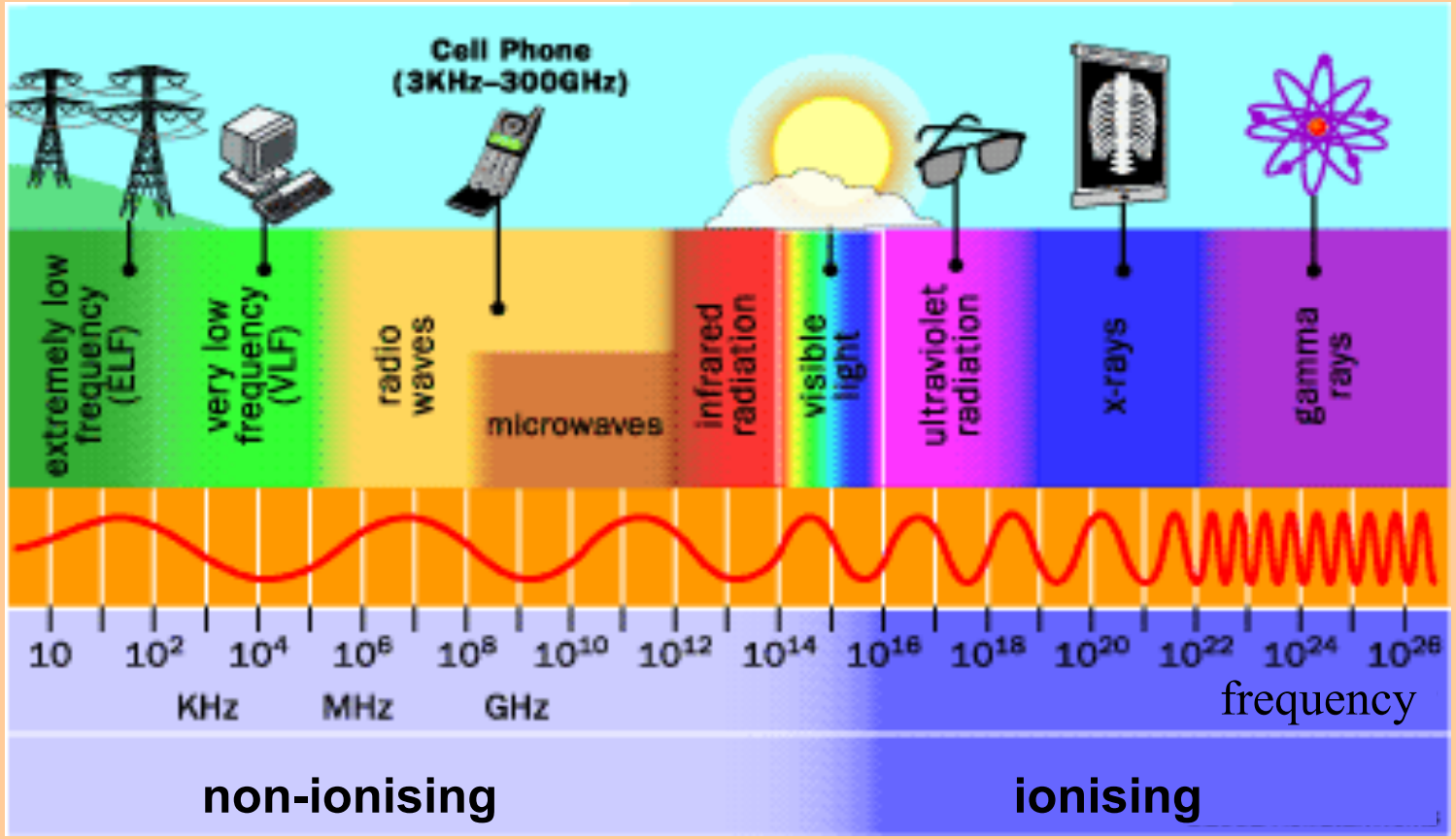
Dual nature of light

Wave – electric and magnetic fields vary sinusoidally

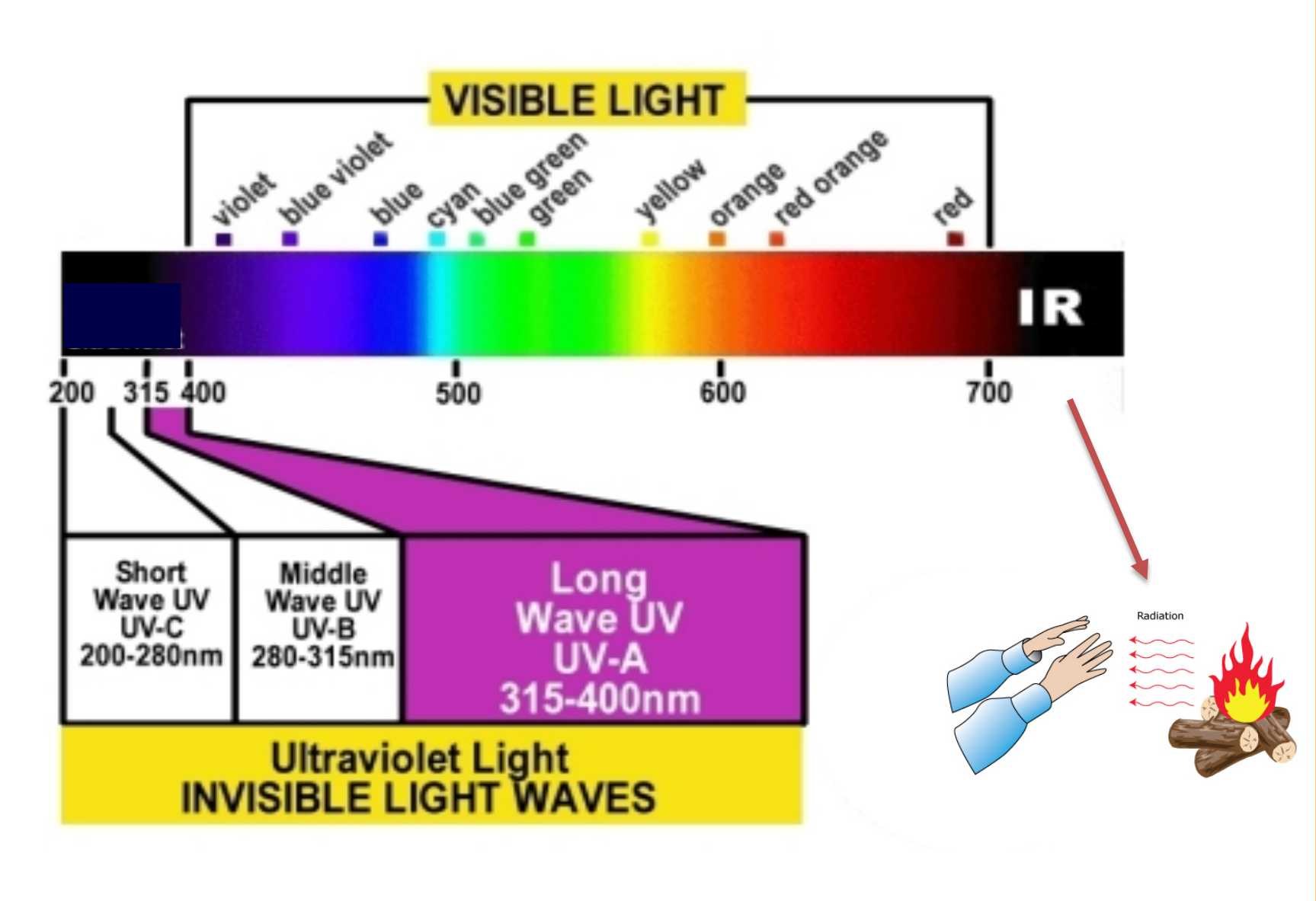
Electromagnetic radiation



Ranges of electromagnetic radiation



Optical range

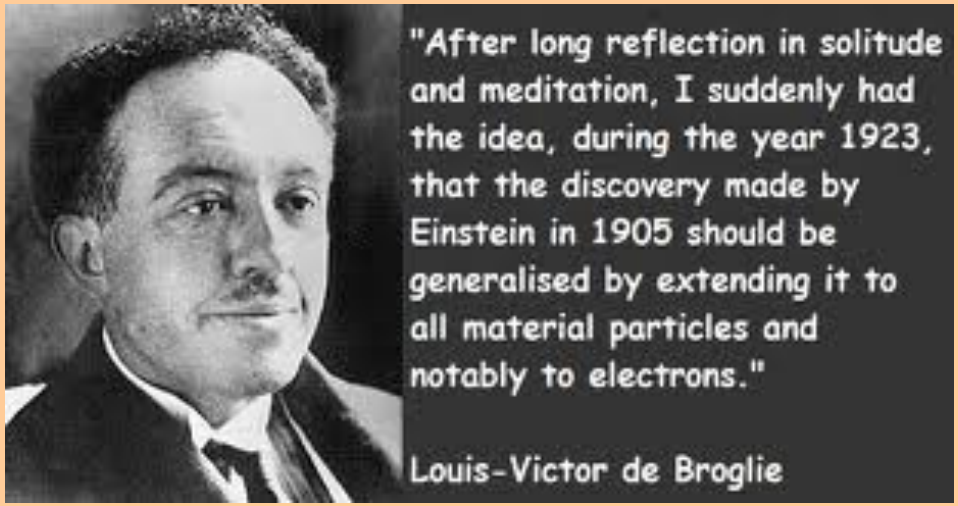


Why only light could have dual nature?

De Broglie concept: the wave–particle duality

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

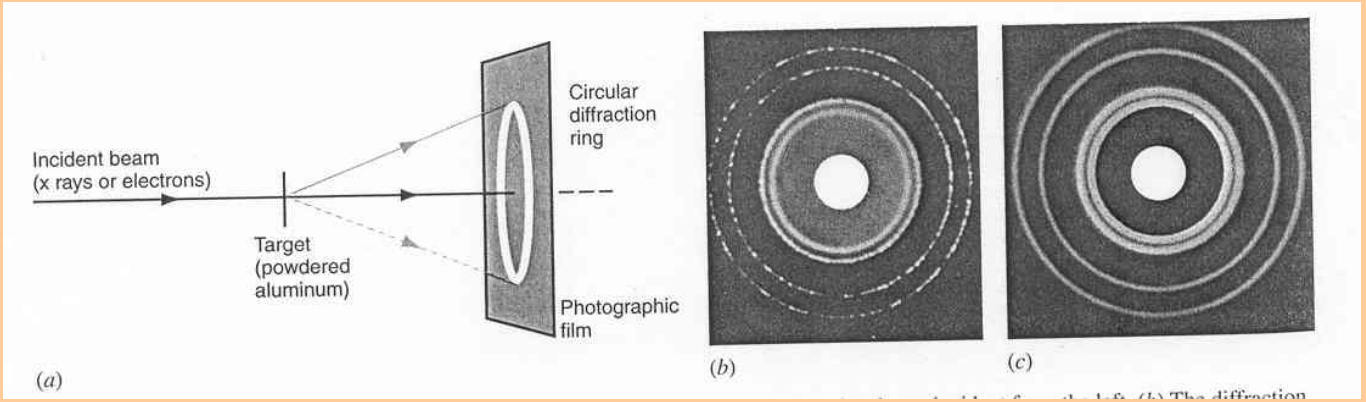
Momentum of the electron: $p = m_e v$



$$\lambda = h / p$$

Nobel prize in 1929

Particles can behave as 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"

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
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