Biophysics I

1. Introduction, Radiations

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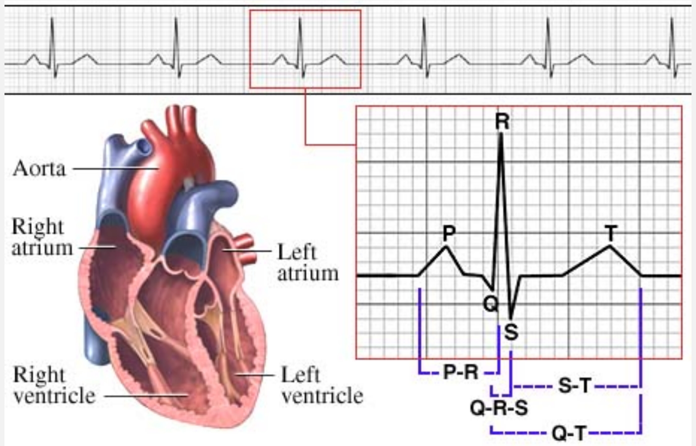
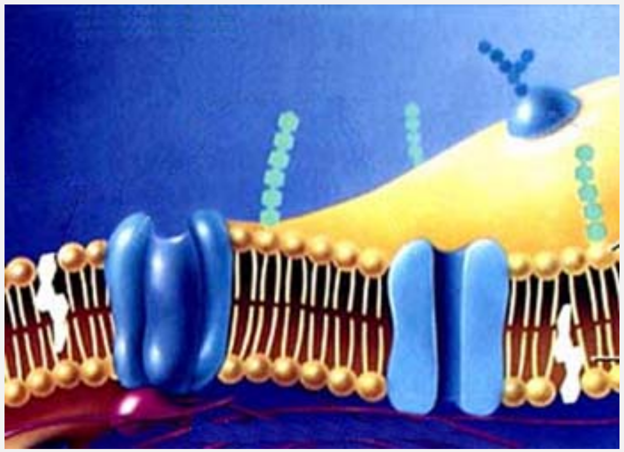
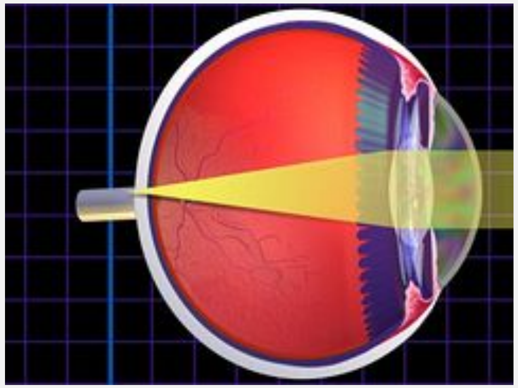
What is the subject of biophysics?

Physical backgrounds of biological processes

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



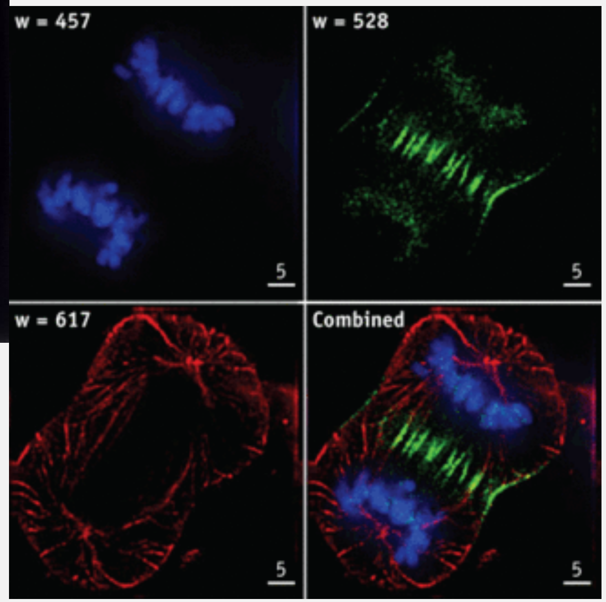




What is the subject of biophysics?

Physical methods in biology and medicine

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



Scientific method

Observations, experiments = data collection

Data analysis = finding causative relations among data

Relations = mathematical models describing the dependence of observations on independent variables (parameters)

Model building is always simplification. Based on a model, we make assumptions out of the known observation to validate them experimentally. If the new results agree with the model prediction than we keep the model, if not than we must modify the model = models are ***falsifiable***! = experimental results support or disprove a model. Occam's razor = from alternative explanations (models) of a phenomenon, we should select the one posits the fewest assumptions.

Medical sciences (!)

Math and physics we need for biophysics

(formula collection)

quantitative models = mathematical functions

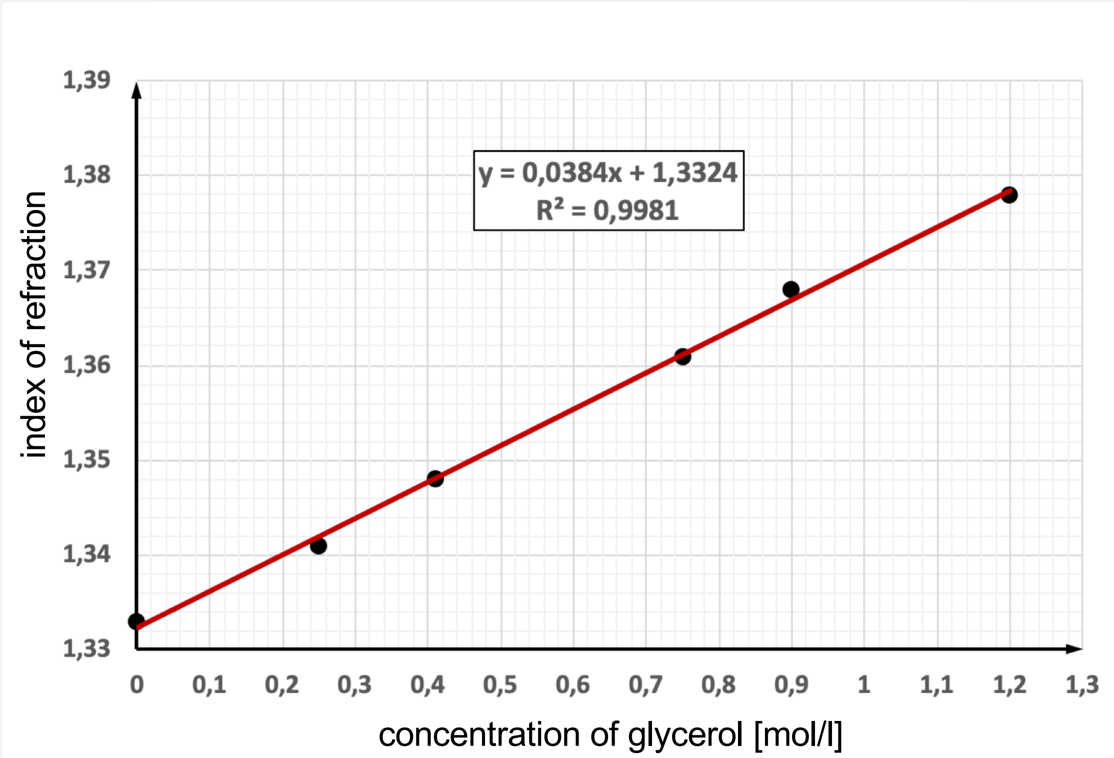
an example – how the index of refraction changes as a function of the concentration of soluts in diluted solutions? $n = n_0 + k*c$

what we need:

- *linear function*
- *power function*
- *exponential and logarithmic function*
- *harmonic function*

good to know:

- *transformations of formulas*
- *vectors*
- *units*



Physical bases of biophysics

Department of Biophysics and Radiation Biology
Semmelweis University - Faculty of Medicine

Home | **Education** | Research | Services | Staff | Contact

Faculty of Medicine
- Biophysics Labs
- Mathematical and Physical Basis of Medical Biophysics
- Medical biophysics 1.
- Medical biophysics 2.
- Medical statistics, informatics and telemedicine
- Teaching assistant work

Faculty of Dentistry
- Biophysics 1. Dentistry
- Biophysics 2. (Dentistry)
- Biophysics Labs
- Physical bases of biophysics
- Physical Foundations of Dental Materials Science
- Teaching assistant work

Faculty of Pharmacy
- Biophysics 1.
- Biophysics 2.
- Biophysics Labs
- Physical bases of biophysics
- Teaching assistant work

Other undergraduate education

Physical bases of biophysics
2021-2022

Information | Lectures | Exam

General information
Elective course (lectures only)

1 credit

The course will be held in Hári lecture hall during the first four Tuesdays (19:10 - 20:40) and Fridays (16:50 - 18:20) of the semester.

Important: passing the closing test from the course material is mandatory for all medical students. Passing the test is a requirement for obtaining a signature in Biophysics I.

Therefore, we recommend it to every student to attend this course, as it will help in preparing for the mandatory test and for studies in Biophysics.

Closing test of the course: the date will be announced later

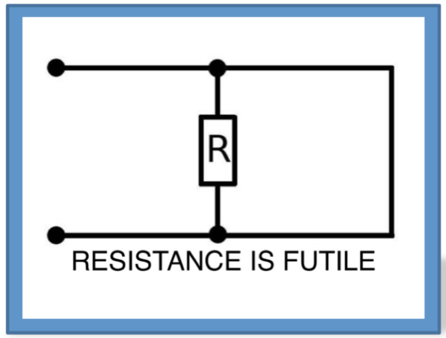
Aims of the subject within the medical studies
The aim of the subject is to remedy the deficiencies in the education of mathematics and physics in secondary schools, and to provide the background knowledge necessary for the Biophysics subject.

Supporting educational materials (textbooks, notes etc.)
- Physical Bases of Biophysics (manual)
- Unit conversion
- Transposition of formulae

Mathematical and Physical Basis of Medical Biophysics

Supplementary material for the „Medical Biophysics" and „Biophysics" courses

Edited by: Dr. Ferenc Tölgyesi, associate professor



Semmelweis University
Department of Biophysics and Radiation Biology
2016

Important concepts: energy (work, power), momentum, force (fields), kinematics (velocity, acceleration)...

Topic list of the first semester

1	Introduction to biophysics, radiations, elektromagnetic spectrum
2	Ray optics: Fermat's principle, refraction, lenses, microscope
3	Wave optics: Huygens's principle, diffraction, interference, resolution
4	Light interacting with matter: scattering, absorption, reflection, color vision
5	Atoms, molecules, structure of matter
6	Thermal emission; emission of human body infradiagnostics
7	Luminescence, applications in medicine
8	Lasers, applications in medicine
9	Modern microscopy techniques
10	X-ray: production, characteristics, and applications
11	Photobiology, applications in medicine
12	Bases of X-ray diagnostics
13	Nuclear radiations, bases of isotope diagnostics
14	Clinical applications of nuclear radiations

Radiations

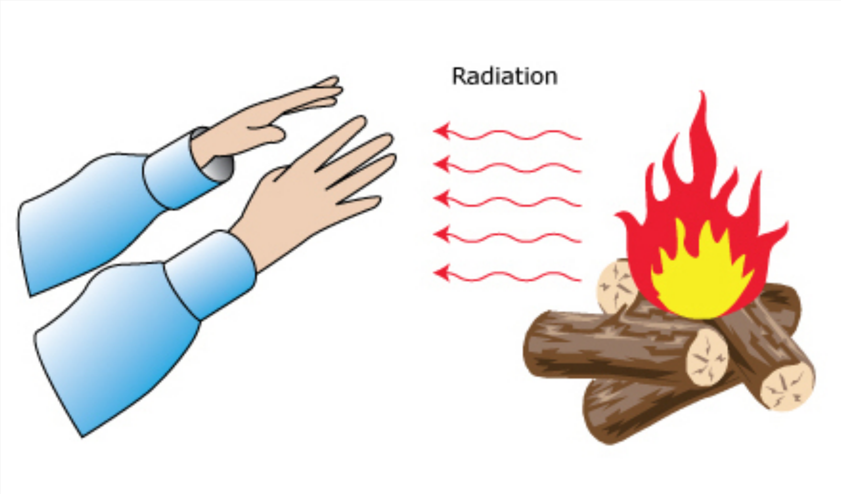
radiation = release (emission) and transfer (propagation) of energy (in the form of waves or particles)

Examples:

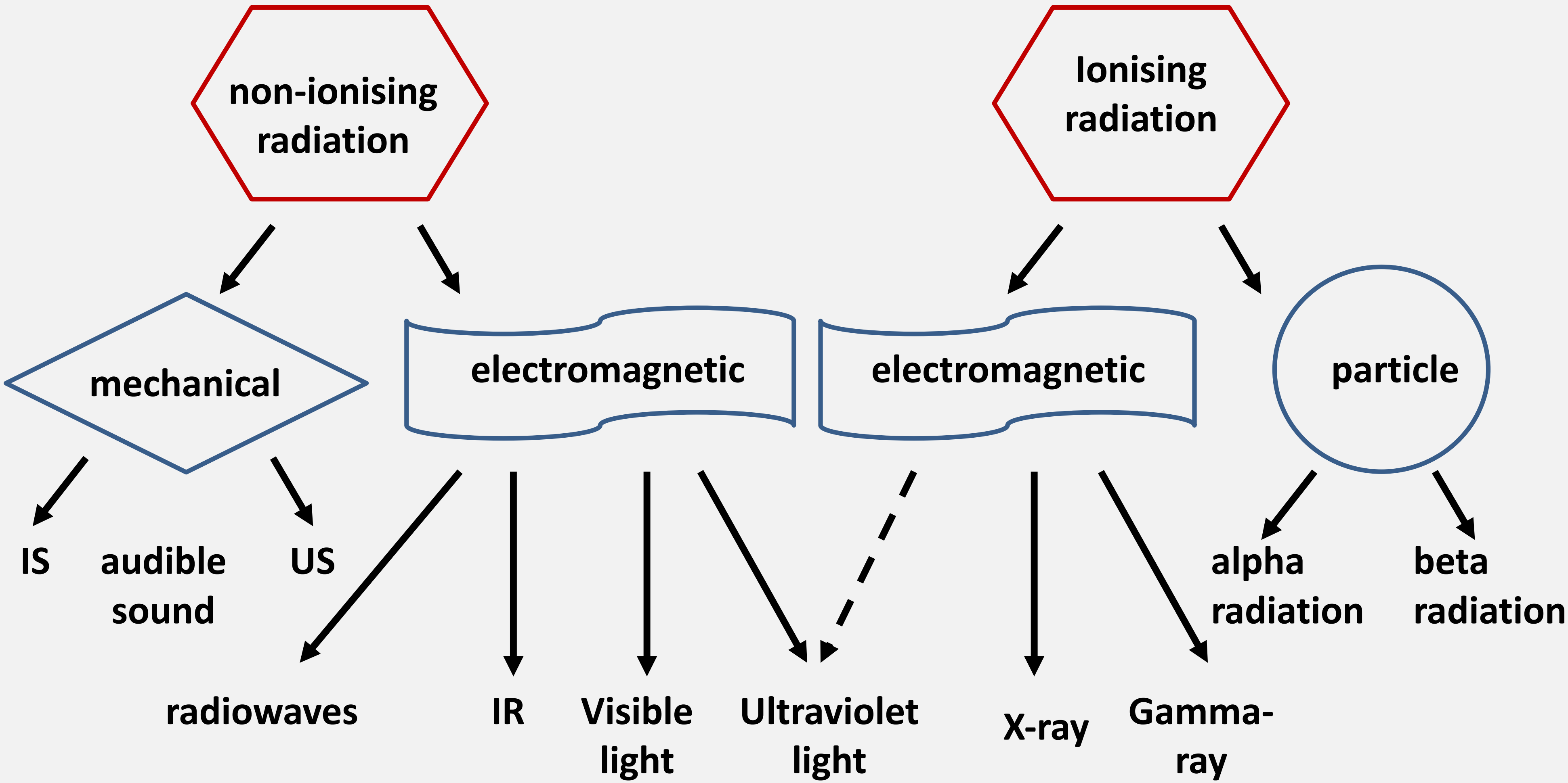
sound, light

radiowaves, X-ray

nuclear radiations



Classification of radiations



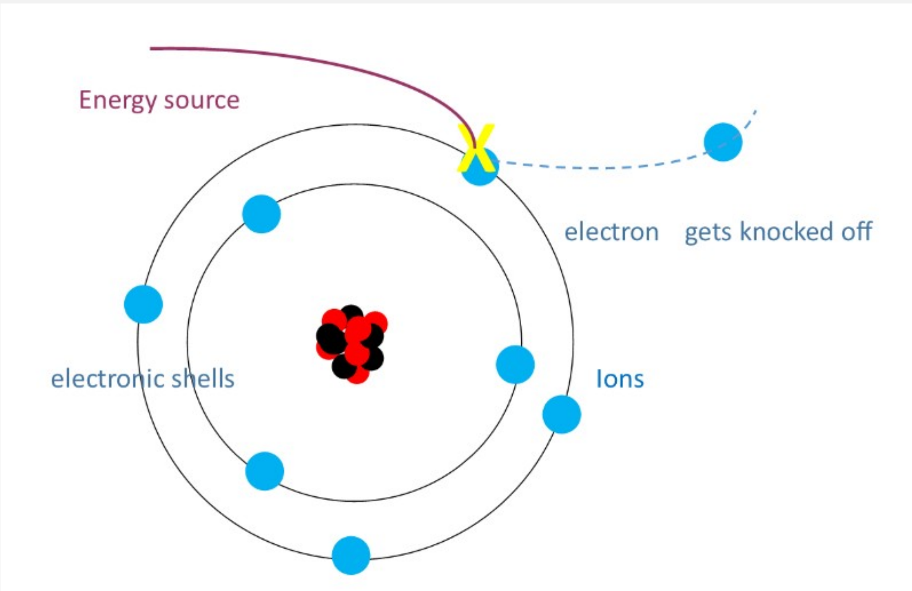
Classification of radiations

non-ionising radiation

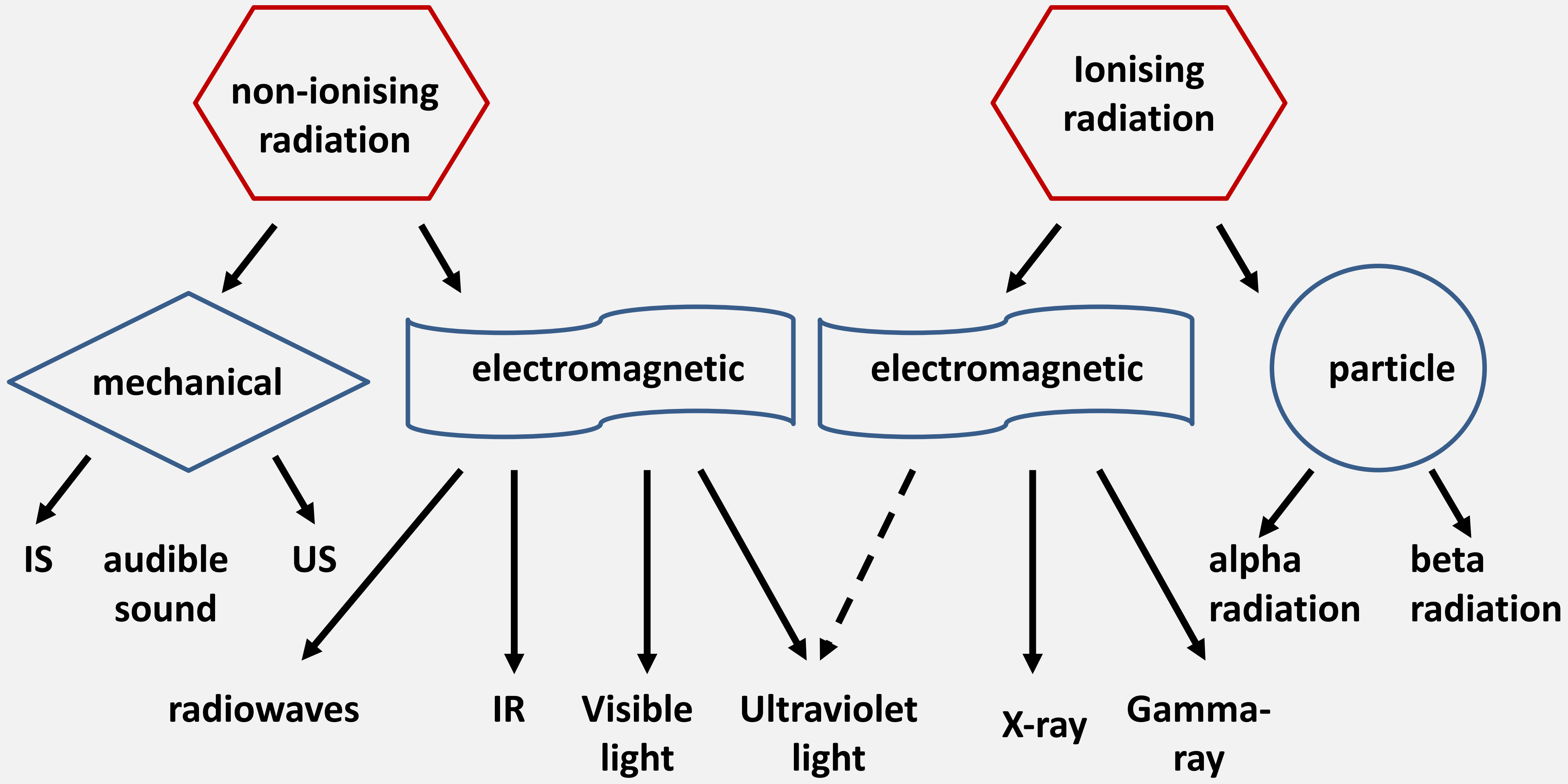
Ionising radiation

What is the basis of classifications?

IONISATION



Classification of radiations



General description of waves

periodic disturbances in space and time, transferring energy

Waves differ in

- type of energy
- intensity
- mechanism of propagation

Characteristic values

Period in space – *wavelength*

λ [m] or [nm]

displacement – *amplitude*

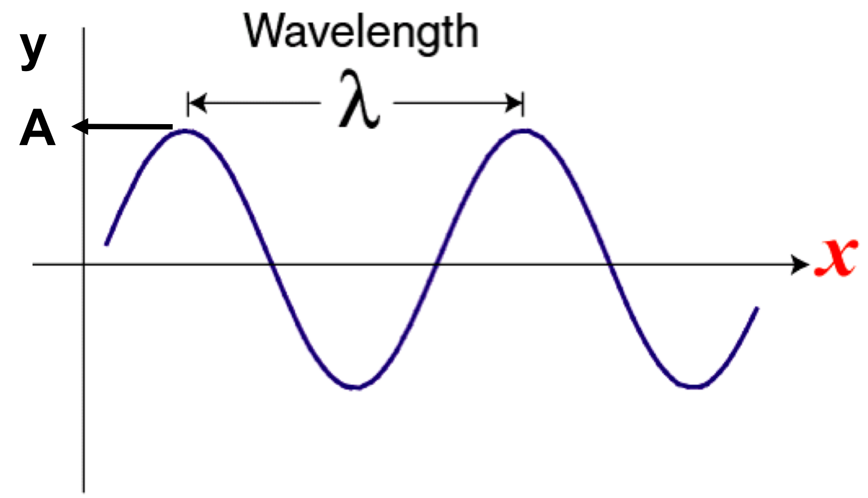
$$E \sim A^2$$

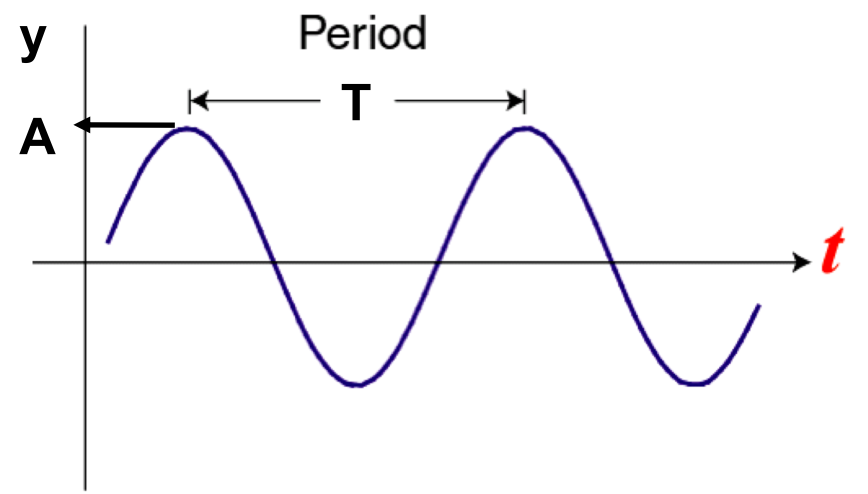
Period in time – *period, T*

– *frequency, f*

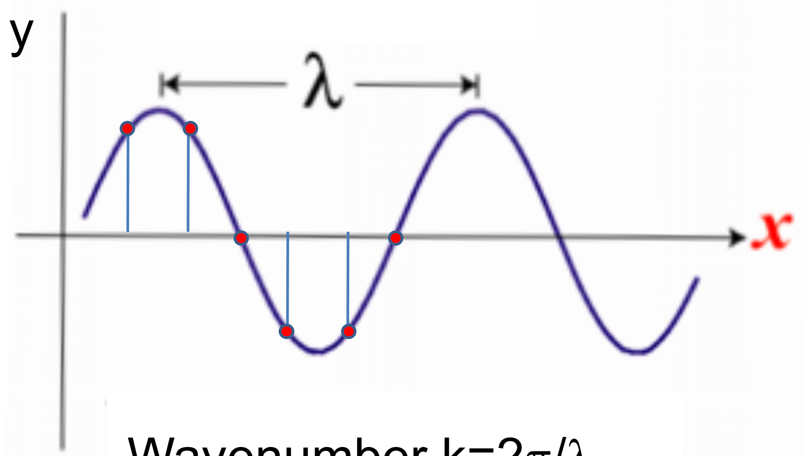
$$f = \frac{1}{T}\left[\frac{1}{s}\right]$$

velocity of waves: c = λ/T = λf

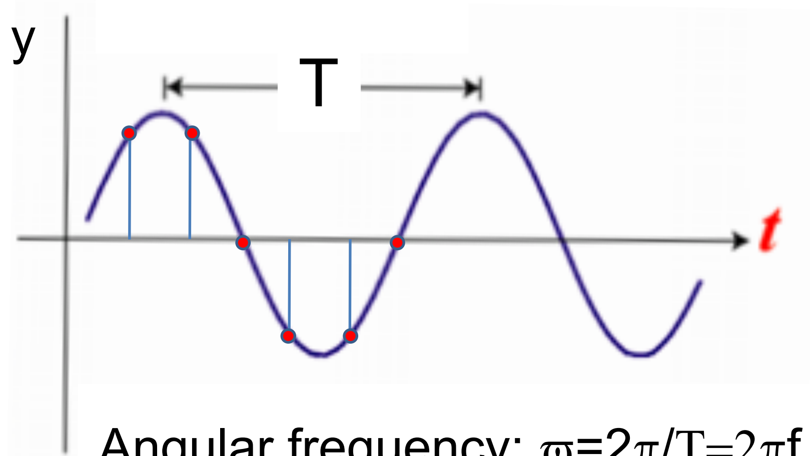




Phase: the location or timing of a point within a period



Wavenumber $k=2\pi/\lambda$



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

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

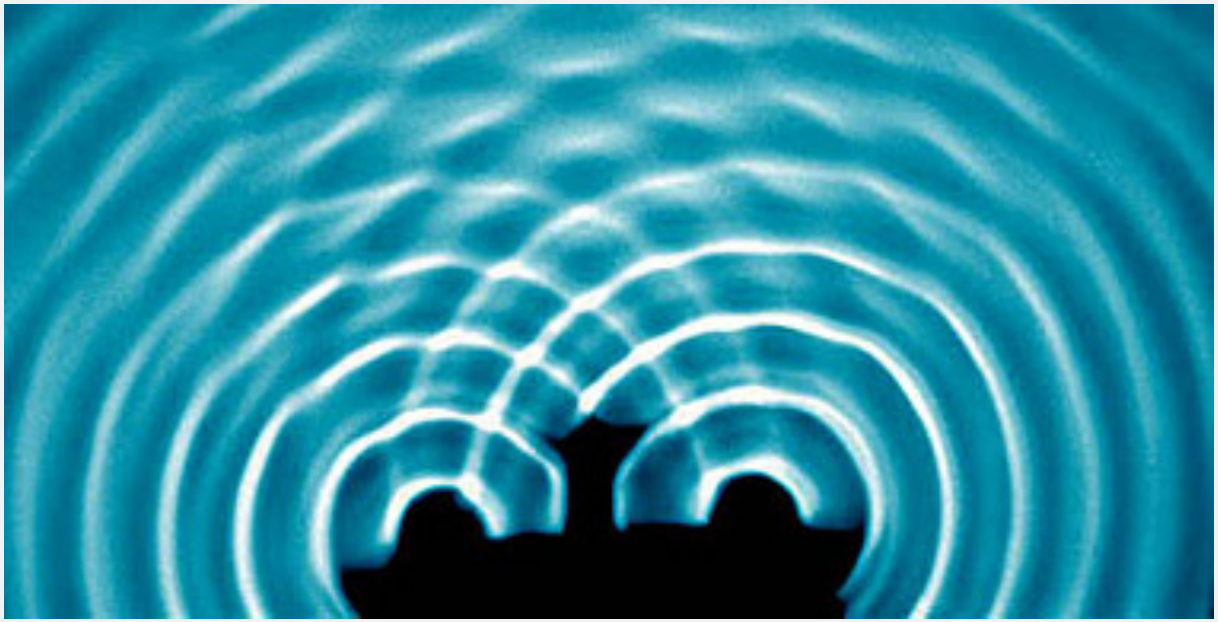
$\phi(t)=\varpi t+\phi_o$

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

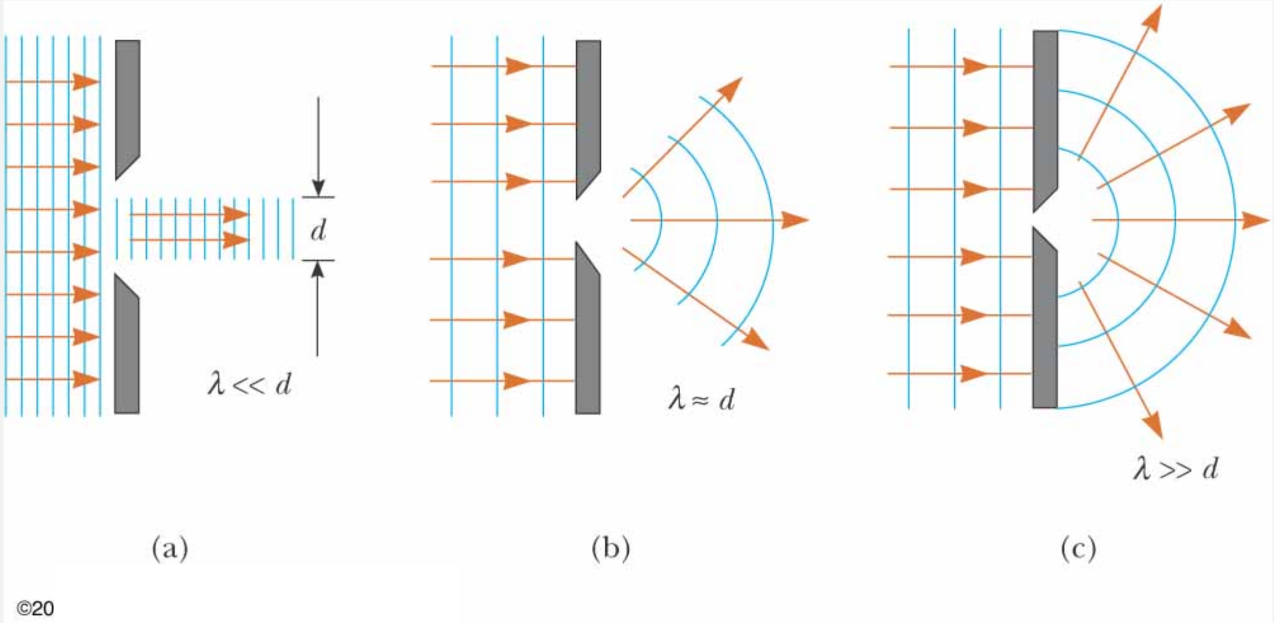
Phase: fraction of the wave cycle that has elapsed relative to the origin

Indications for a wave nature:

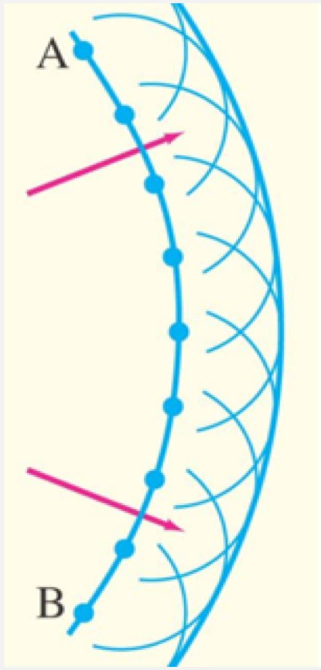
- diffraction
- superposition / interference
- polarisation



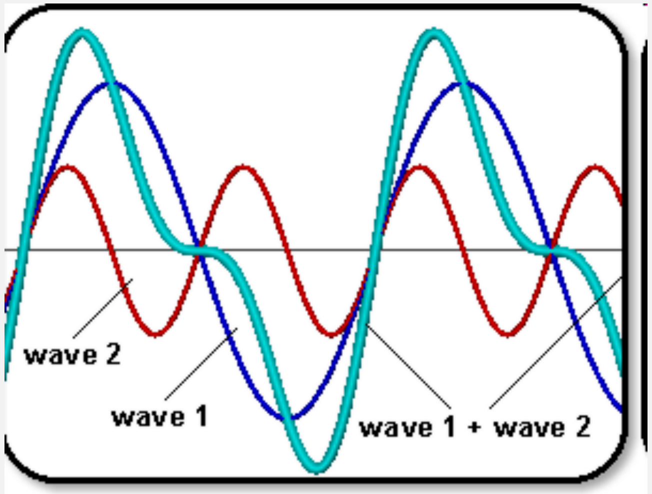
Diffraction



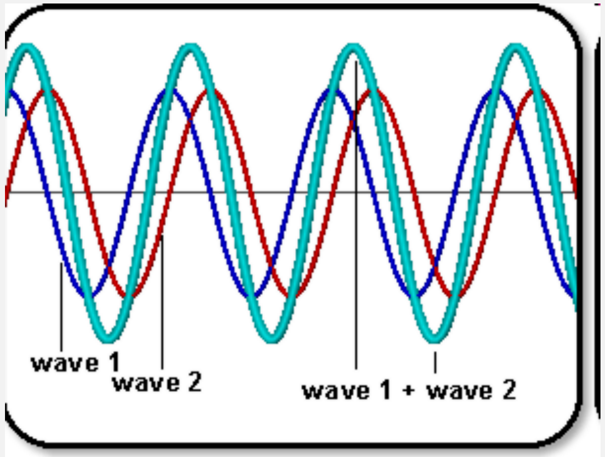
Huygens' principle: every point in a propagating wavefront serves as the source of spherical secondary wavelets, such that the wavefront at some later time is the envelope of these wavelets.



Superposition: The principle of superposition applies 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.

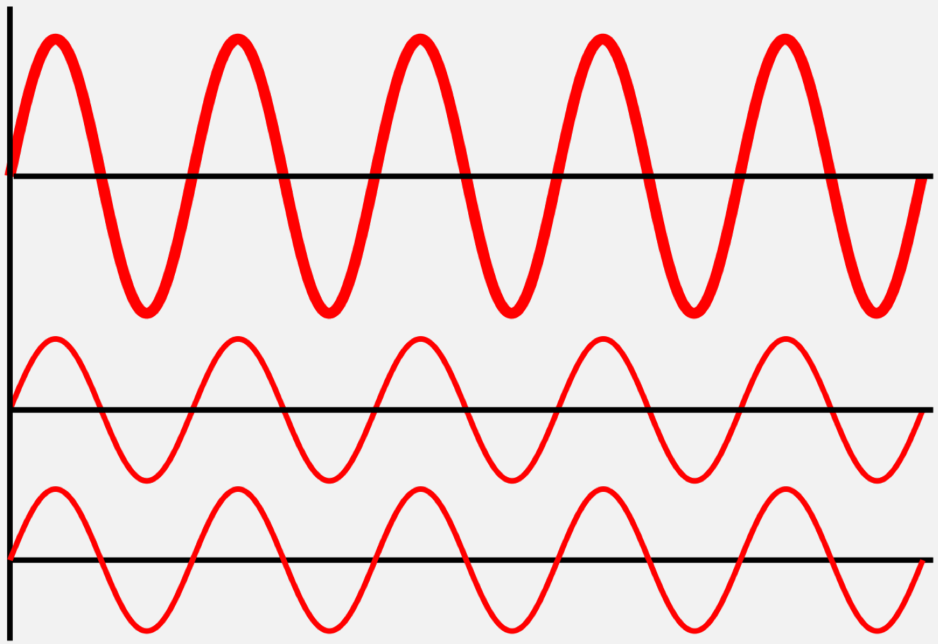


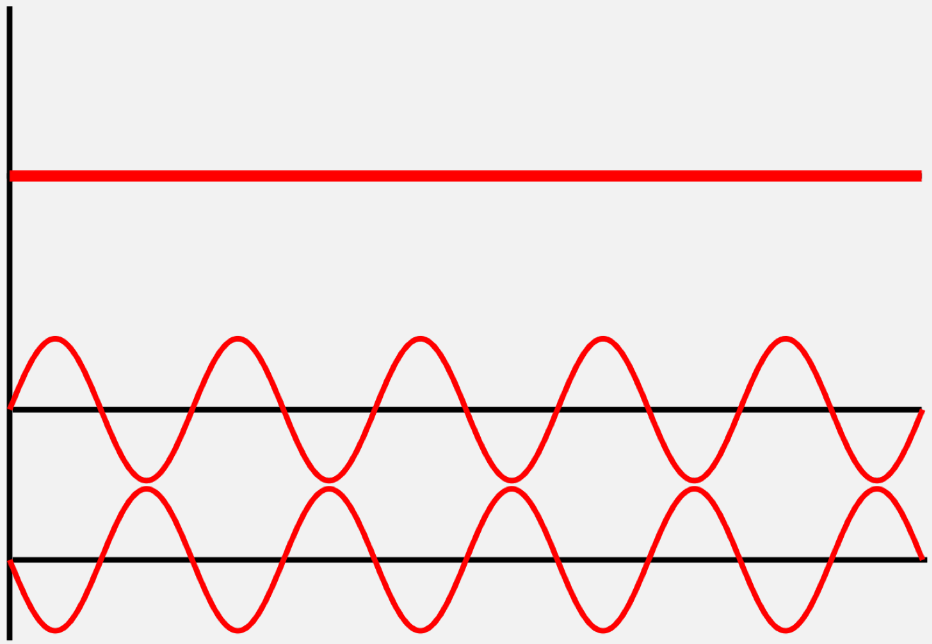
Un-equal frequencies



Equal frequencies

Interference: superposition of coherent waves





Similar phases

Constructive interference

$$\Delta\Phi = 0^\circ$$

Opposite phases

Destructive interference

$$\Delta\Phi = 180^\circ$$

The nature of light is...

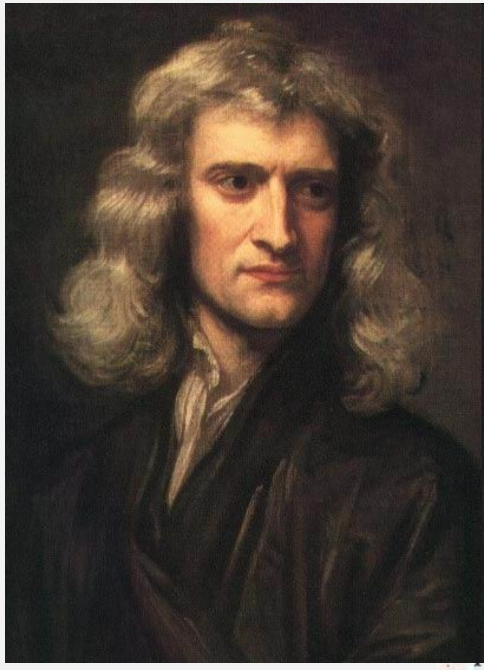
a wave?

particle?

Christiaan Huygens

(1629 - 1695)

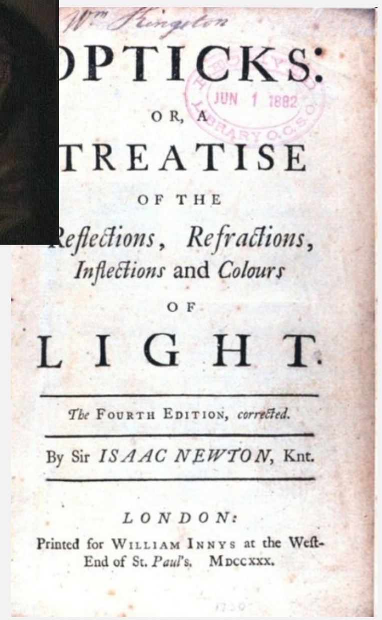
Traité de la lumière
1690



Isaac Newton

(1642 - 1727)

Opticks
1704



OPTICKS:
OR, A
TREATISE
OF THE
Reflections, *Refractions*,
Inflections and *Colours*
OF
LIGHT.

The Fourth Edition, *corrected*.

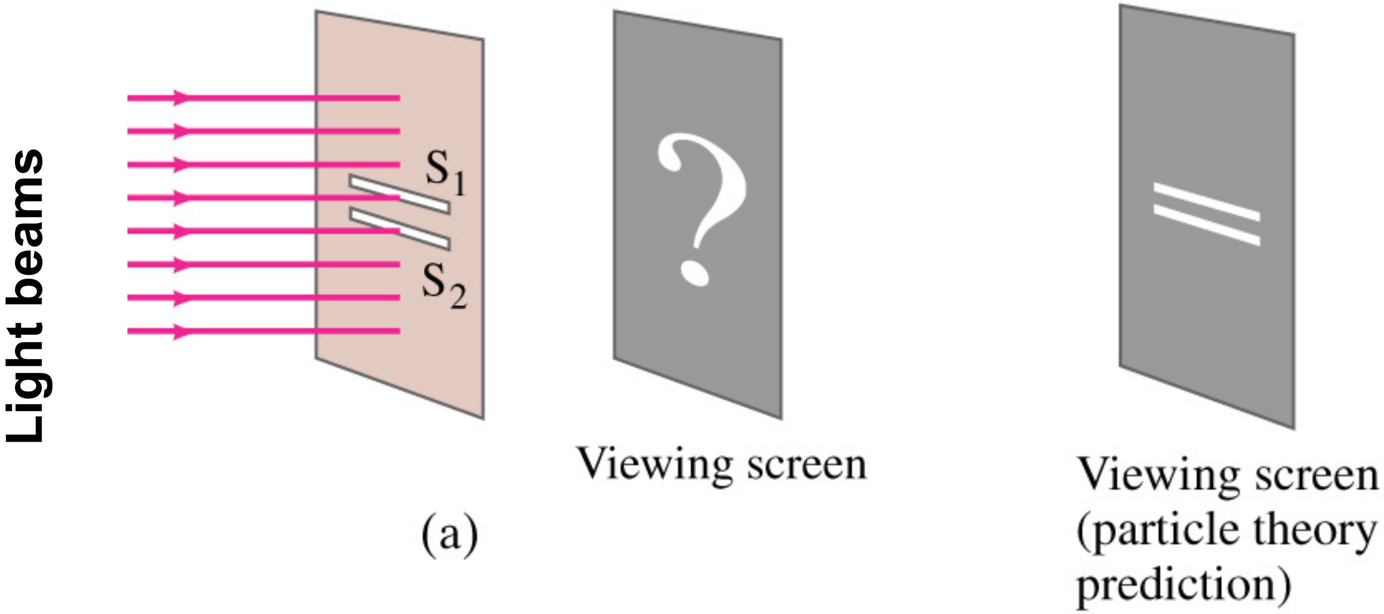
By Sir *ISAAC NEWTON*, Knt.

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



Wave or particle?

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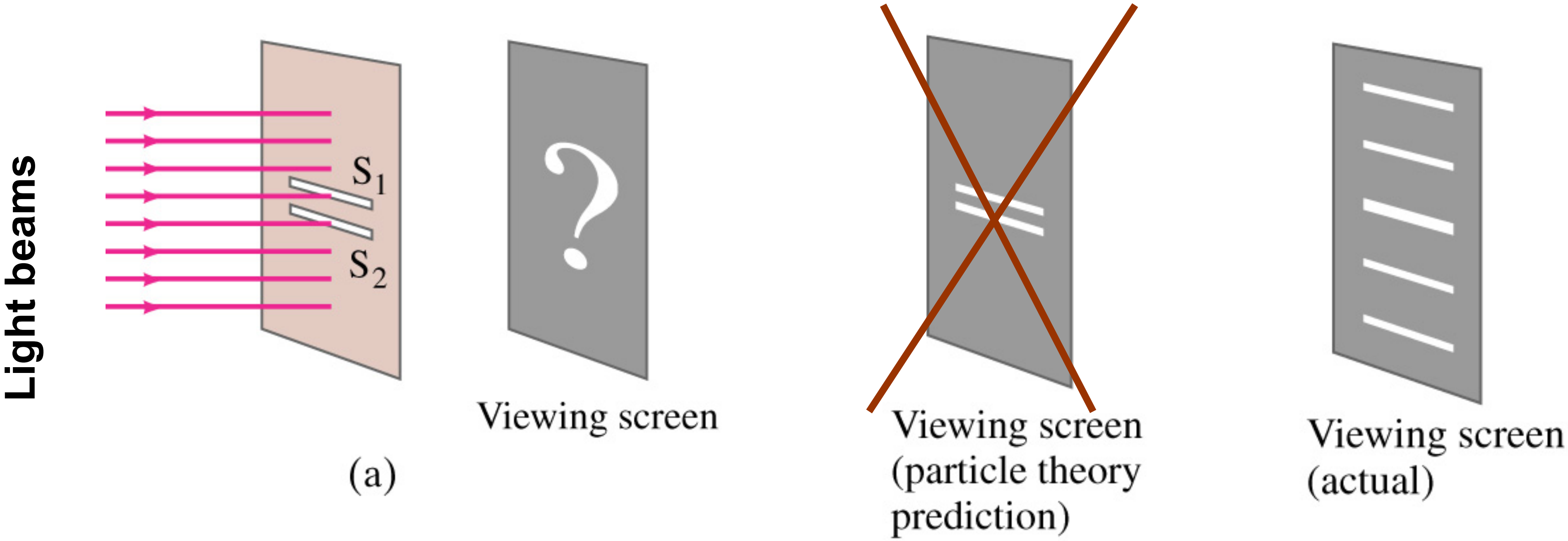
1. Thomas Young's double-slit experiment



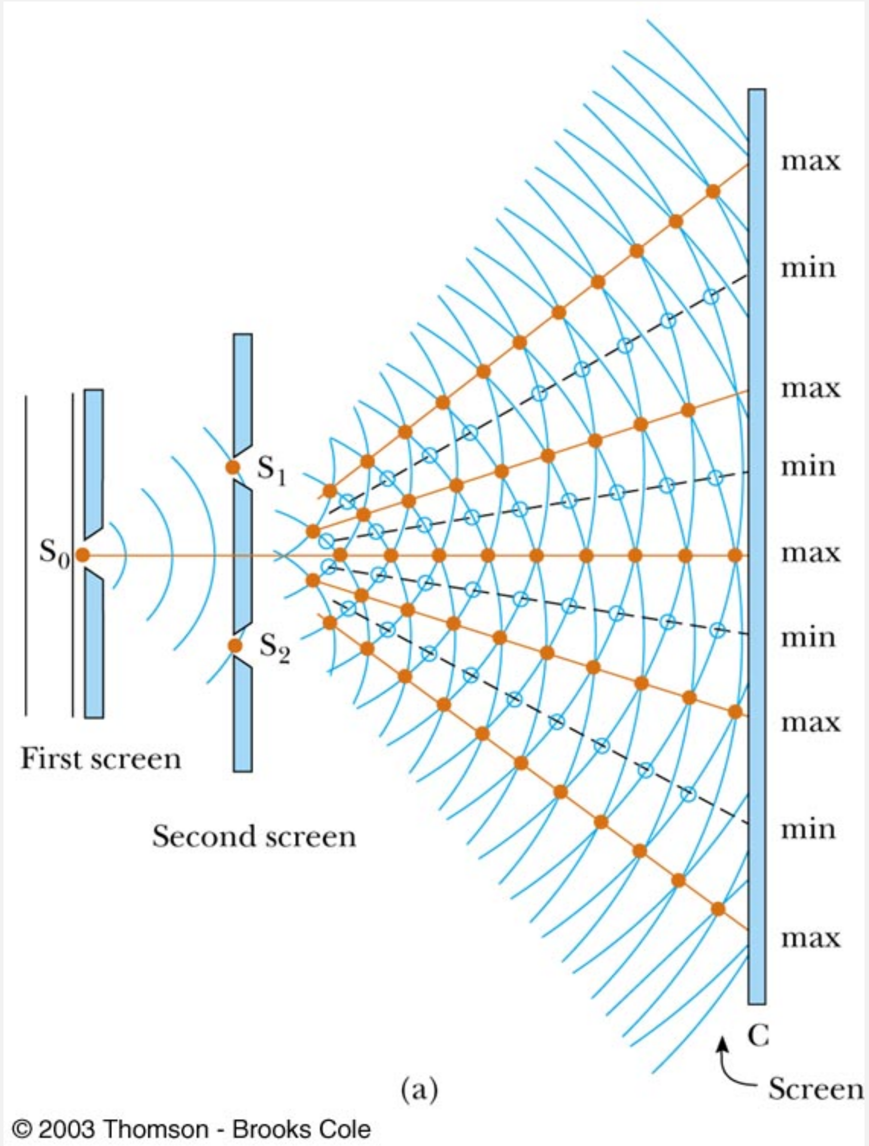
Interpretation of Thomas Young's double-slit experiment

S_1 and S_2 slits are wavesources

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

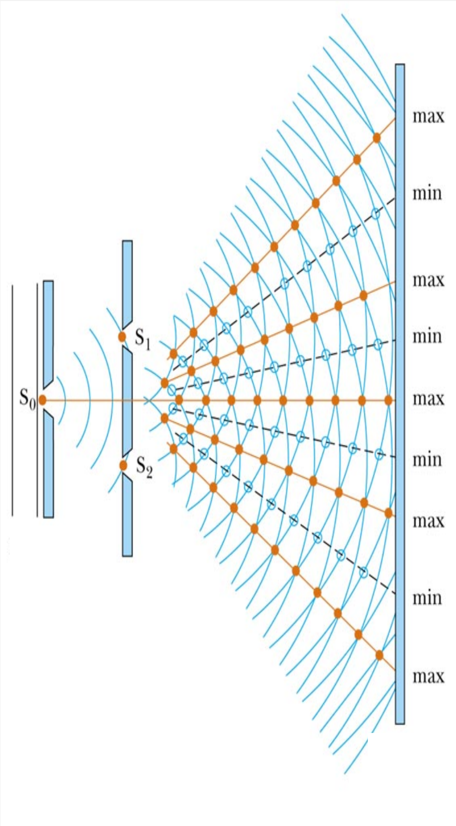
⇓⇓

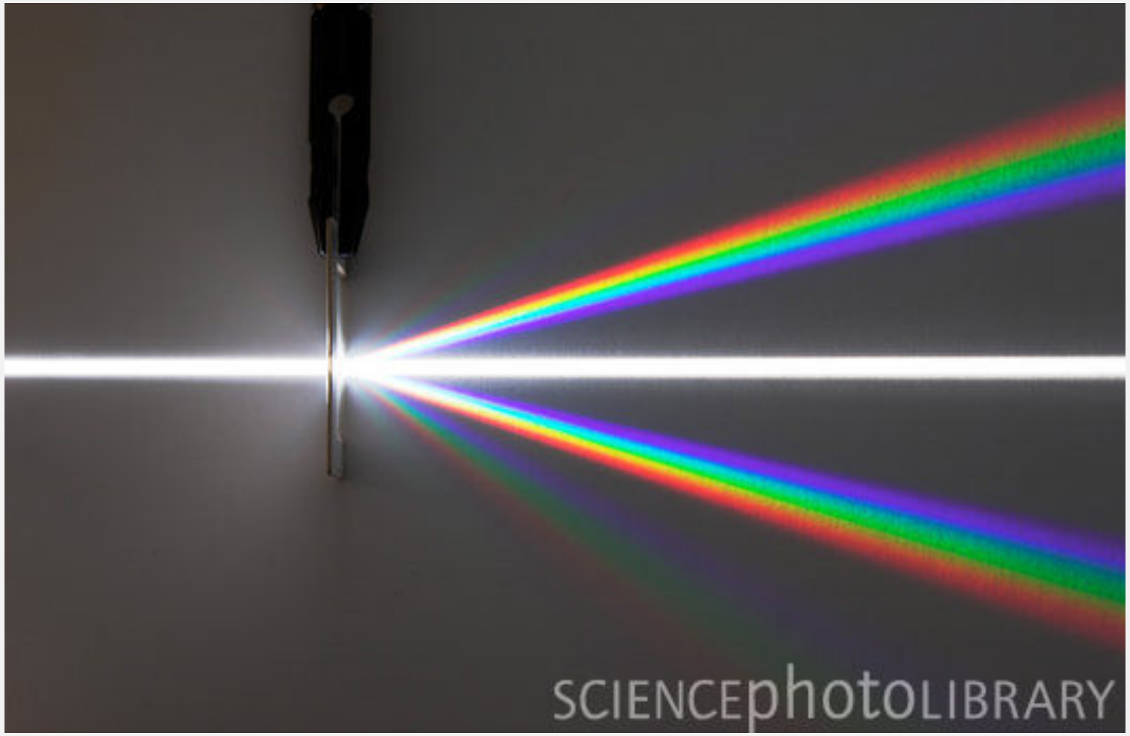
interference



Interference fringes on a screen

Dispersion of light by a diffraction grating

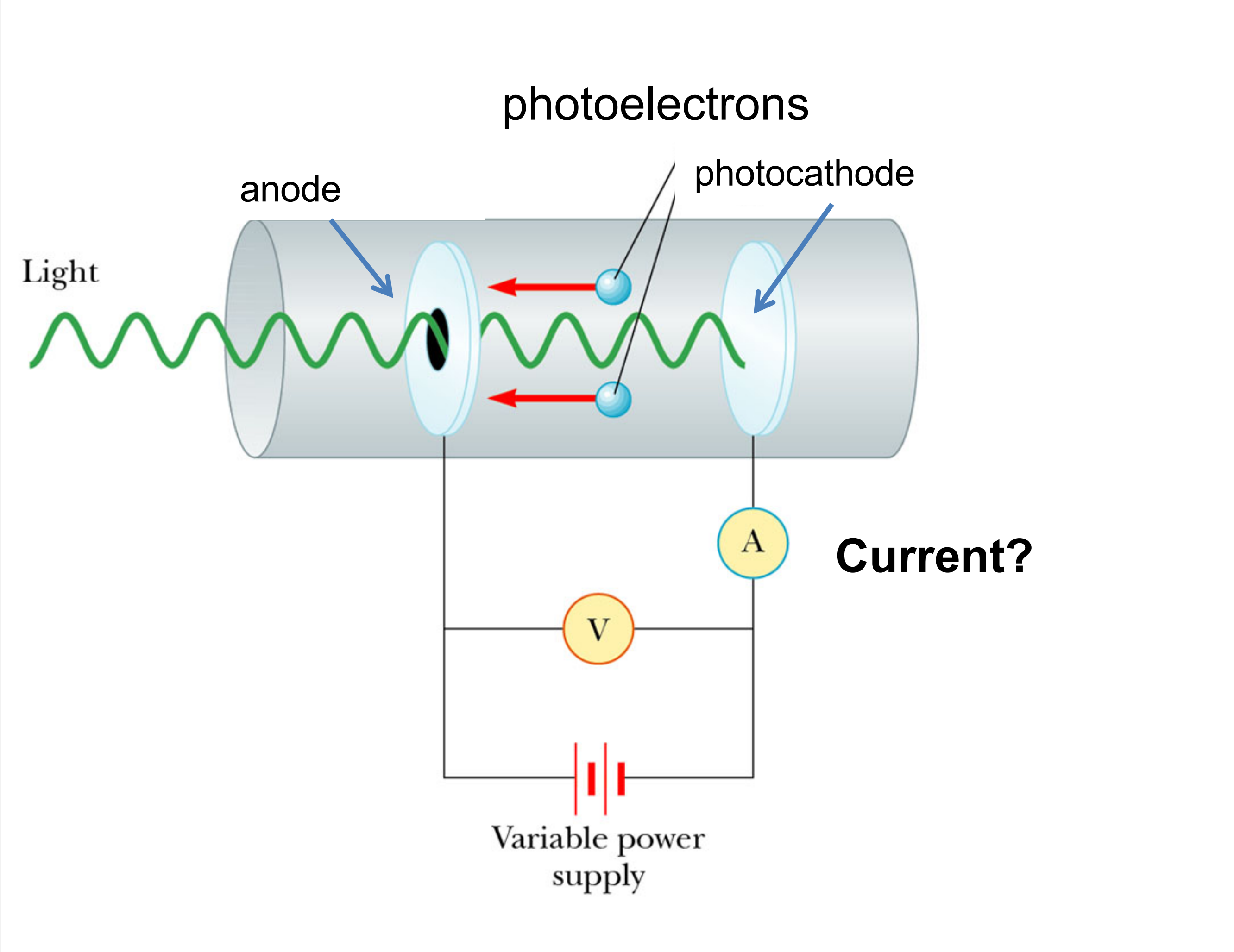




Wave or particle?

2. Hertz's experiment

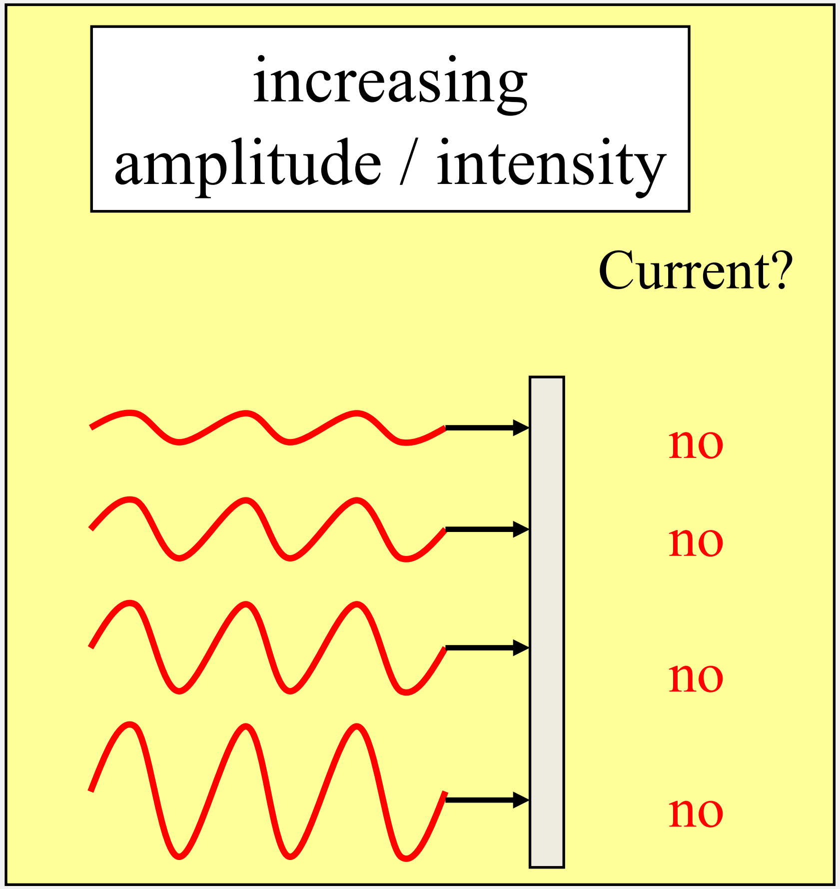
Heinrich Hertz
1887



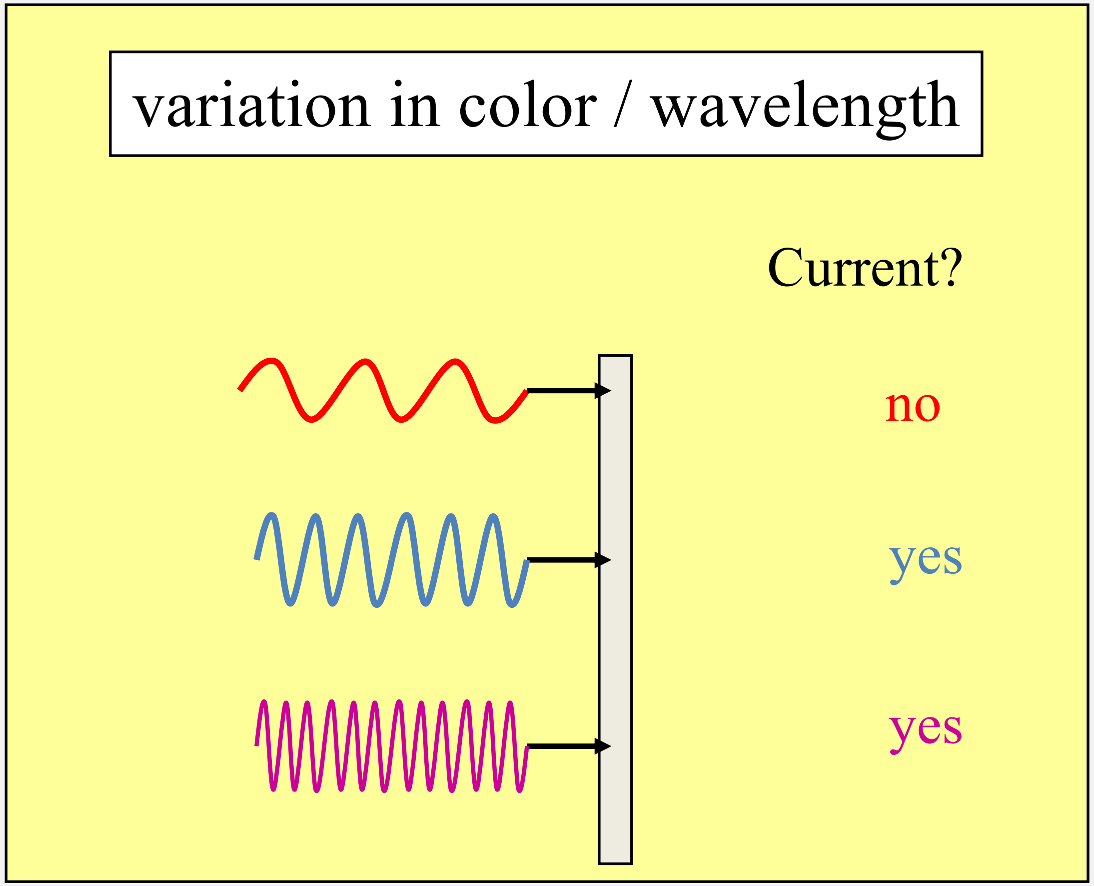
Fotoelectric effect

Light irradiation with

Similar color / wavelength



Similar amplitude

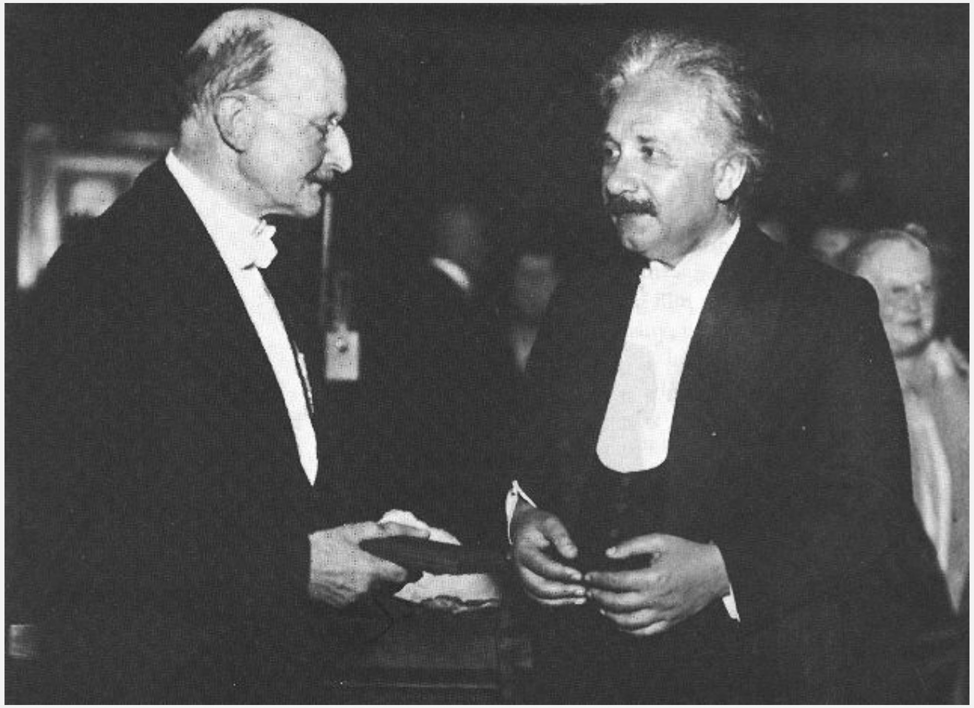


No current below a critical frequency!

Interpretation of photoelectric effect

- Based on the wave character it is not possible!
- Planck - foundation of quantum physics (1900): $E=hf$
- Einstein's concept is based on 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 below the work function
- 1 photon – 1 electron interaction
- Kinetic energy of the released electron: $E_{kin} = hf - A$

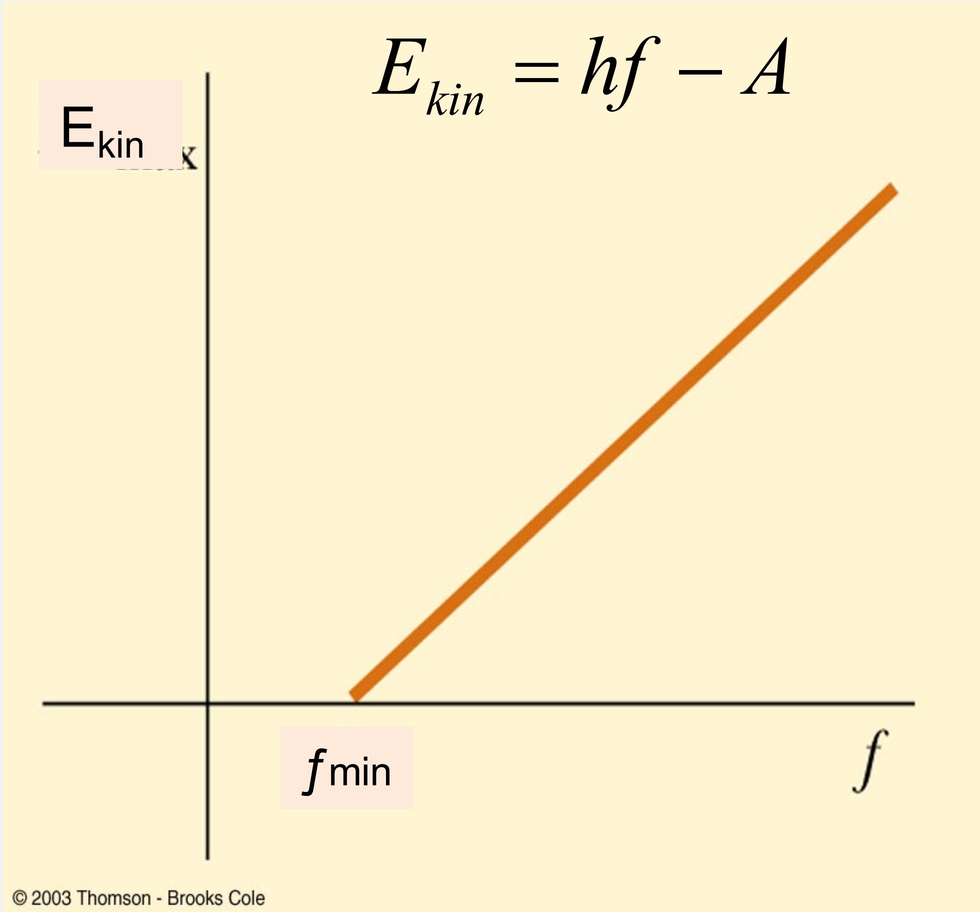
Einstein's interpretation and the frequency limit

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 quantized, a photon is an elementary particle, the quantum of the electromagnetic interaction

Energy of photon: $$E = hf = h\frac{c}{\lambda}$$

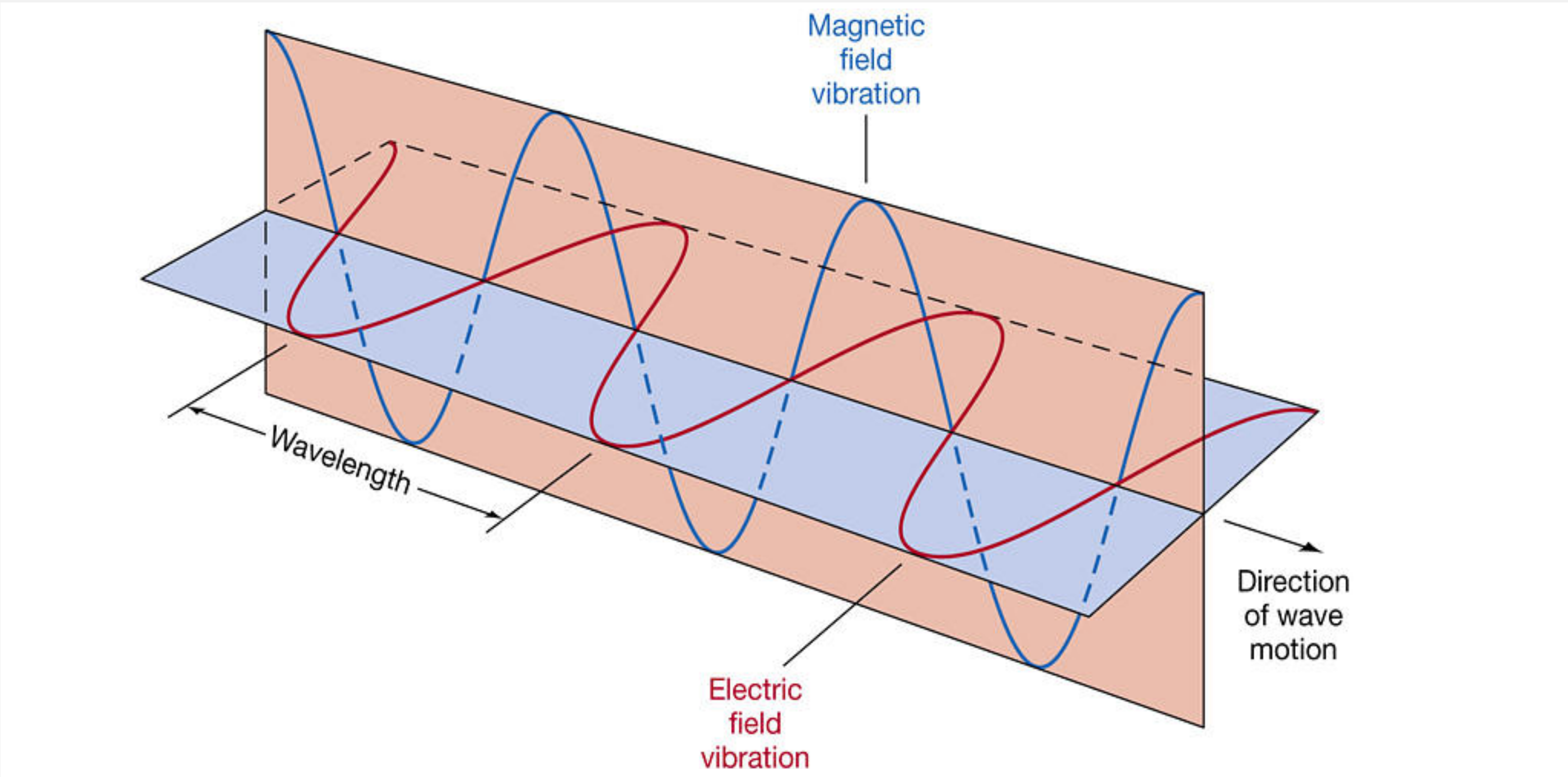
Planck constant: $$h = 6.62 \cdot 10^{-34}\, Joule \cdot s$$

Photons have no resting mass and propagate in vacuum

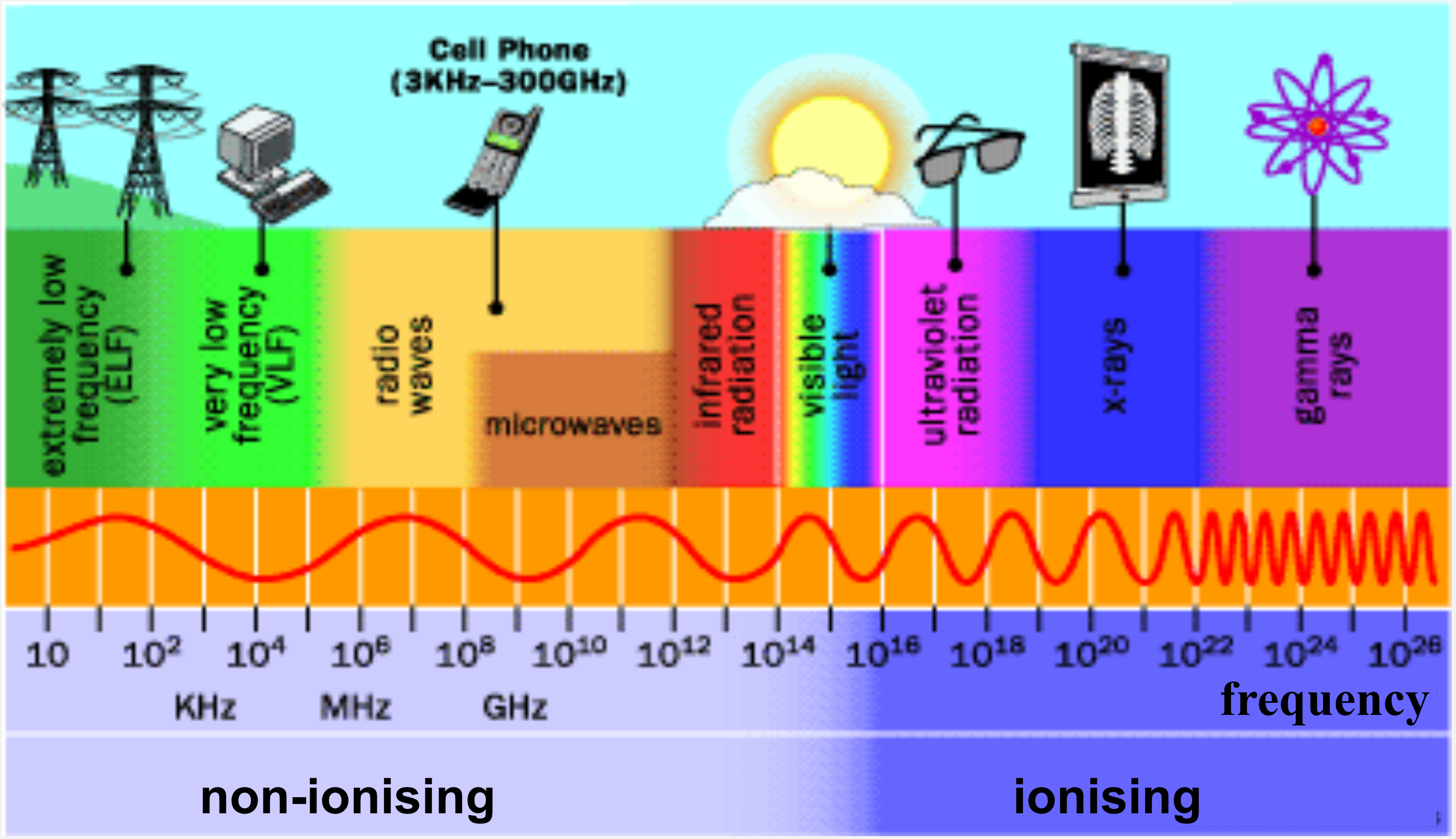
Dual nature of light

Wave – electric and magnetic fields vary sinusoidally

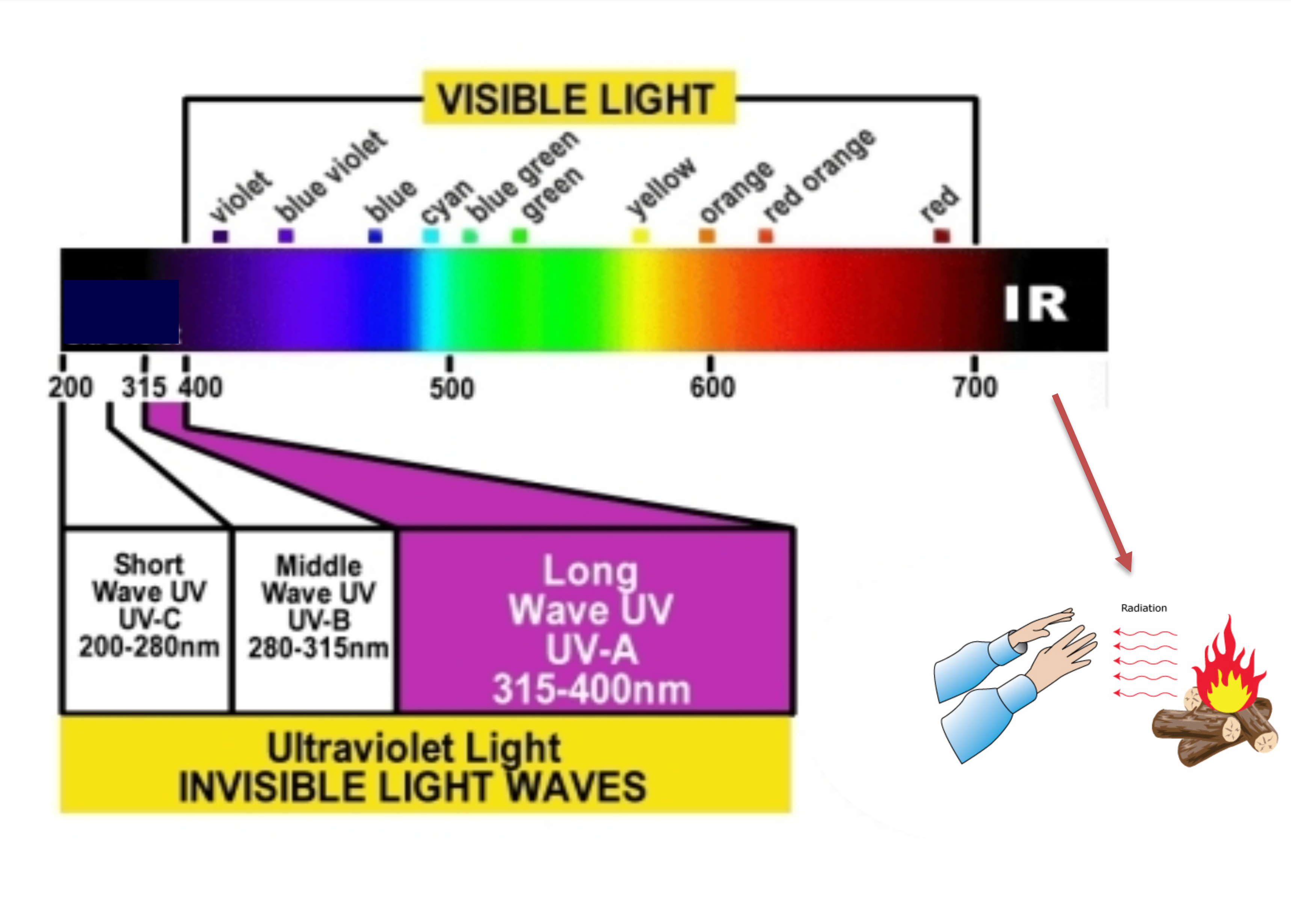
Electromagnetic radiation



Ranges of electromagnetic radiation



Optical range

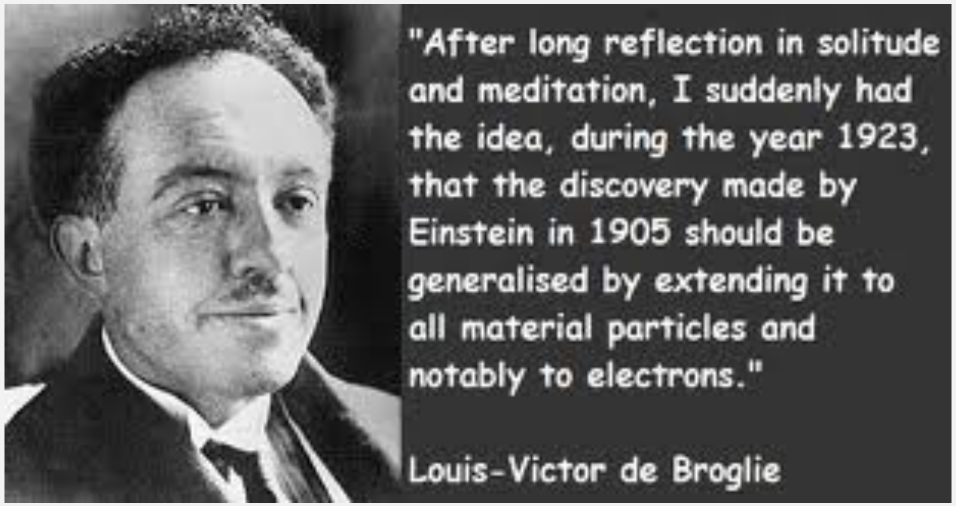


Why only light could have dual nature?

De Broglie's concept: the wave–particle duality

All particles exhibit both wave and particle properties

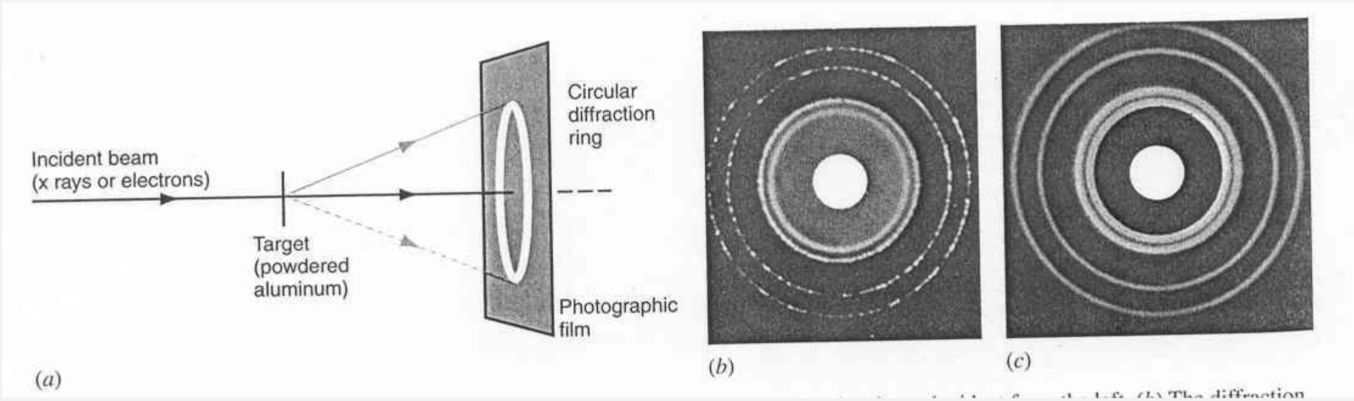
Momentum of the electron: $p = m_e v$



$$\lambda = h / p$$

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 is a radiation?
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 particle nature of light?
How can we give the energy of the photon?
What is the matter wave?

Measures and units
wavelength
frequency
energy
intensity

Related chapters in

Damjanovich, Fidy, Szöllősi: Orvosi Biofizika

II. 2. 1.

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