Light as electromagnetic wave and as particle

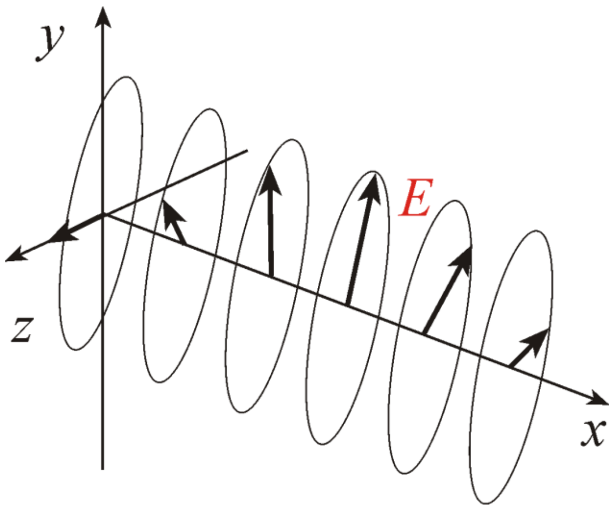
What is light? Visible electromagnetic radiation

Thus the word **light** refers to **electromagnetic waves** observable to the human eye, i.e. of wavelengths **between 400 and 800 nm**.

electromagnetic wave is transversal

thus can be polarized
linearly polarized light or **plane** polarized light

But **elliptically (or circularly)** polarized light also exists.



Optical anisotropy

E.g. in an „anisotropic matter" the speed of a suitably linearly polarized light depends on the direction of propagation.
The reason of it is connected to the structure of matter.

Consequences, applications: double refraction, polarization microscope, polarimetry

Hallwachs experiment:
ultraviolet irradiation causes the emission of negative charge carriers from the exposed metal surface. This phenomenon is called the **photoelectric effect**.

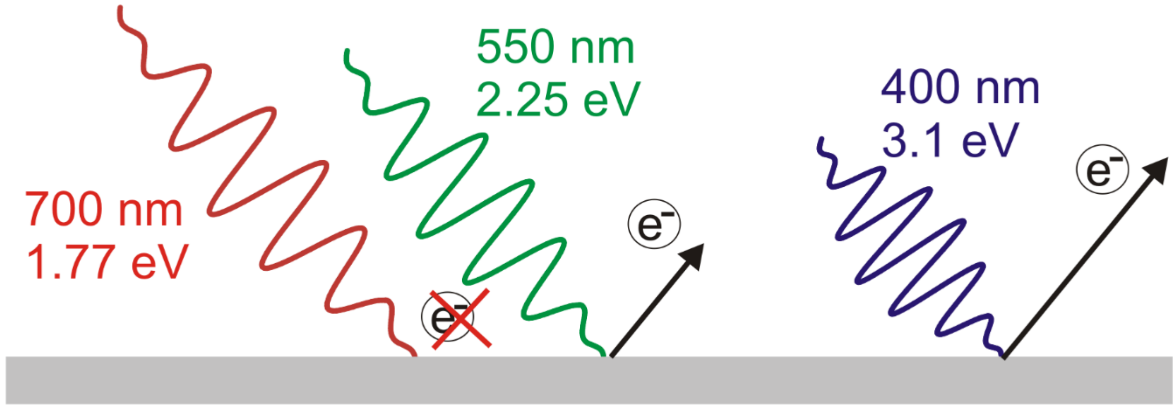
Lenard investigated the phenomenon in further detail, and concluded:

• the emitted charge carriers are **electrons**,
• **the effect does not occur under a threshold frequency** (specific for the metal), not even if we increase the intensity of the light,
• **the maximum velocity of the emitted electrons depends on the colour**, i.e. frequency **of the light**, but not the intensity (this velocity increases with higher frequencies),

These findings cannot be explained using a theory of electromagnetic waves.

Einstein: the **photon** is the elementary **particle** which carries the energy of electromagnetic radiation.

Photoelectric effect: An incident photon removes an electron from the bound electrons of an atom or molecule, while the photon is absorbed.



$$hf = W + E_{\text{kin}} = W + \frac{1}{2} m_e \upsilon^2$$

Phenomenon

Can be explained in terms of waves.

Can be explained in terms of particles.

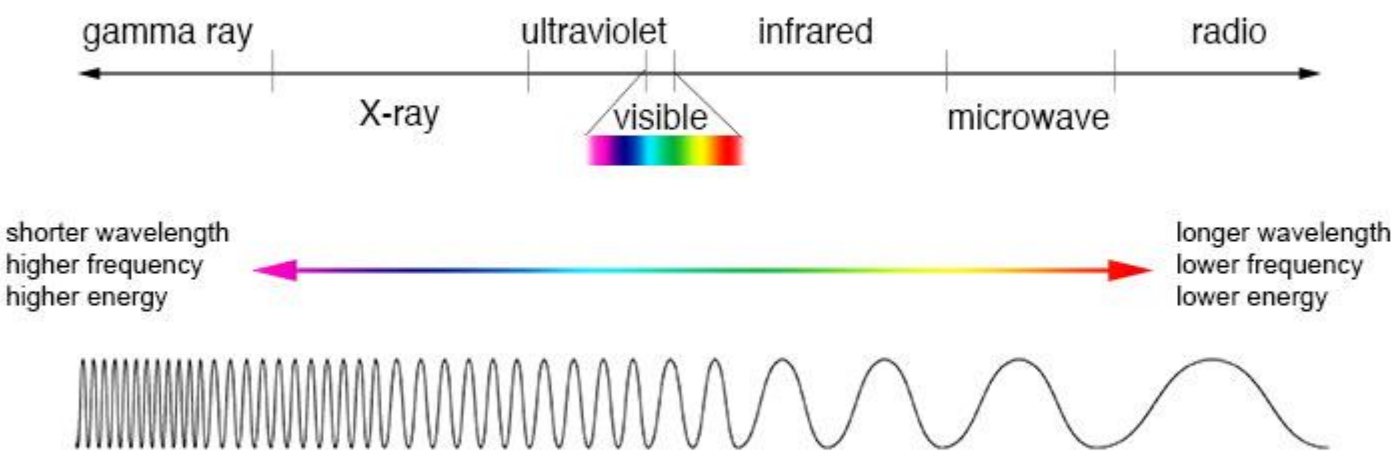
	waves	particles
Reflection	+	+
Refraction	+	+
Interference	+	-
Polarization	+	-
Photoelectric effect	-	+

"Prehistory"

Are not all hypotheses erroneous, that assume **light to be a kind of pressure or motion, propagating in some medium**? **Should light rays not consist of small particles**, emitted by the glowing substance?
Newton (1642-1726): Optics

..., if we consider … (light)rays may traverse each other without difficulties, … seeing an object emitting light **cannot happen through a flow of substance**, originating in the object and travelling towards ourselves, **as bullets** or arrows move in air;...Thus light propagates in a different way, and **to understand this, we must use our knowledge about the propagation of sound(waves)**.
Huygens (1629-1695): Traité de la lumiére

Electromagnetic spectrum:



Basics of radiometry

Source, radiation, irradiated target

Emitted power (P), intensity (J_E), (Flux density)

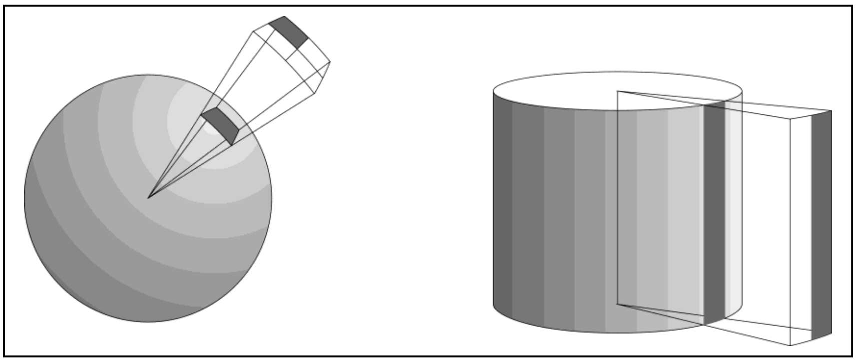
$$J_E = \frac{\Delta E}{\Delta t \Delta A} \qquad\qquad M = \frac{\Delta P}{\Delta A}$$

Point-like isotropic radiator

Radiation is independent of the direction in the whole solid angle.

Total emitted power per unit surface area

Simple laws: the roles of symmetry, distances and angles



1. Spherical symmetry

$$P = M_1 A_1 = M_2 A_2$$

$$\frac{M_1}{M_2} = \frac{r_2^2}{r_1^2} \qquad\qquad M \sim 1/r^2$$

2. Cylindrical symmetry

$$M \sim 1/r$$

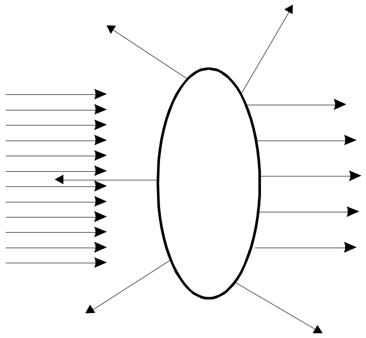
(Planar symmetry)

3. Out of perpendicular incidence

$$M = J \cos\alpha$$

4.)

radiation



matter

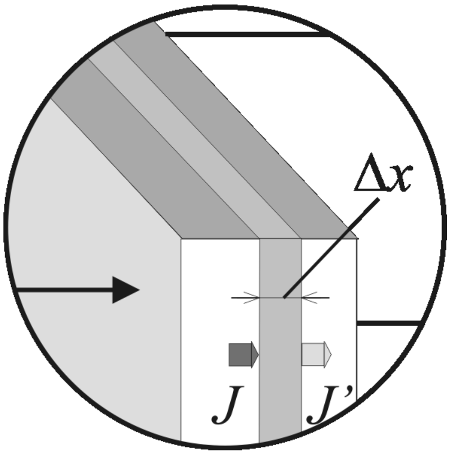
interaction: J decreases, but how? (experiment)

$\Delta J = J_{out} - J_{in}$ depends on

— incident intensity J_{in}
— layer thickness; (number of layers) $x = k\Delta x$
— quality of matter μ

Initial essumptions:

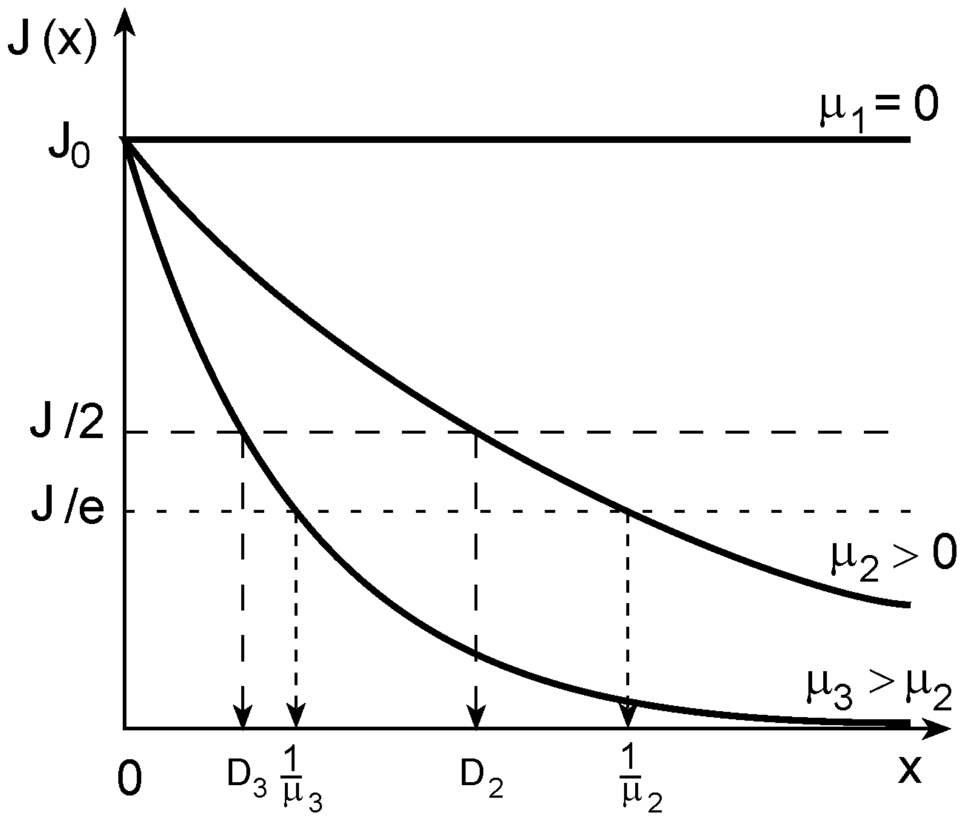
- for „small" Δx $\Delta J \sim \Delta x$ and $\Delta J \sim J$ *(propotional)*
- if $\Delta x = 0$ $J_{out} = J_{in} = J_0$



$\Delta J = J' - J$

x characteristic for the **quantity** of matter,
μ for the **quality** of matter
For layers with "extreme" small Δx $\Delta J = J' - J = -J\mu\Delta x$

$$J(x) = J_0 e^{-\mu x}$$


J (x)
μ1 = 0
J0
J /2
J /e
μ2 > 0
μ3 > μ2
0
D3
1/μ3
D2
1/μ2
x