

# Light as electromagnetic wave and as particle

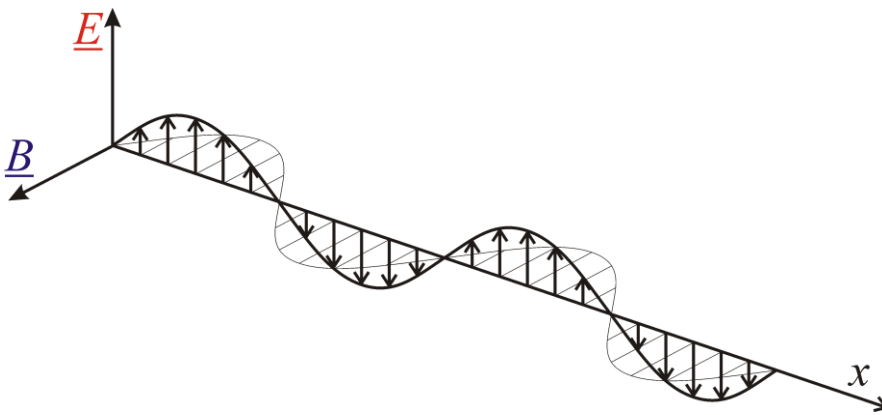
What is light? Visible **electromagnetic radiation**

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

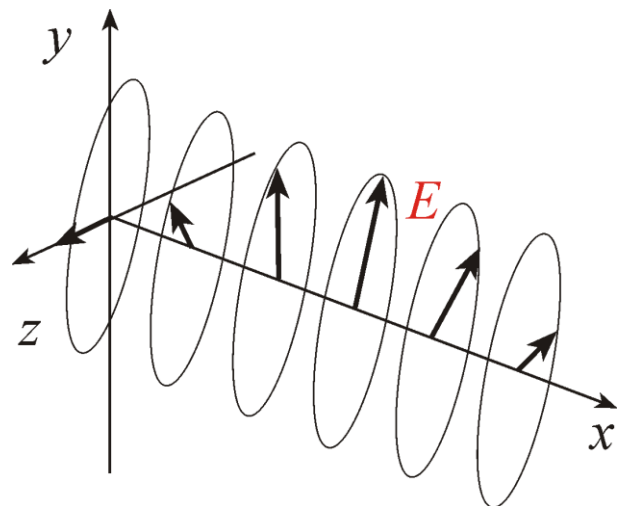


But **elliptically (or circularly) polarized light** also exists.

## 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**.

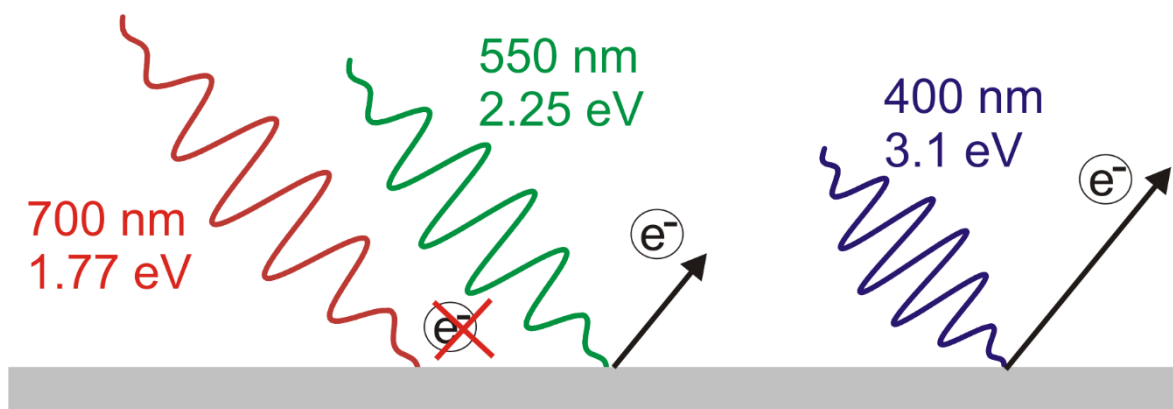
**Lenard** investigated the phenomenon in further detail, and concluded:

- 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.



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

## Phenomenon

Can be explained in terms of **waves**.

Can be explained in terms of **particles**.

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

“Prehistory”

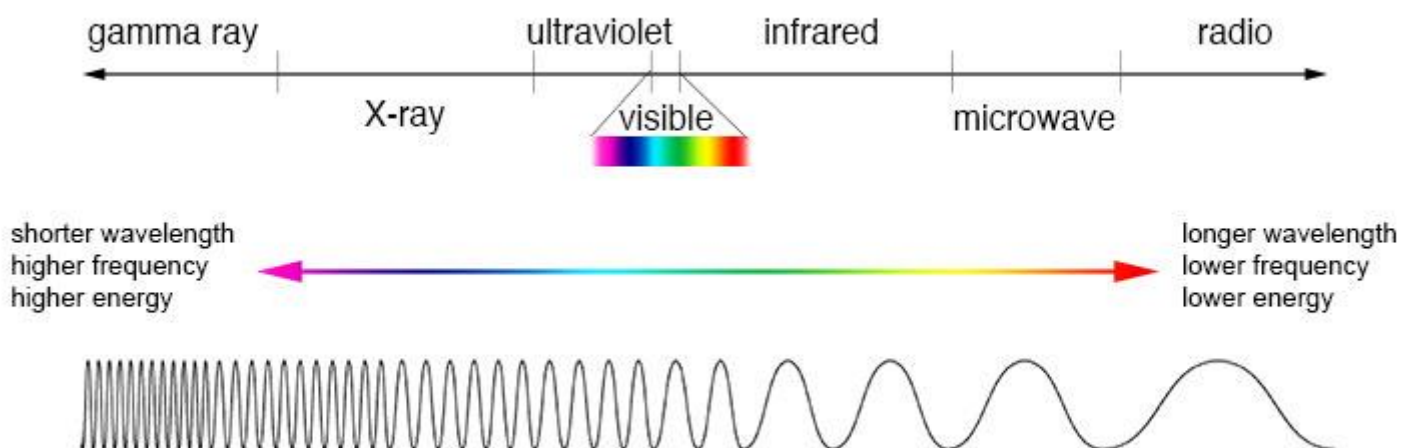
**Are not all hypotheses erroneous, that assume light to be a kind of pressure or motion, propagating in some medium? Should light rays not consist of **small particles**, emitted by the glowing substance?**

**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 lumière

Electromagnetic spectrum:



## Basics of radiometry

Source, radiation, irradiated target

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

$$J_E = \frac{\Delta E}{\Delta t \Delta A}$$

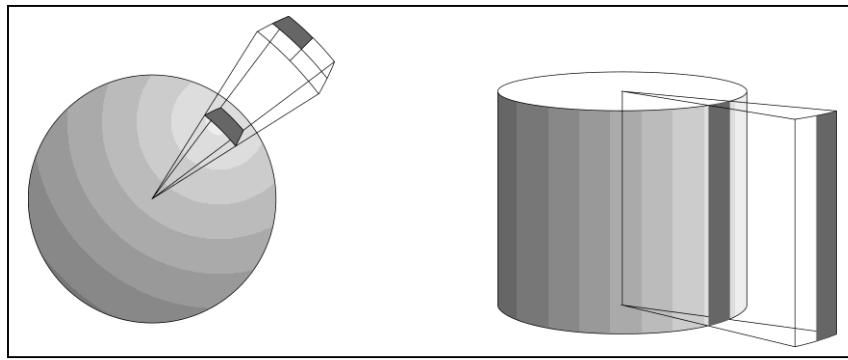
$$M = \frac{\Delta P}{\Delta A}$$

## 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

$$P = M_1 A_1 = M_2 A_2$$

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

### 2. Cylindrical symmetry

$$M \sim 1/r$$

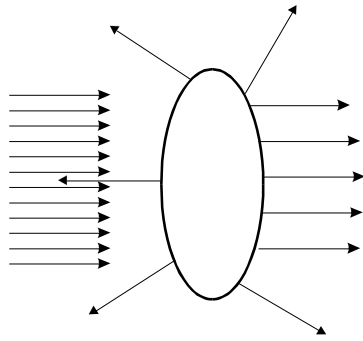
(Planar symmetry)

### 3. Out of perpendicular incidence

$$M = J \cos \alpha$$

4.)

**radiation**



**matter**

interaction:  $J$  decreases, but how? (experiment)

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

- incident intensity
- layer thickness; (number of layers)
- quality of matter

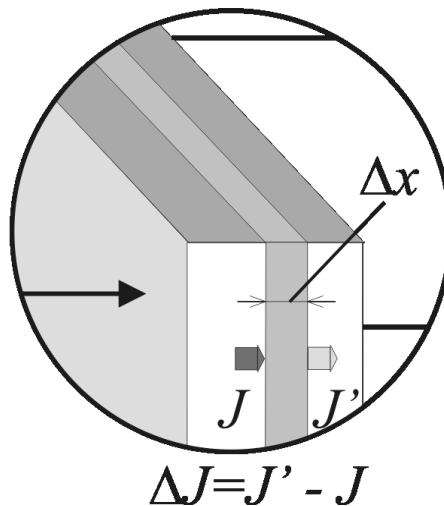
$J_{\text{in}}$

$x = k\Delta x$

$\mu$

Initial assumptions:

- for „small”  $\Delta x$        $\Delta J \sim \Delta x$     and     $\Delta J \sim J$  (proportional)
- if  $\Delta x = 0$        $J_{\text{out}} = J_{\text{in}} = J_0$



$x$  characteristic for the **quantity** of matter,  
 $\mu$  for the **quality** of matter

For layers with “extreme” small  $\Delta x$        $\Delta J = J' - J = -J\mu\Delta x$

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

