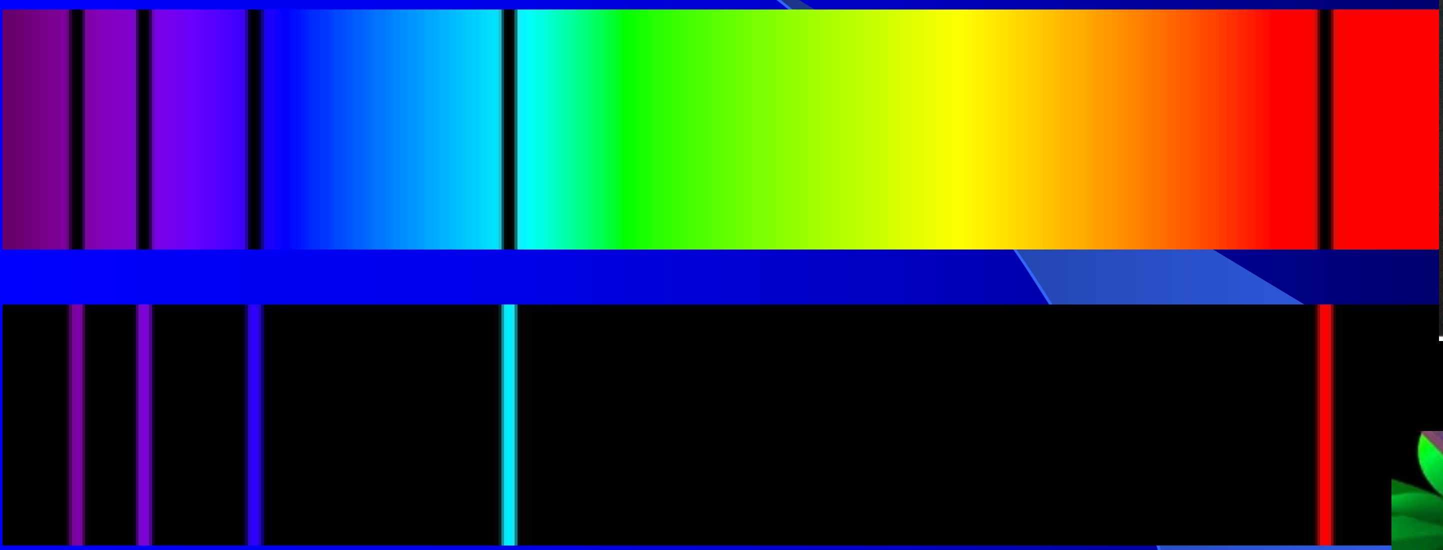
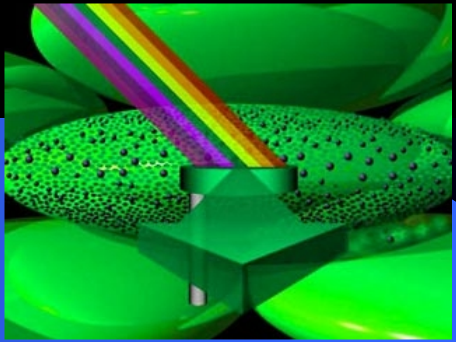
Department of Medical and Biological Physics

# *Emission and absorption of electromagnetic waves by a substance*





Lecture 6

# Overview

**Atomic and molecular energy levels**

**Types of spectra. Spectral apparatuses**

**Ultraviolet and infrared radiation**

**Luminescence. Chemiluminescence**

**Light absorption and scattering**

**Photocolorimetry**

**Photobiological processes**

# Corpuscular and wave properties of light and elementary particles

- **A photon is an elementary particle of light with wave properties**
- **Energy of light photon is equal to $E=hf=h(c/\lambda)$, where h is a Plank's constant, f is a frequency**
- **The motion of particles (electrons, neutrons and so on) can be considered as a wave process with wavelength**

$$\lambda = \frac{h}{m\ v}$$

**where m is the mass of a particle,**

**$v$ is velocity**

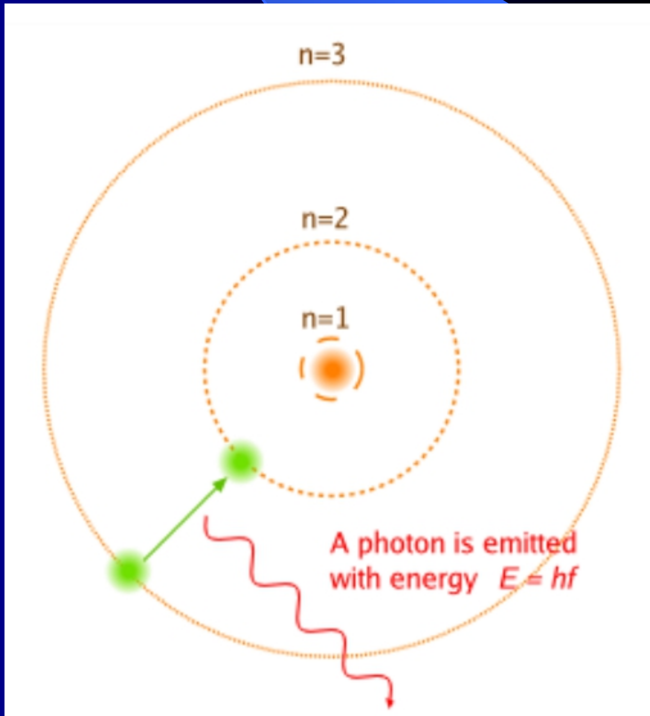
# The Bohr model

Niels Bohr put forward in 1913 a theory of hydrogen atom:

1) An electron in an atom can circle the nucleus without losing energy only in certain specific orbits

2) When an electron jumps from one orbit to another orbit it emits or absorbs a photon of light.

$$E_1 - E_2 = hf$$



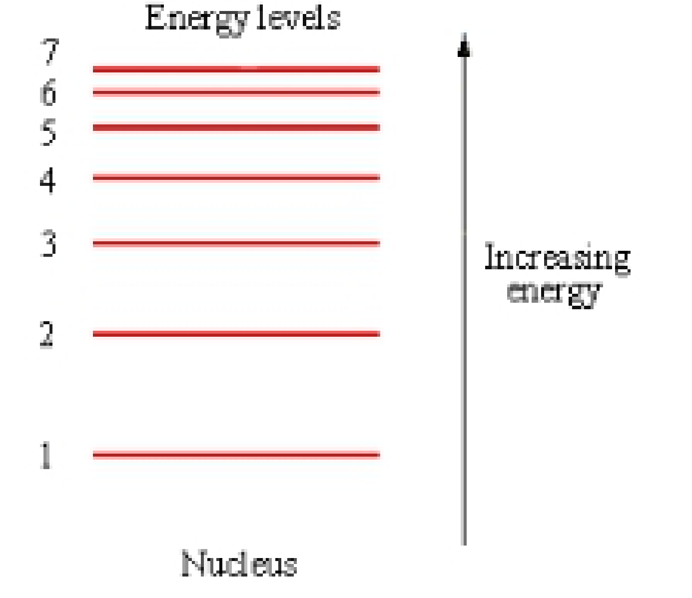
- The frequency of emission (or absorption) of hydrogen atom can be expressed as

$$f=\frac{c}{\lambda}=\frac{E_n-E_k}{h}=\frac{me^4}{8\varepsilon_0^2h^3}\quad -\frac{1}{n^2}-\quad -\frac{1}{k^2}$$

$$\frac{1}{\lambda}=R\quad \frac{1}{k^2}-\frac{1}{n^2}$$

where R is a Rydberg constant

R= 10973731.568508(65) $m^{-1}$.

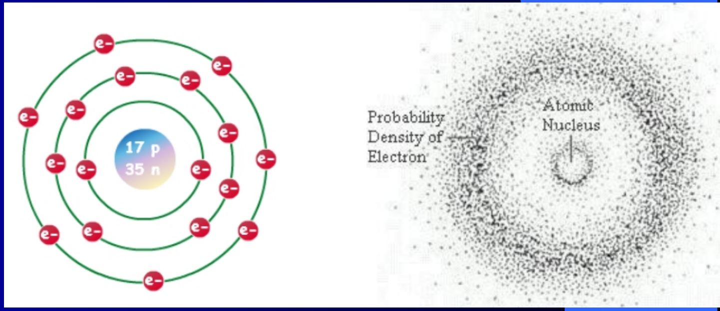


# The bases of quantum theory

- In modern quantum theory the charge of electron is allocated within atomic space forming electron cloud with varying density. The density of electron cloud at any point of atom is equal to the probability of the detection of electron at the certain point.

The motion of electron in an atom is characterized by 4 quantum numbers:

- Principal quantum number ($n=1,2,3\ldots$)
- Orbital quantum number ($0 \le l \le n-1$)
- Magnetic quantum number ($l \le m_l \le l$)
- Spin quantum number ($+1/2$ or $-1/2$)

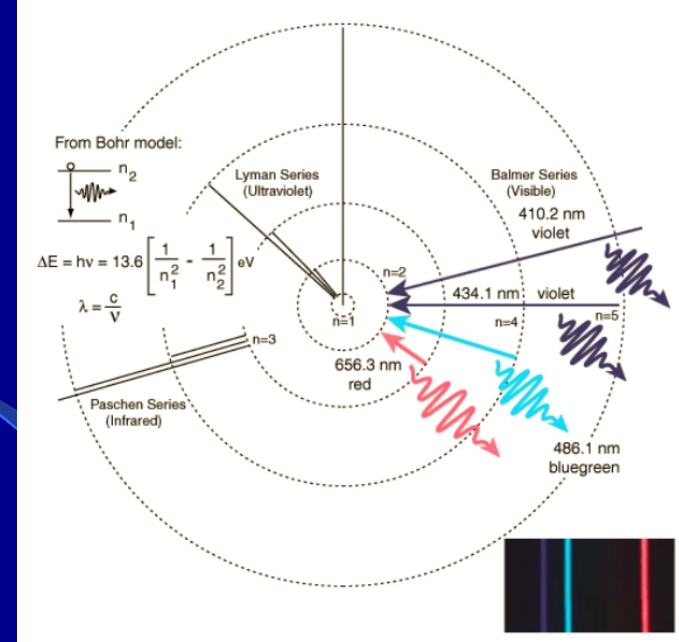


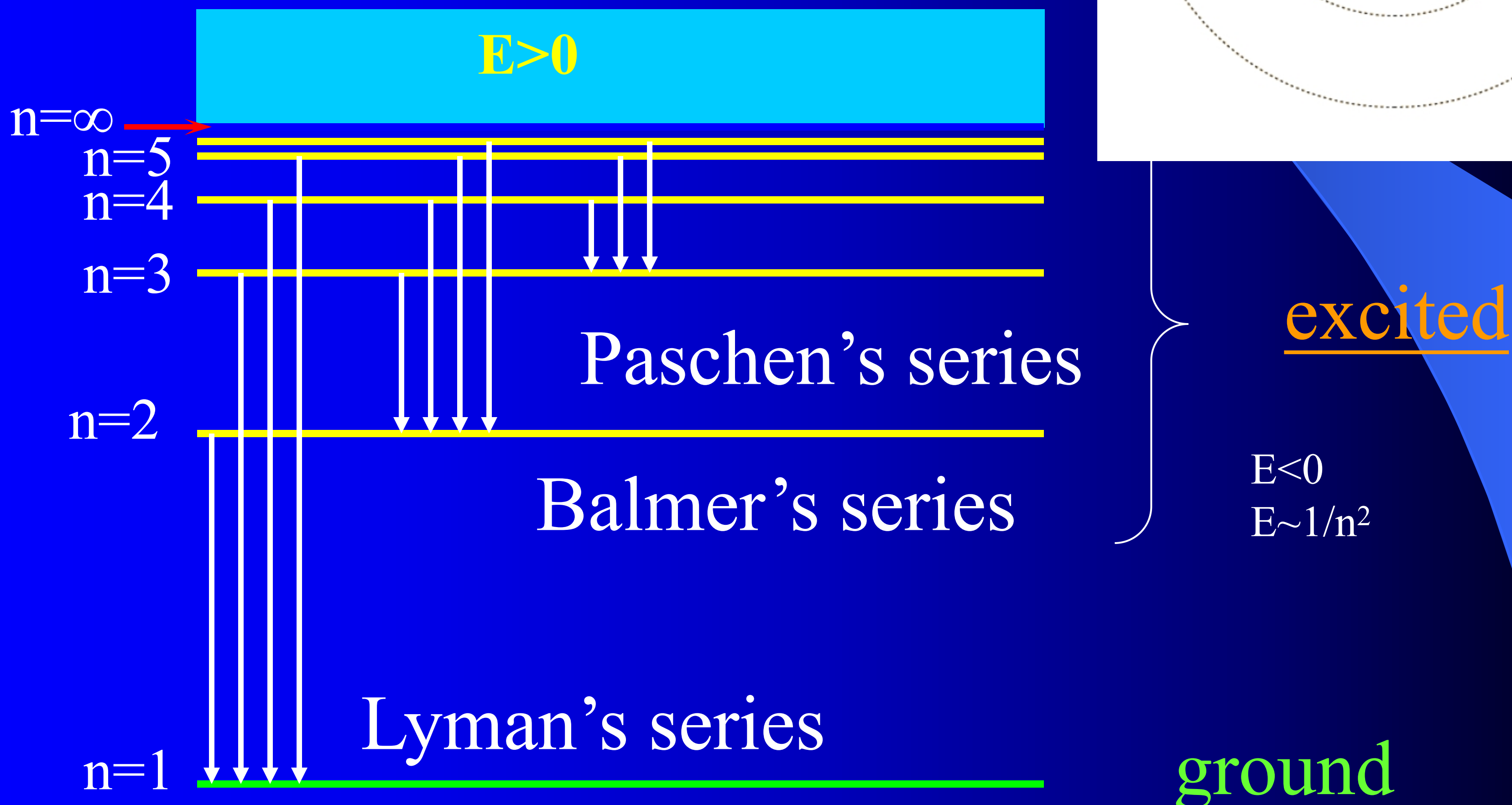
# The principles of the distribution of electrons into energy levels

- Pauly’s principle: There are no electrons in an atom with the same set of quantum numbers
- Minimal energy principle: The distribution of electrons in an atom conforms to minimal energy of an atom

Each electron is characterized by the unique set of quantum numbers
The aggregate of electrons with the same principle quantum number form an atomic energy level

# Atomic energy levels and the principal emission series of hydrogen atom



# Molecular energy levels

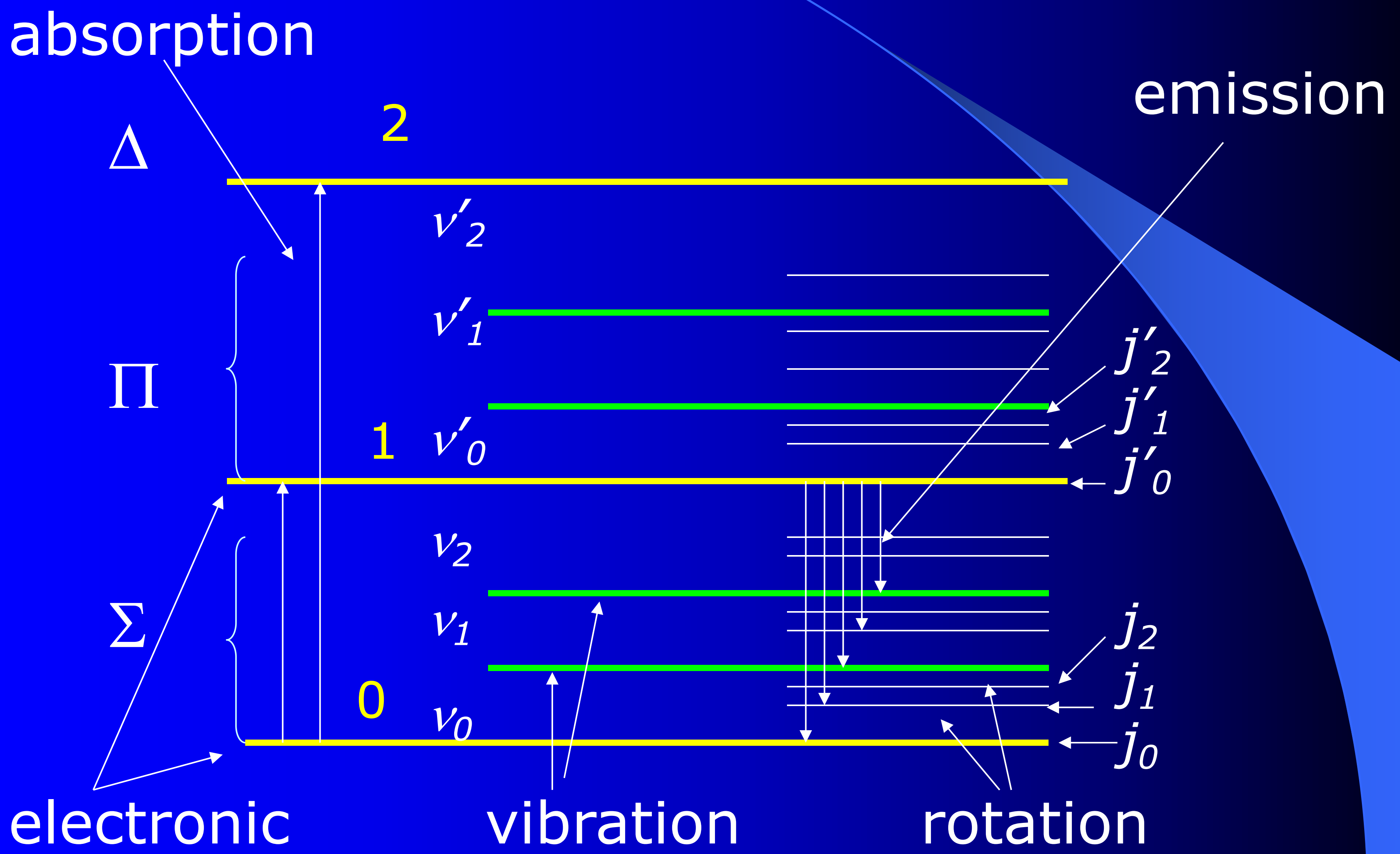
In polyatomic molecules we can distinguish three types of motion:

- Electronic (the motion of electrons around a nucleus)
- Vibration (the vibration of nuclei)
- Rotation (the change of orientation of molecular parts in a space)

The energy of molecule is equal to $E=E_e+E_v+E_r$

$E_e \sim 1\ eV,\ E_v \sim 10^{-2}\ eV,\ E_r \sim 10^{-4}\ eV$

# Molecular energy levels

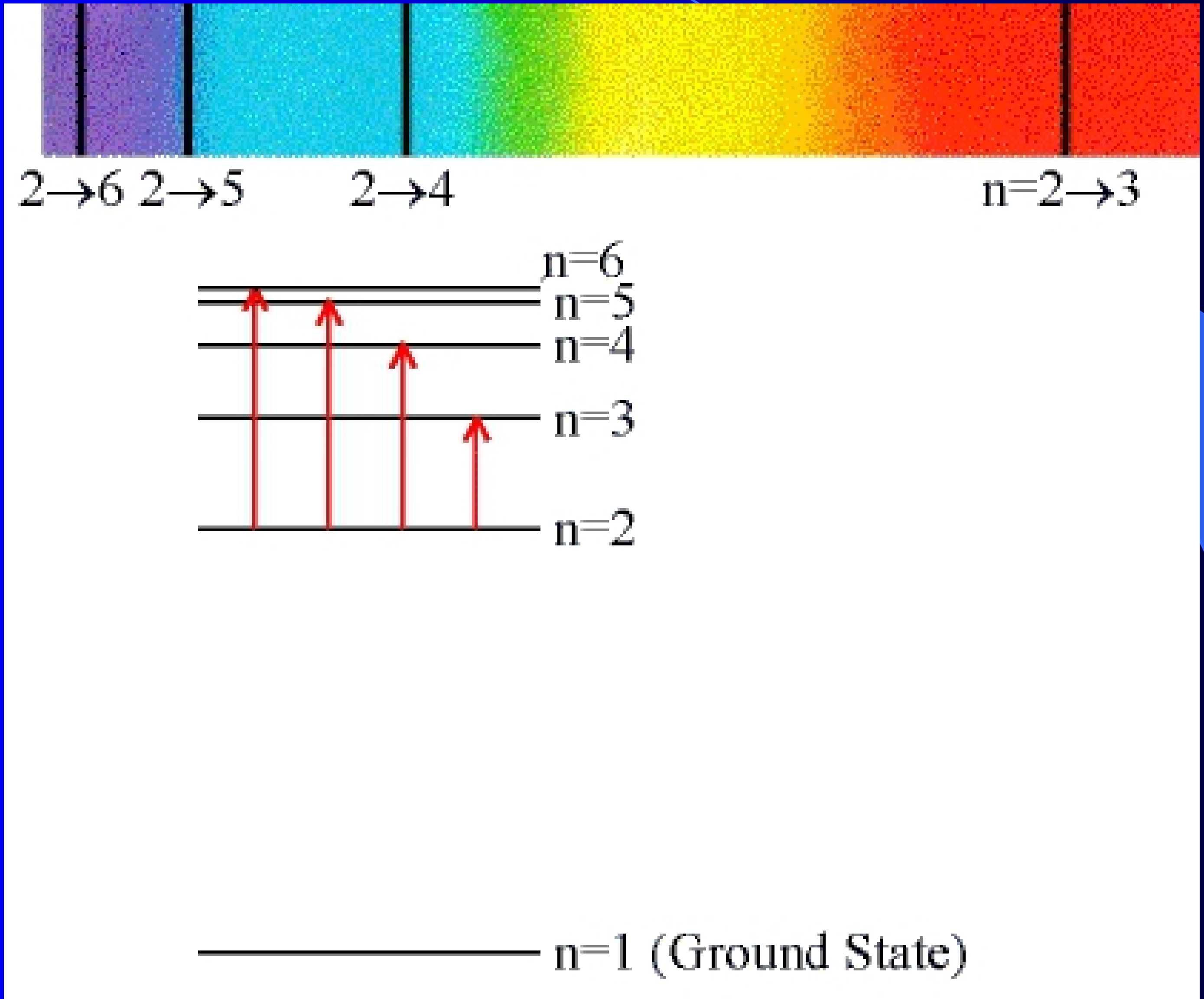


# Spectra

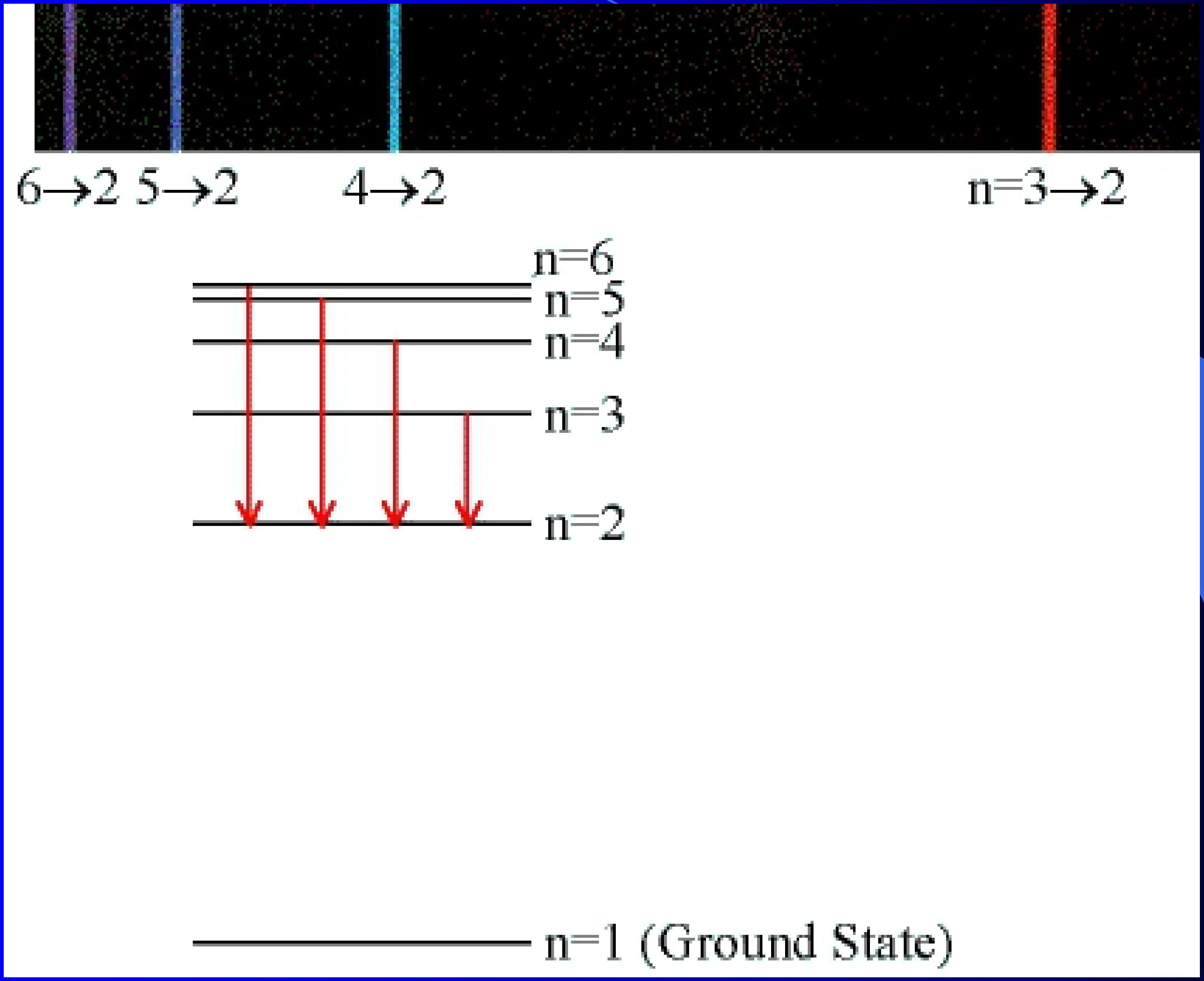
Spectrum is a plot of any quantity as function of either wavelength ($\lambda$) or frequency (f)

- The types of spectra:
- Continuous and line spectra
- Absorption and emission spectra

# Absorption lines of hydrogen



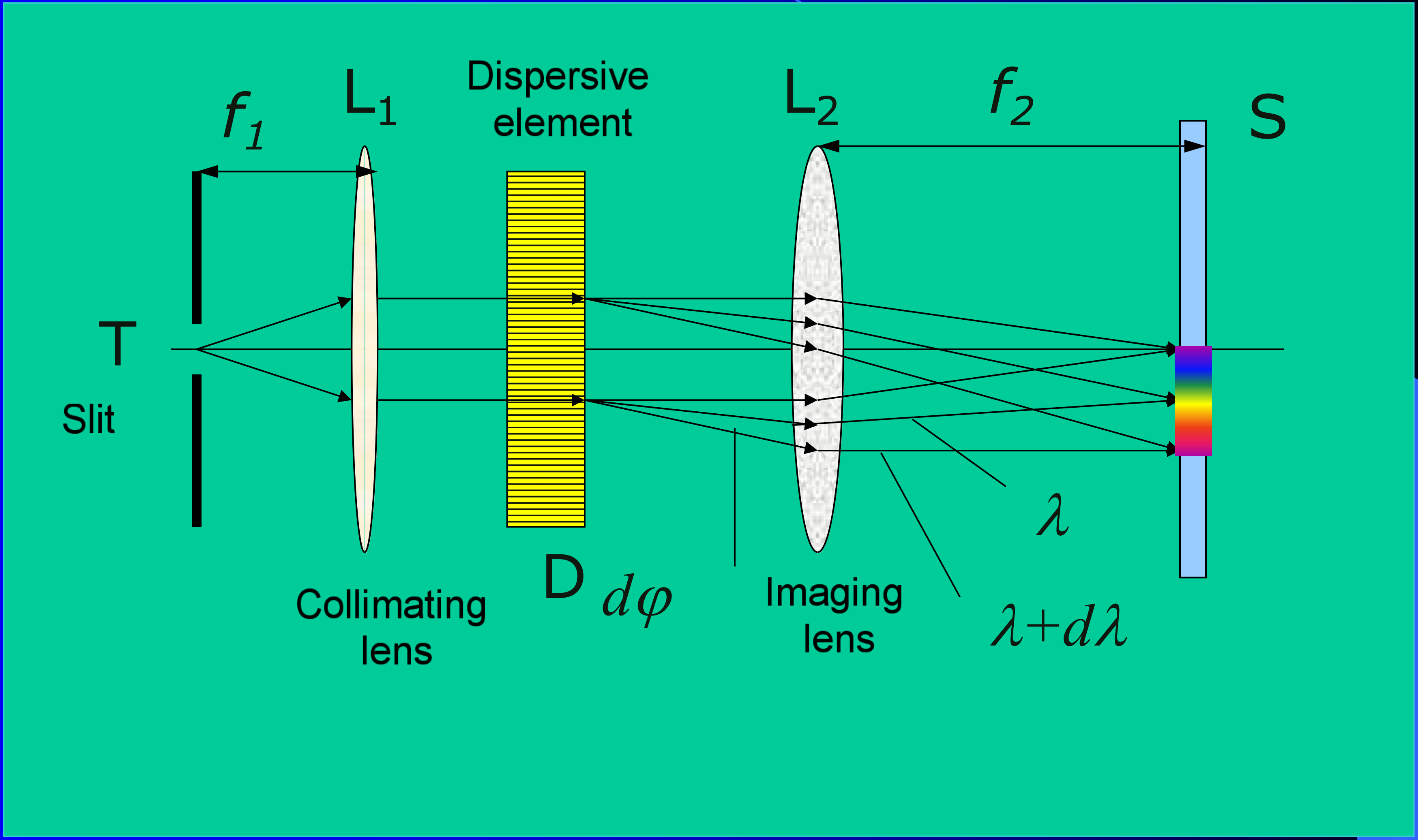
# Emission Lines of hydrogen



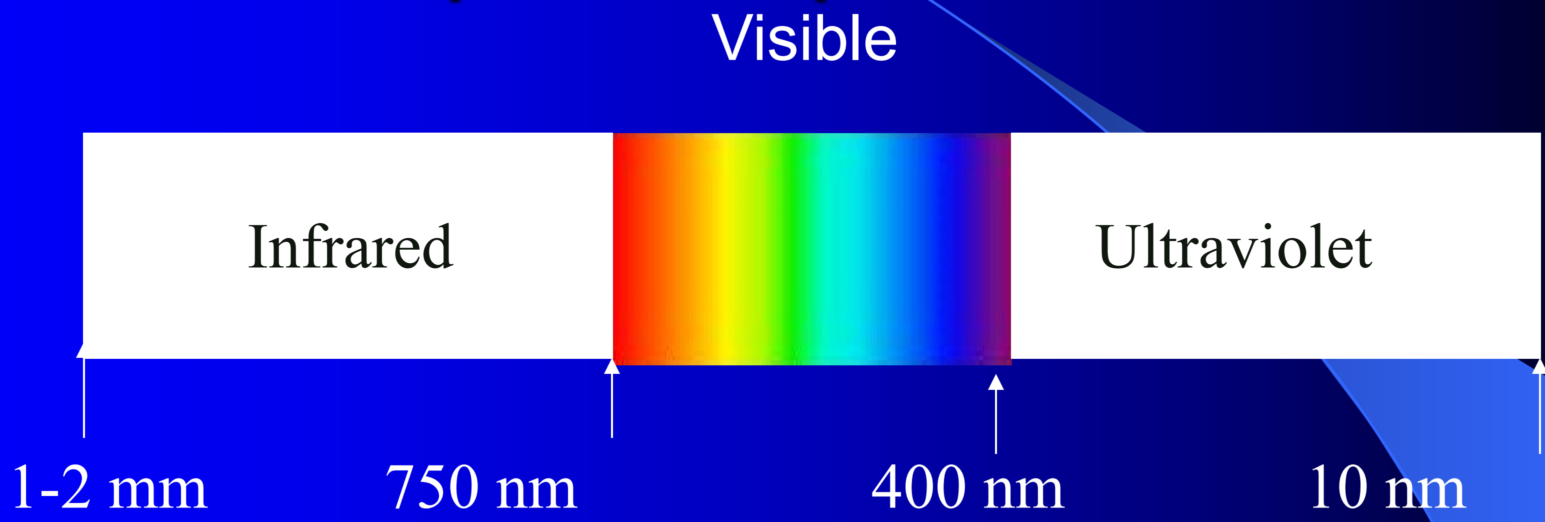
# Spectral apparatuses

- Spectral apparatus is used to separate the electromagnetic radiation (within optical band) into its components (wavelengths or frequencies) or analyze this radiation
- The apparatuses used for the visual observation of spectra are called spectroscopes
- The apparatus with photographic detectors of spectra is called spectrograph, with photoelectric detectors of radiation is called spectrometer

# General scheme of spectral apparatus



# Optical spectrum



# Ultraviolet radiation in medicine

Medical ultraviolet ($\lambda$>200 nm)

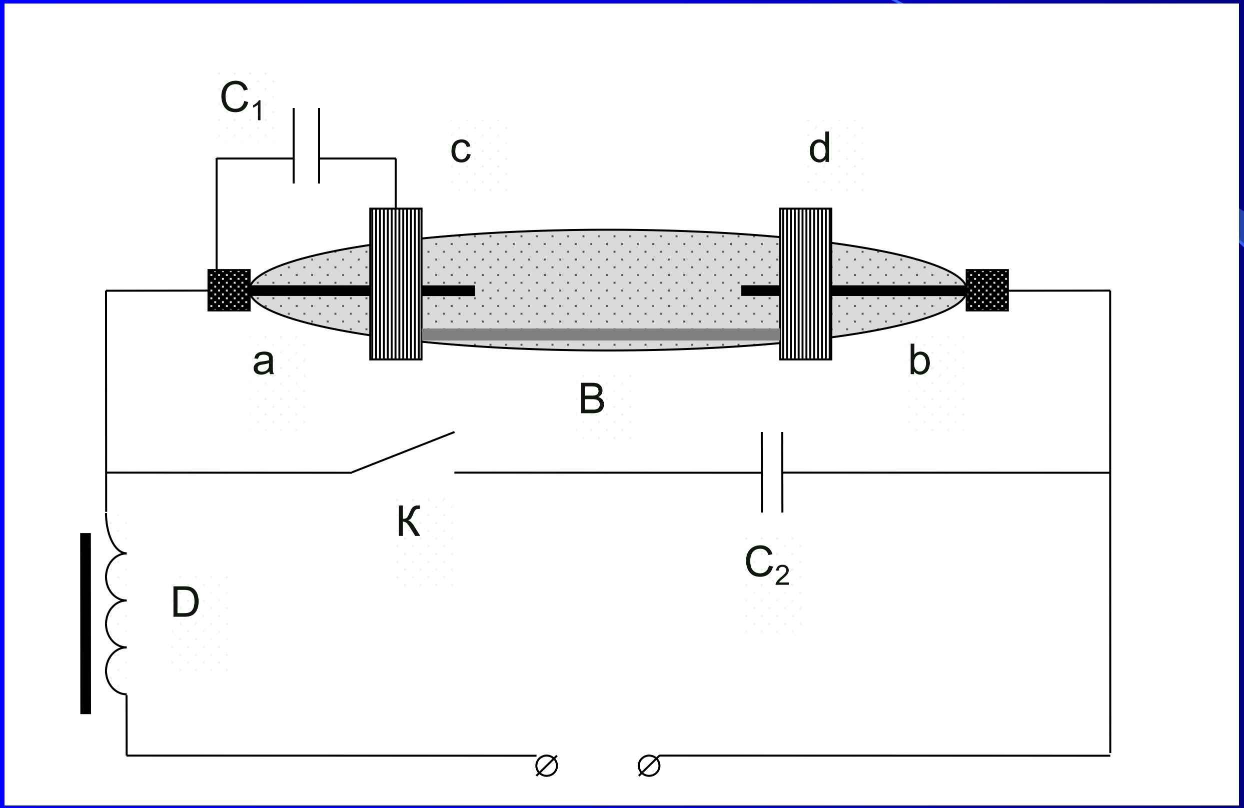
| | | |
|---|---|---|
| ***C*** (200÷280 nm). | ***B*** (280÷315 nm) | ***A*** (315÷400 nm) |

- The region UV-C is the most dangerous for living organisms and causes a bactericidal effect.
- The regions UV-A and UV-B are used for vitamin D formation.

# Mercury lamps

- The medical resources of UV radiation are mercury lamps
- There are two types of mercury lamps:
- high-pressure lamp (150÷ 400 millimeters of mercury) and
- low-pressure lamp (0,01÷1,0 millimeters of mercury )

# The high-pressure mercury lamp ($\lambda_{max}$= 365 nm)




- *There is an argon gas with mercury drops inside quartz lamp*
- a, b are electrodes,
- B is a plate,
- c, d are rings,
- K is a switch,
- D is a throttle,
- $C_1$, $C_2$ are capacitors

- The high potential difference between electrodes and rings cause at first glow discharge then arc discharge
- Mercury vaporizes and emits UV radiation

# Infrared radiation in medicine

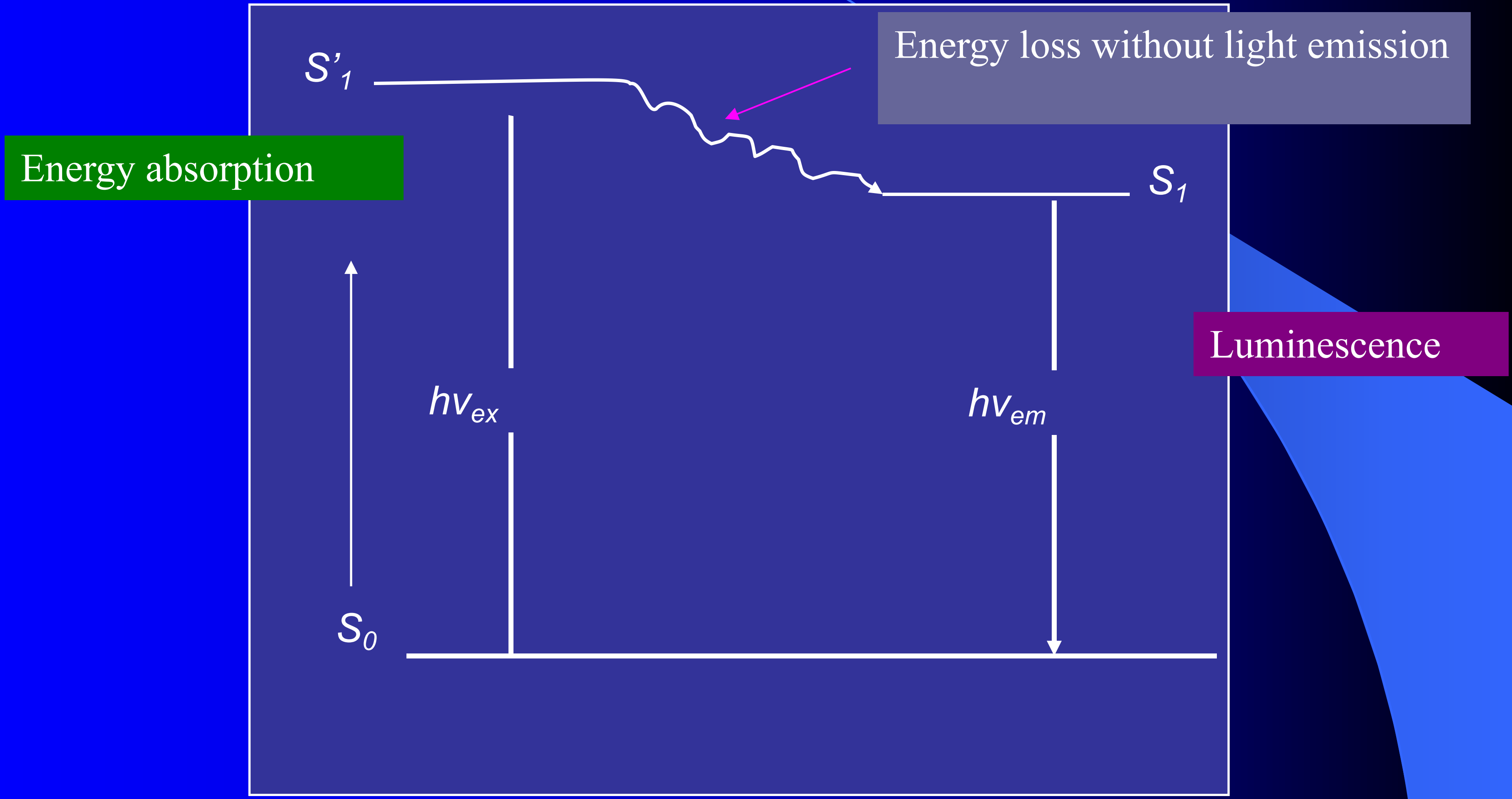
*Infrared radiation*

| ***near*** | ***middle*** | ***far*** |
|---|---|---|
| (760nm÷2,5 μm), | (2,5÷50 μm) | (50÷2000 μm). |

- Infrared radiation is used for heating, for the activation of the cellular processes under the action of the temperature gradient.
- The IR sources are heated bodies

# Luminescence

Luminescence is a process of producing light without involving or generating heat that lasts over the optical vibration period

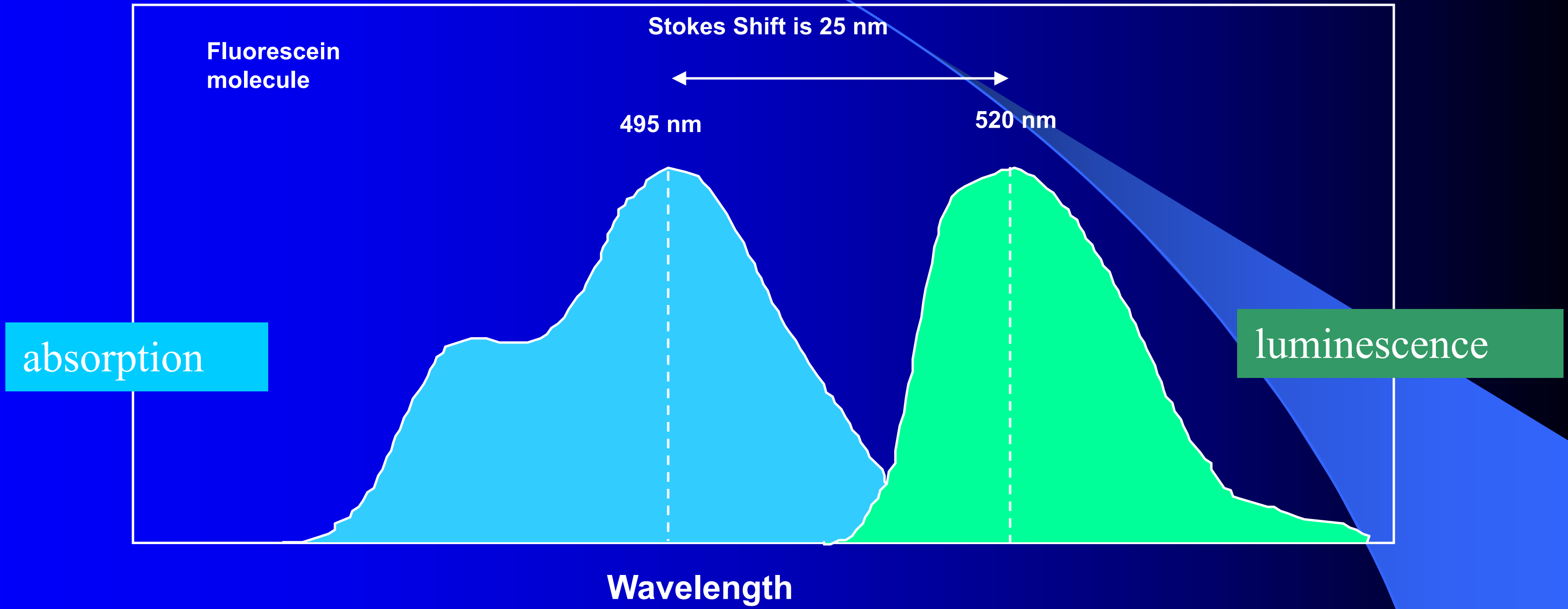



Simplified *Jablonski Diagram*

# Characteristics of luminescence

- Stokes shift
- Quantum Yield
- Energy Yield

# Stokes Shift




- Lumenescence spectrum and its peak shift to the higher wavelength region in comparison with the energy peak of absorbance.
- $E_{abs}=E_{non\text{-}radiating}+E_{flu}$

- Quantum Yield

$$Q = \frac{photons\ emmited}{photons\ absorbed}$$

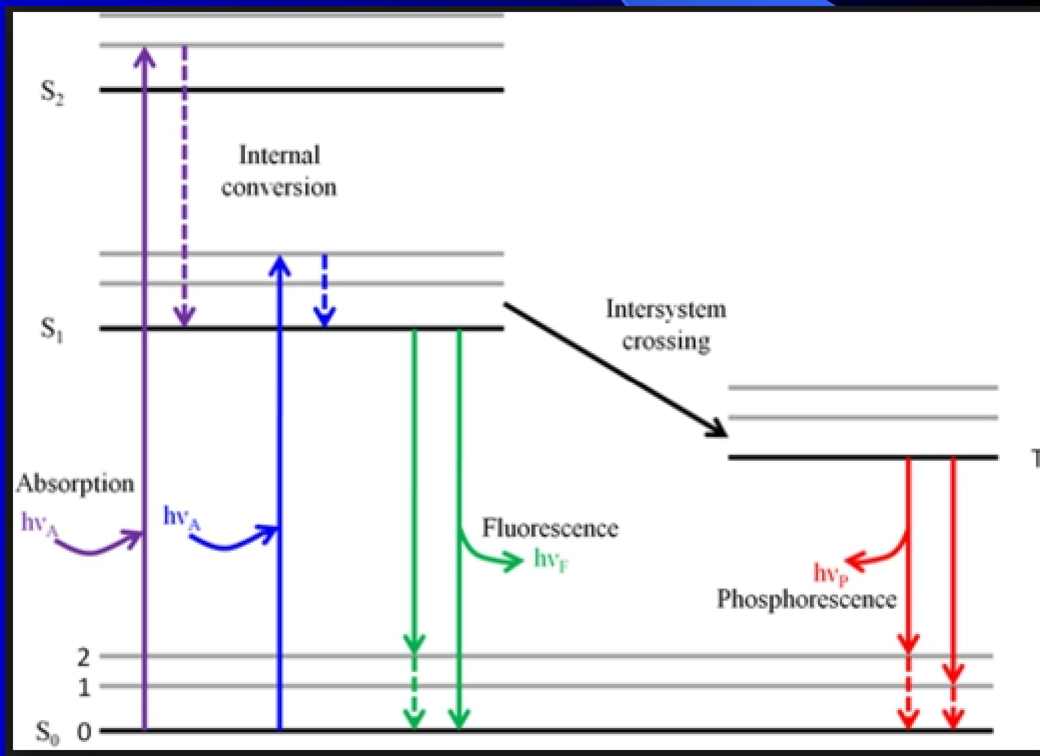
- Energy Yield

$$W = \frac{energy\ emmited}{energy\ absorbed}$$

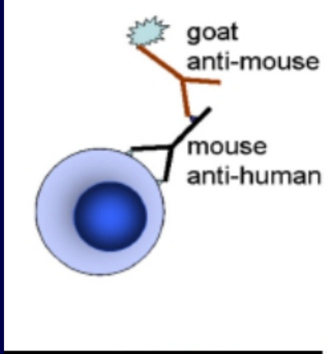
# Two types of luminescence:

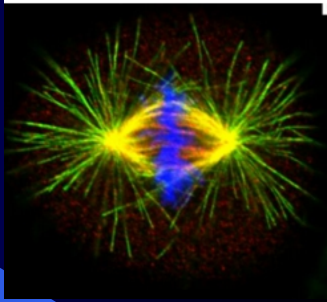
- **Fluorescence** (short-duration luminescence)**:** Emission involves a spin allowed transition (short excited state lifetime)
- **Phosphorescence** (long-duration luminescence)**:** Emission involves a spin forbidden transition

(long lived excited state).

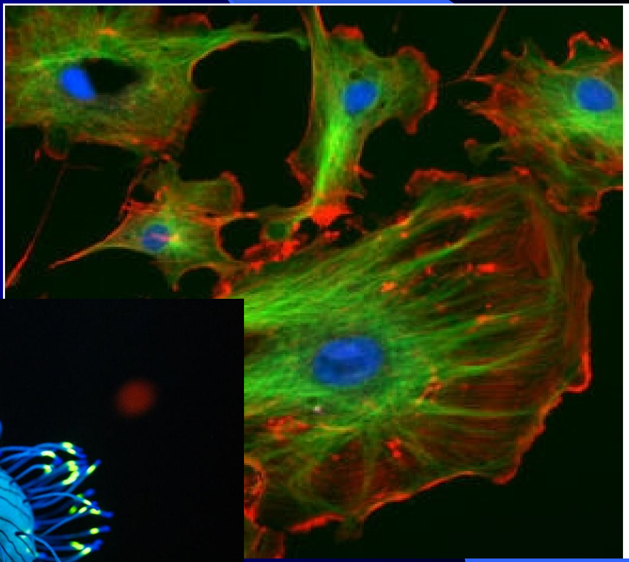


# Luminescence in medicine



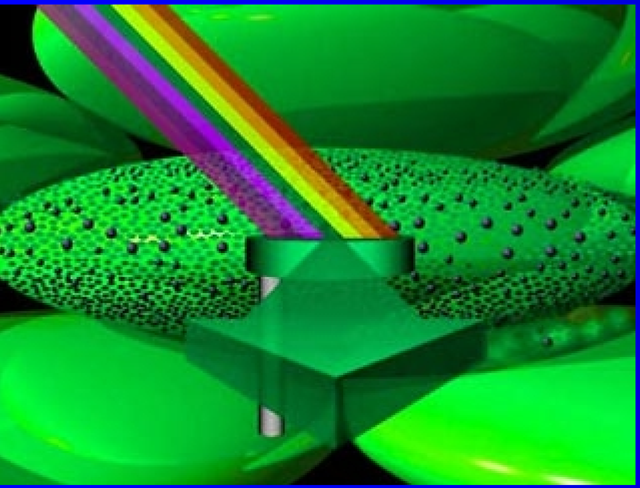



- The **green fluorescent protein (GFP)** from jellyfish exhibits bright green fluorescence when exposed to light in the blue to UV range. It is widely used in fluorescent microscopy.
- Luminescence analysis is allows to detect the compounds in the concentrations about $10^{-10}$ M

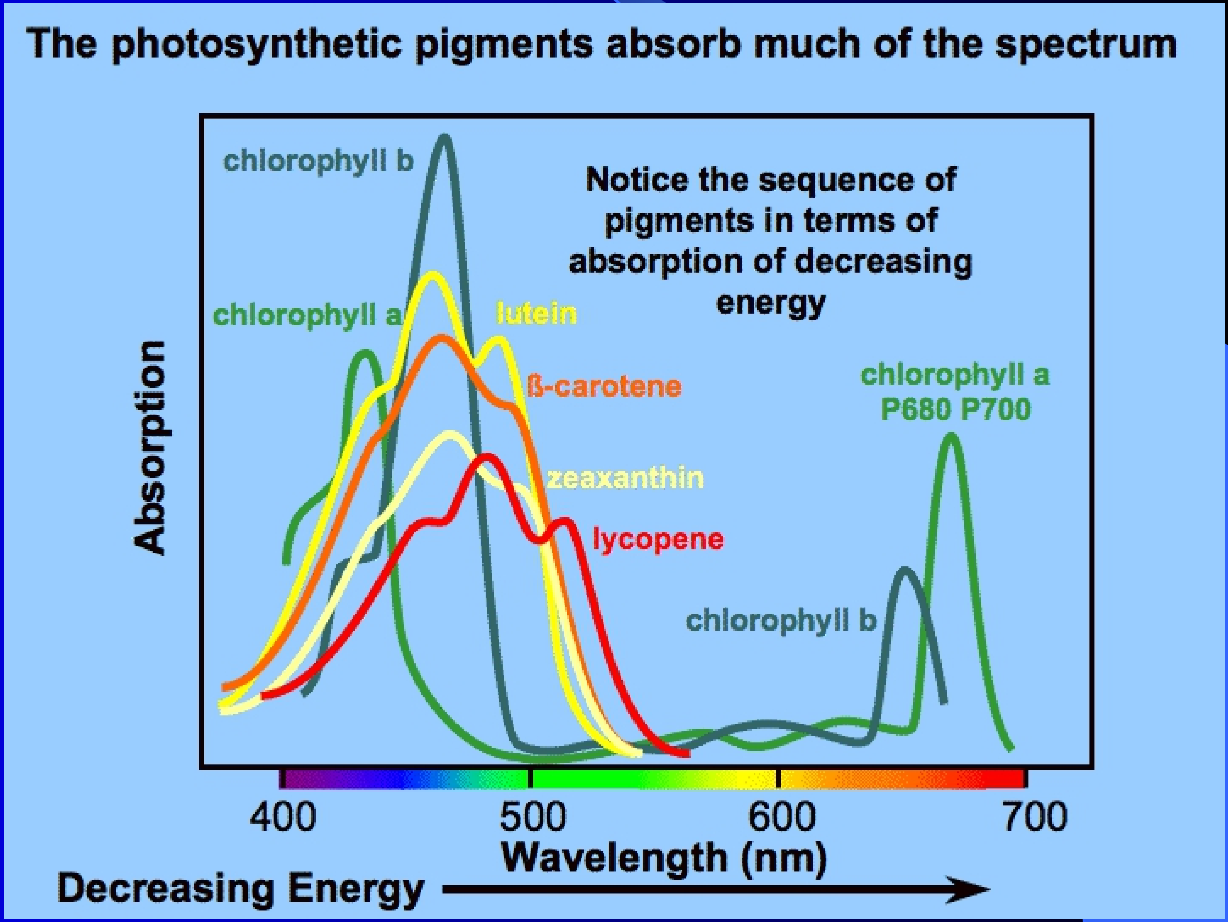


- The bacterial and mycotic colonies are characterised by specific luminescence. This luminescence is used for diagnosing different diseases in dermatology.

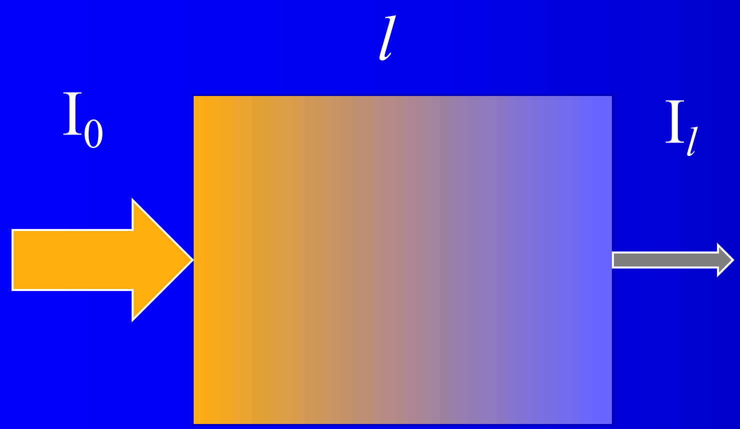
# Light absorption is a light energy transformation into other types of internal energy



Green colour of leaf is due to the absorption of blue and yellow/red light



# *The law of light absorption*




$$I_l = I_0 e^{-\alpha l}$$

The intensity of light passing through a material exponentially decreases with increasing an light path.

The constant $\alpha$ is called ***the absorption coefficient* at the wavelength considered**.

# Beer-Lambert law of light absorption

- For diluted solutions:

- $$I_l = I_0 e^{-\varepsilon_1 c l}$$ or $$I_l = I_0 10^{-\chi_1 c l}$$

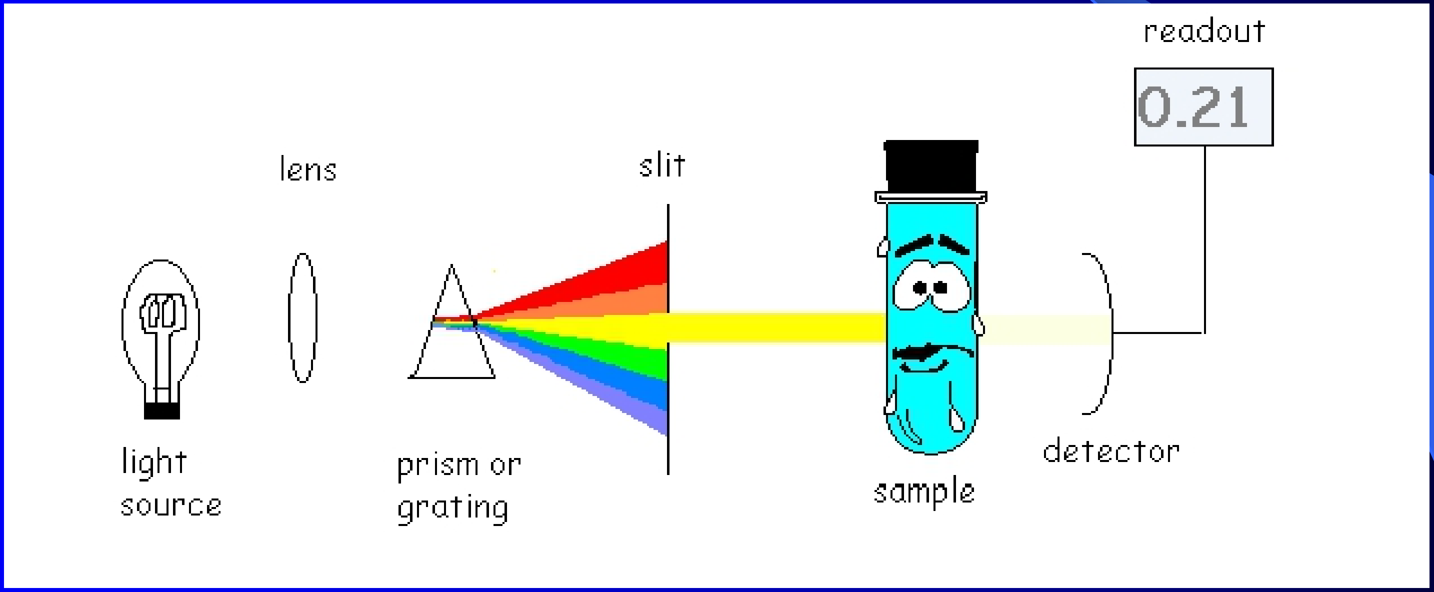
where ***ε and χ*** are the ***absorptivity of the substance*** **at the wavelength considered** for the unit of substance concentration (the index of extinction).

# *Photocolorimetry*

- is a method of determination of substance concentrations using the absorbance measurements.

- The devices for photocolorimetry are called ***photo colorimeters***.

# Photo colorimeter principle



# The light-transmission factor
## (or solution transparency)

- is the ratio of the intensity of light transmitted through the sample (***I***) to the intensity of light incident on the sample ($I_0$)

$$\tau = \frac{I_l}{I_0}$$

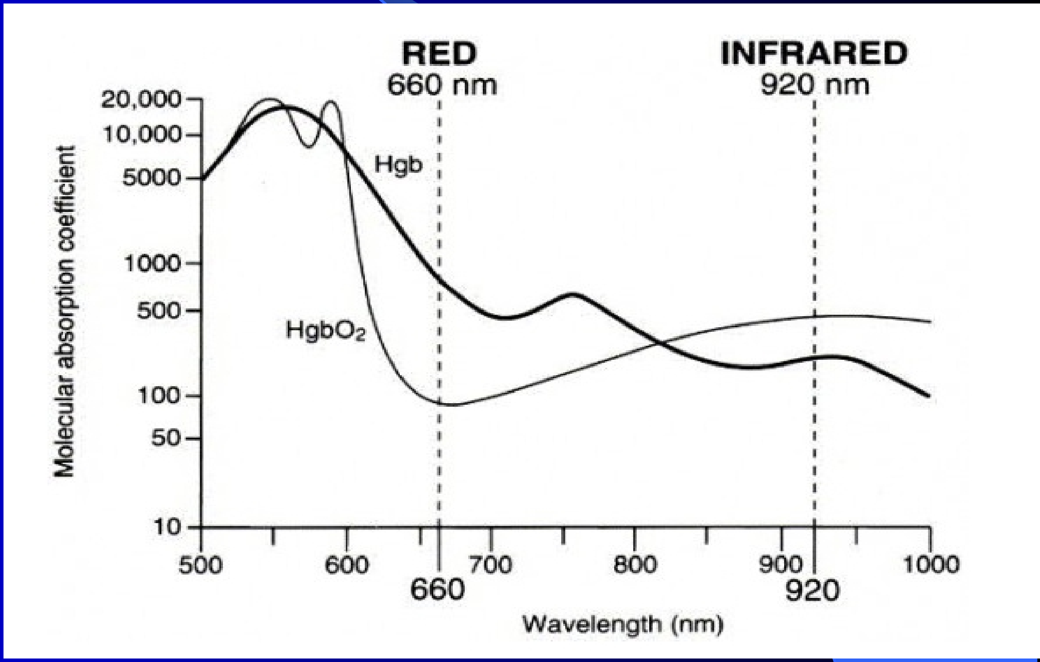
# The absorbance
## (or optical density)

- is the logarithm of the inverse light-transmission factor is called ***an absorbance***

$$A = \log \frac{1}{\tau} = \varepsilon_1 c l$$

# Example.
# Determination of the tissue oxygenation coefficient

To estimate
the concentration of $HbO_2$
and Hb in living tissues
the absorbance is measured
at two wavelengths
(660 nm and 920 nm)

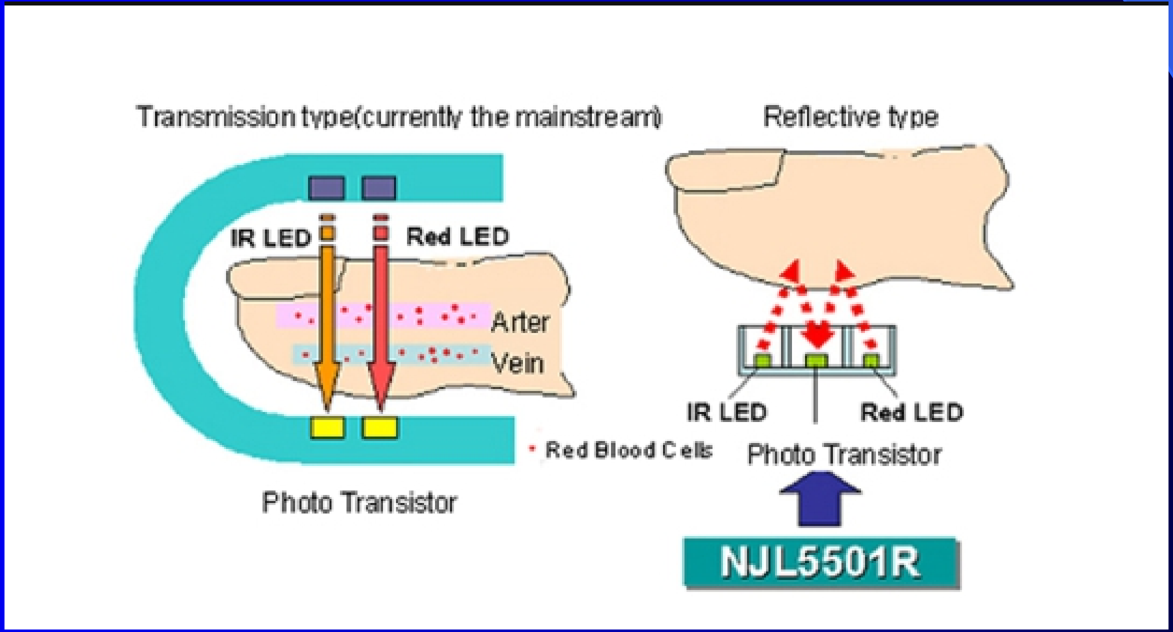



Tissue oxygenation coefficient
can be estimated as

$$pO_2 = \frac{[HbO_2]}{[HbO_2]+[Hb]}$$

The device
for measuring
the tissue oxygenation is

oxymeter (oximeter)

# Light scattering by the turbid medium

- **The phenomenon of the deviation of light from linear propagation in turbid medium is called the light scattering**
- Two types of optical heterogeneities:

***1) small foreign inclusions in homogeneous transparent substance (Tindall's phenomenon)***

2) ***optical heterogeneities appeared in pure substance due to density fluctuations (molecular scattering)***.

$$I \approx \frac{1}{\lambda^4}$$

# The general law of decrease in light intensity due to the light absorption and light scattering

$$I_l = I_0 \; 10^{-\mu l}$$

- where $\mu$ is the loss coefficient, $\mu = \chi + k$,
- $k$ is the scattering coefficient.

# *Turbidimetry (nephelometry)*

- is a method of measurement of scattered light for getting information about particle size and parameters of intermolecular interaction.
- The devices for nephelometry are called nephelometers.

# Photobiological processes

- ***are that start with light absorption and result in a certain physiological reaction of an organism.***

# The positive photobiological processes

- ***vision,***
- ***photoperiodic response*** (the regulation of daily and yearly living rhythms of animals with periodic effect of light and dark.
- ***vitamin D formation from its provitamins***

# The negative photobiological processes

- *phototoxic effects*:
- • **light injury of eyes and skin** (lenticular opacity, erythema)
- • **bactericidal action of UV**;
- • **carcinogenic action of UV**.
- ***photoallergic effects***