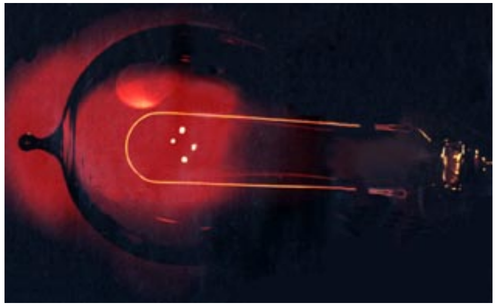
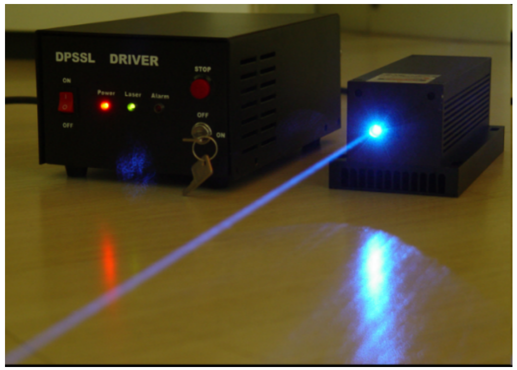
Generation of light – Light sources



Black-body radiation

Luminescence

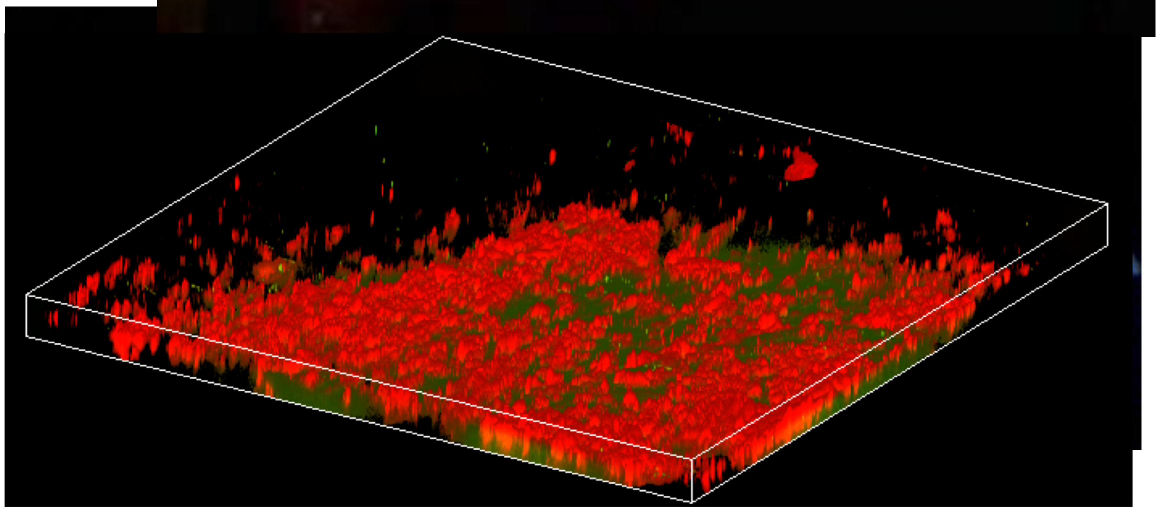
Laser



Jedlovszky-Hajdú, Angéla

19/10/2020

Luminescence



Repetition

- Types of energy states in atoms and molecules are independent (not coupled)
- Energy states are non-continuous, but discrete
- Transition between states involves packets (quanta) of energy

$$E_{total} = E_e + E_v + E_r$$

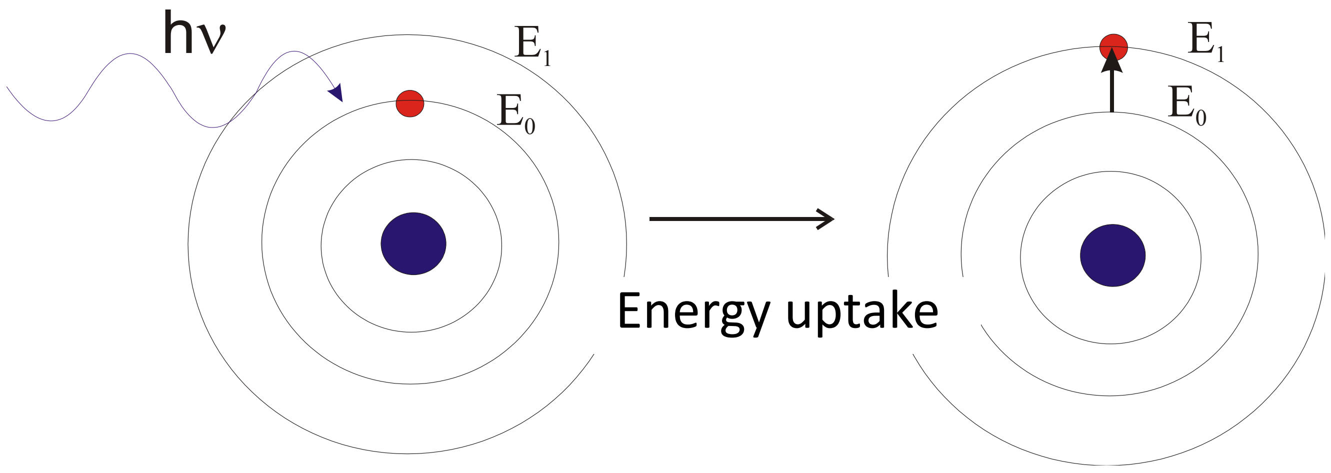
Scales of transition energies between different states are different:

$$E_e > E_v > E_r$$

Consider a **<u>single atom</u>**

- Energy states are discrete
- Electrons occupy the lowest possible energy state (ground state)
- Pauli exclusion principle: no two identical fermions (particles with half-integer spin) may occupy the same quantum state simultaneously

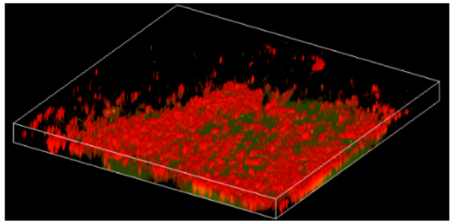
Excitation energy



Ground state

Excited state

Excitation modes



- absorption of radiation (UV/VIS) : *photoluminescence*

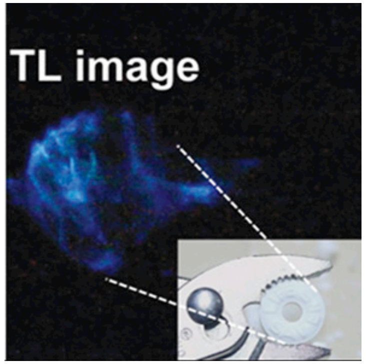
- chemical reaction: *chemo/bio-luminescence*

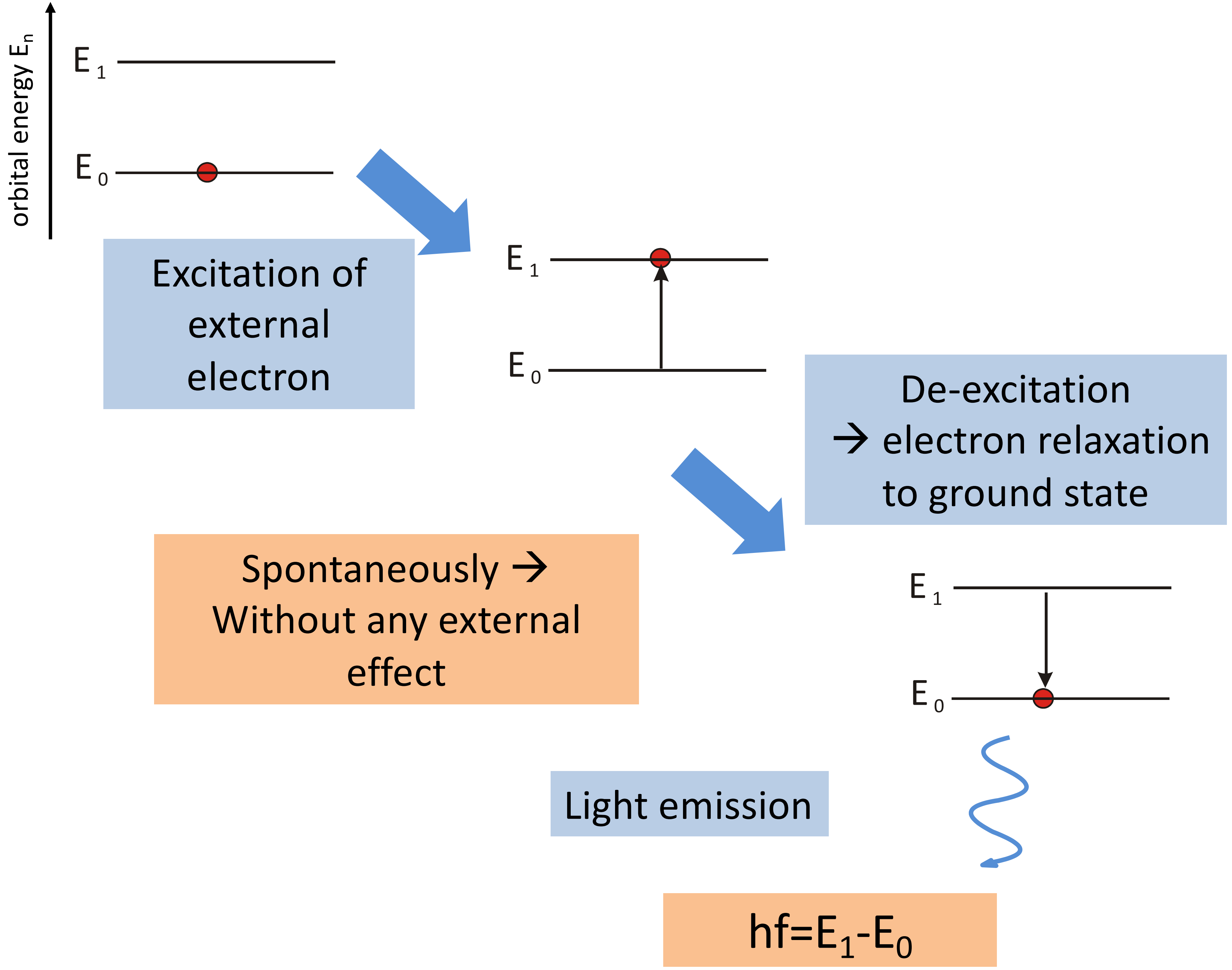
- Injection of charges: *electroluminescence*

- friction → mechanical deformation: *triboluminescence*

-thermally activated ion recombination: *thermoluminescence*

- Sound waves: *sonoluminescence*




orbital energy E_n
E_1
E_0
Excitation of external electron
E_1
E_0
De-excitation → electron relaxation to ground state
Spontaneously → Without any external effect
E_1
E_0
Light emission
$hf=E_1-E_0$

Luminescence:

spontaneous light photon emission by electrons when they return from their excited state to their original (ground) state of lower energy

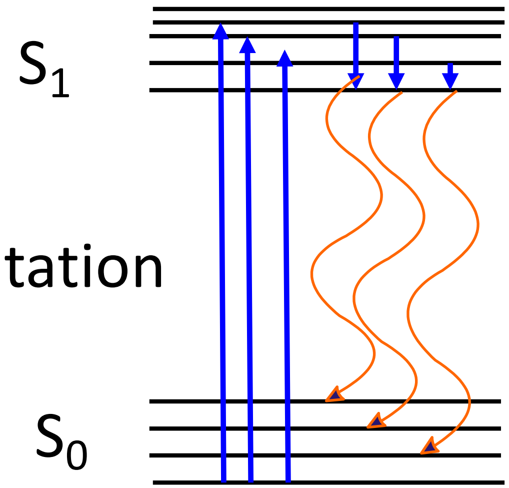
$$hf = E_1 - E_0$$

The emitted photon energy is characteristic for the electronic orbitals, thus for the atom/molecule.

Qualitative information.

The energy of the electronic orbitals in molecules is perturbed by the discrete states of molecular vibrations

Jablonski diagram



excitation

Non-radiant transitions

Light emission

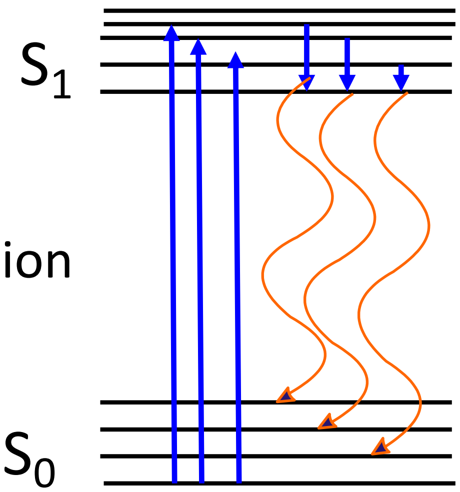
Fluorescence

First excited singlet state

the spin states of
the electrons

sum of all e^- spin quantum
numbers=0

De-excitation by photon emission
between singlet states



Fluorescence

De-excitation by photon emission between singlet states

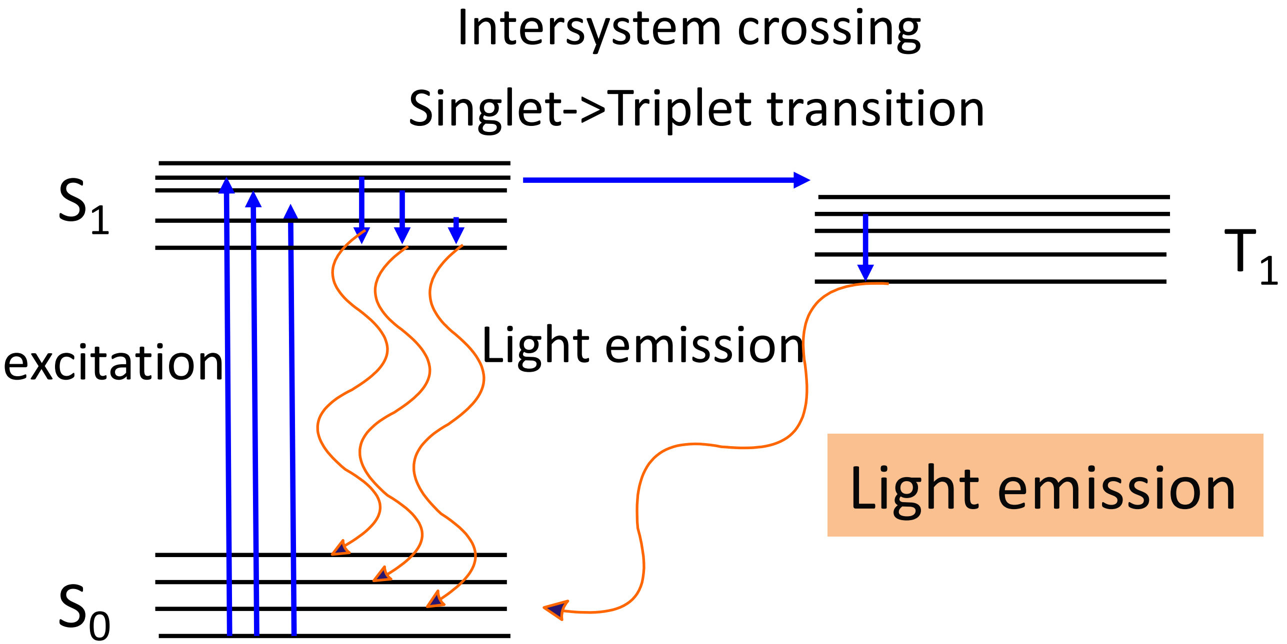
Kasha's rule:

fluorescence originates always from the vibrational state of lowest energy within the lowest electronic excited state.

$$E_{excitation} \geq E_{fluorescence}$$

$$\lambda_{excitation} \leq \lambda_{fluorescence}$$

Stokes-shift



Phosphorescence

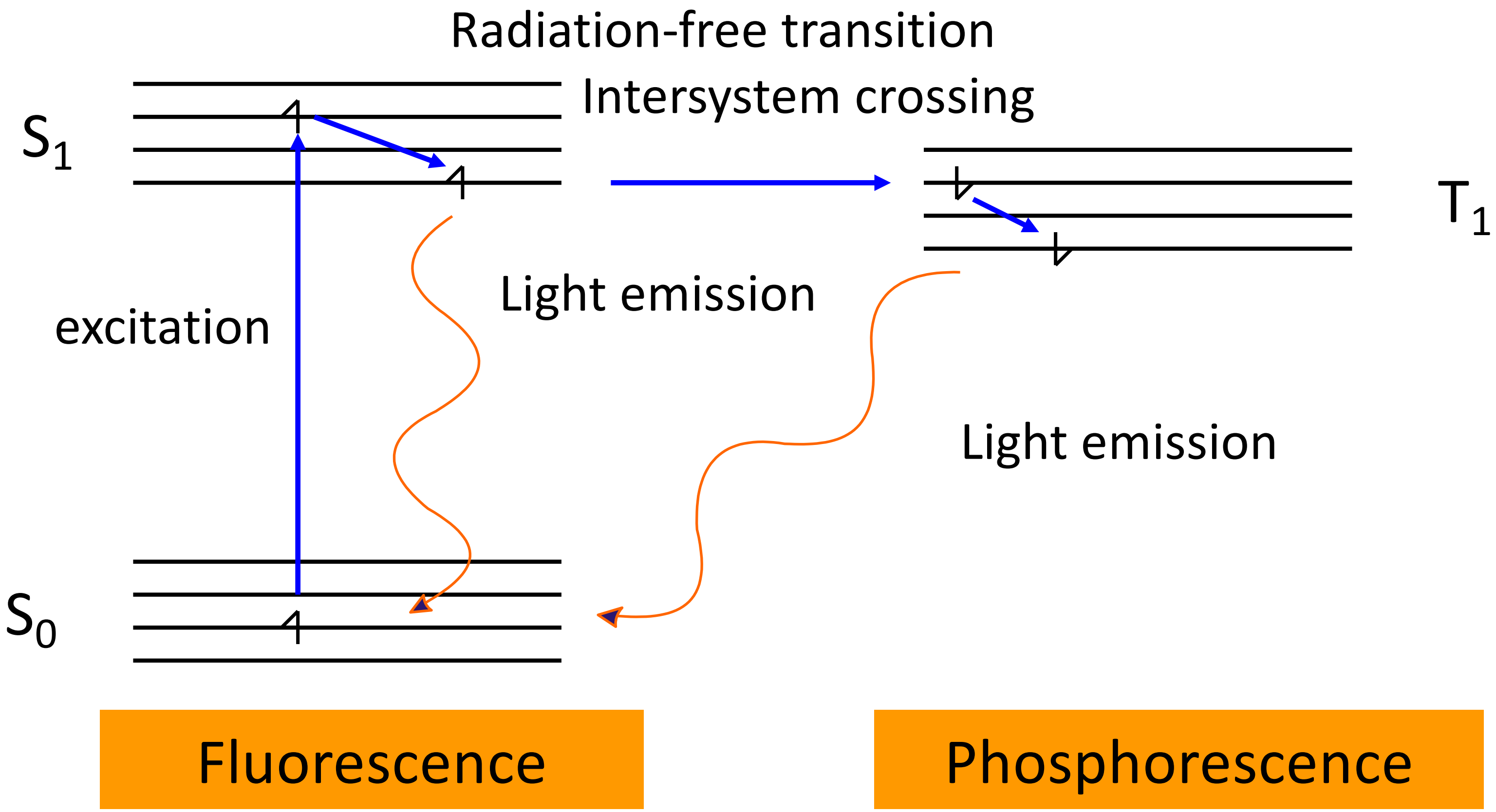
Triplet state

spontaneous light photon emission
from metastable excited state

sum of all e^- spin quantum numbers=1

Metastable state

Emitted photon energies



Stokes-shift

$$E_{excitation} \geq E_{fluorescence} > E_{phosphorescence}$$

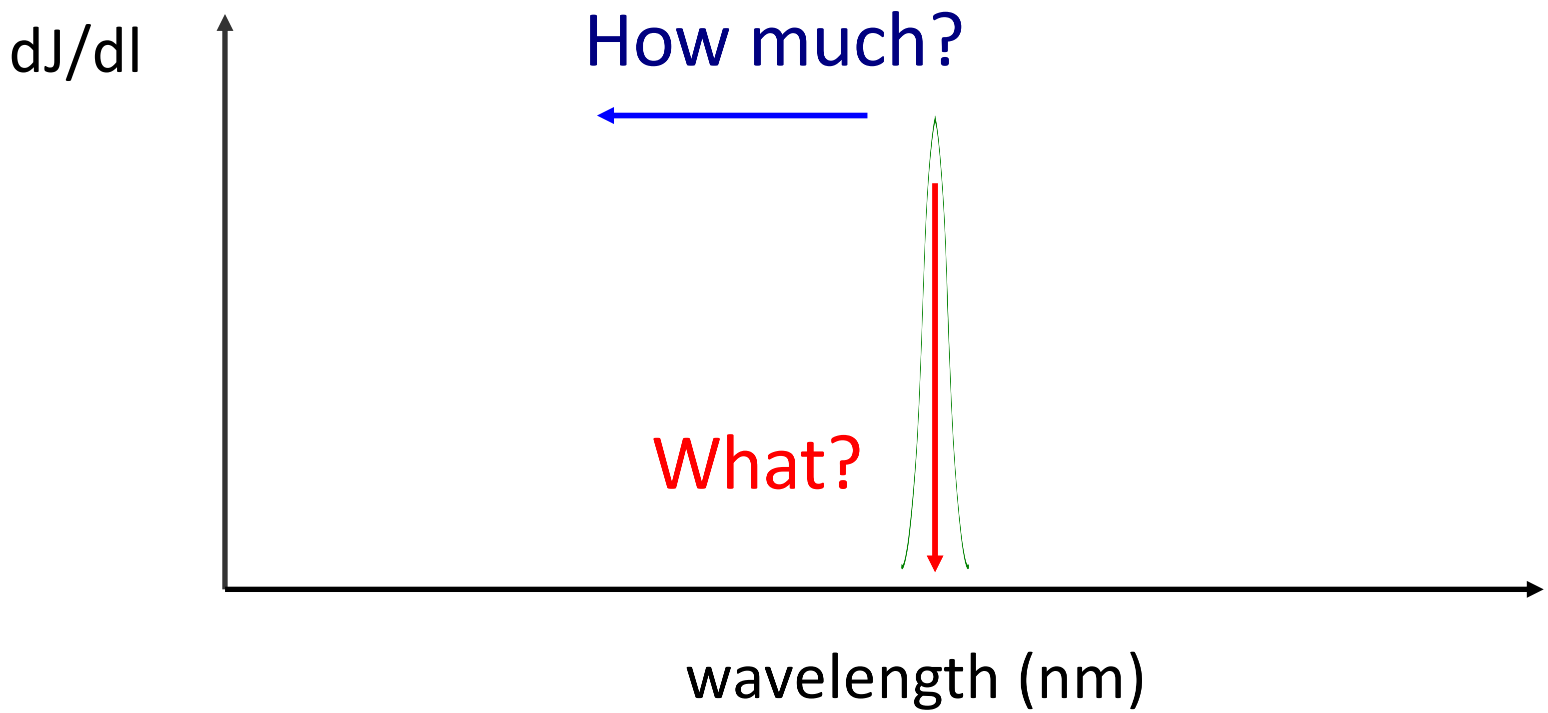
$$\lambda_{excitation} \leq \lambda_{fluorescence} < \lambda_{phosphorescence}$$

Characteristics of emitted light

Wavelength distribution of emitted light

Emission spectrum

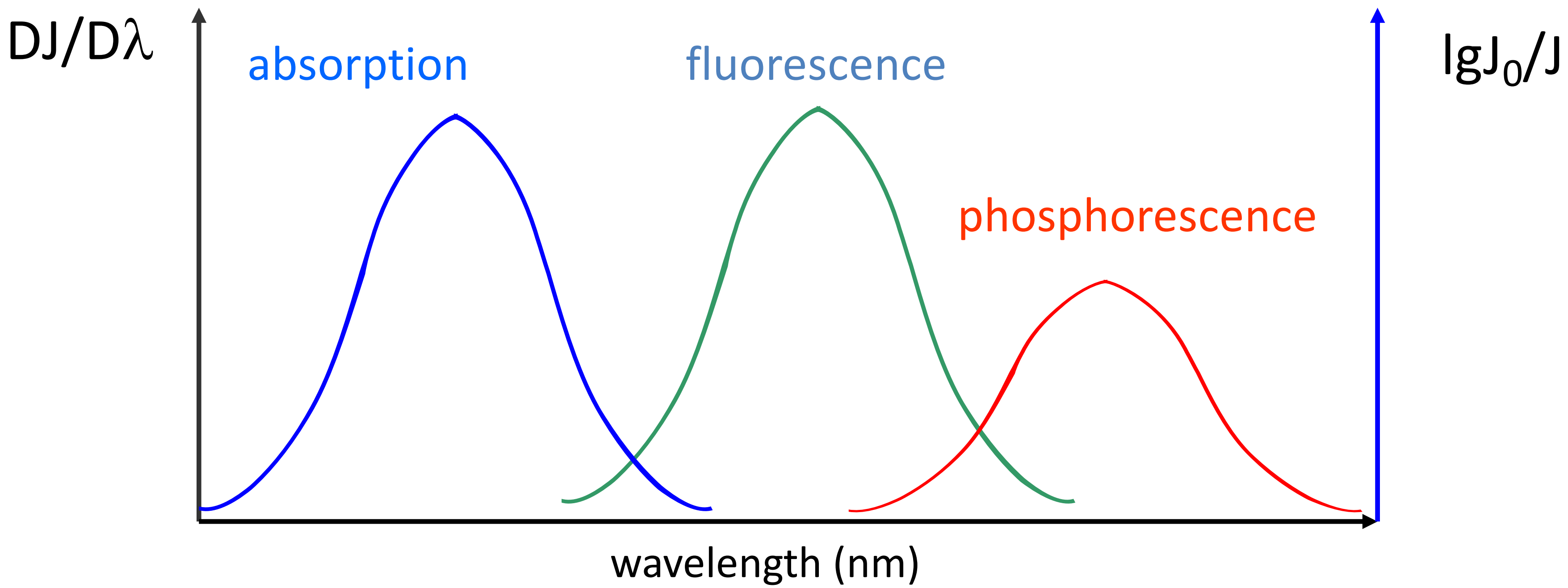
Atoms — line spectrum



Wavelength distribution of emitted light

Emission spectrum

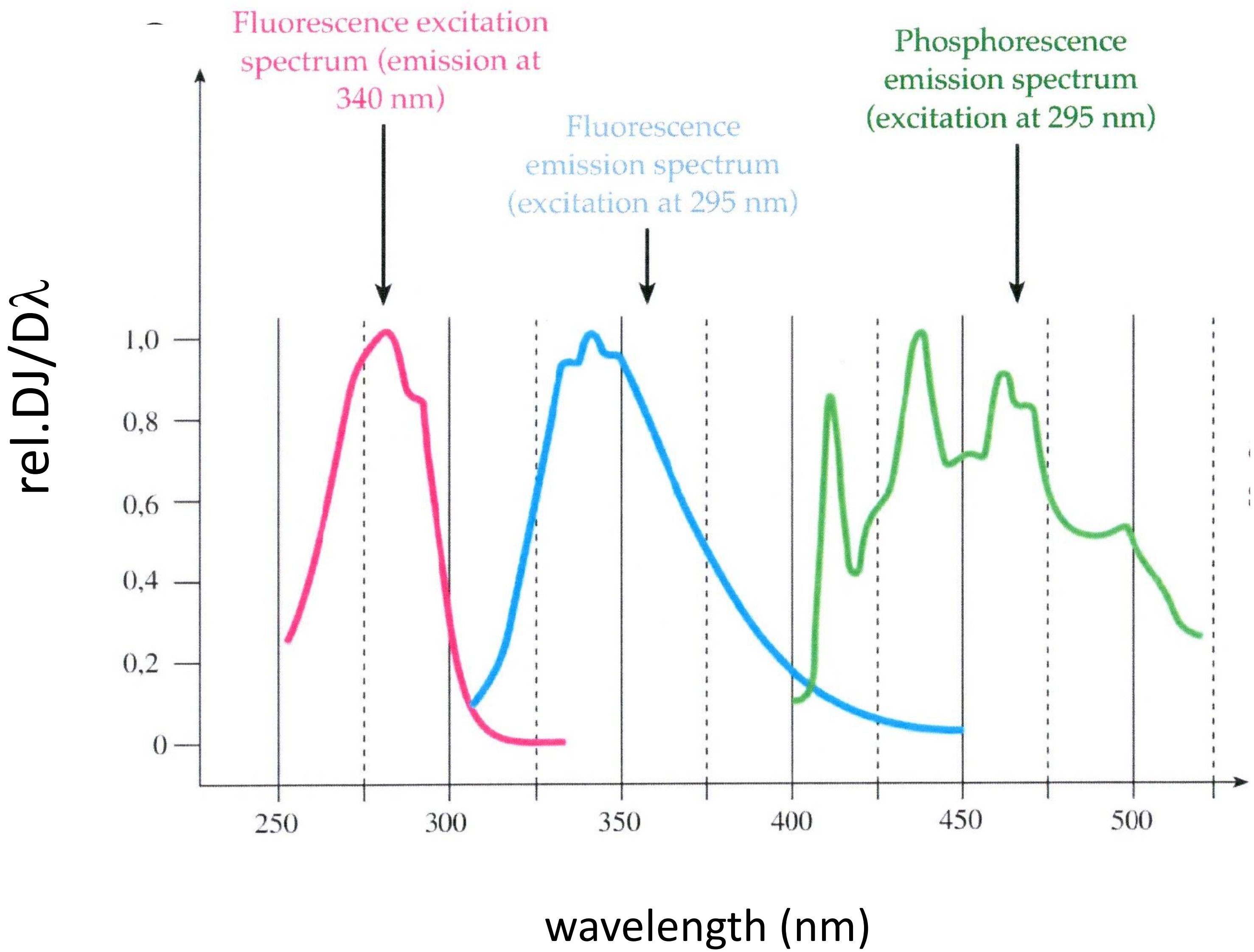
molecules: band spectrum



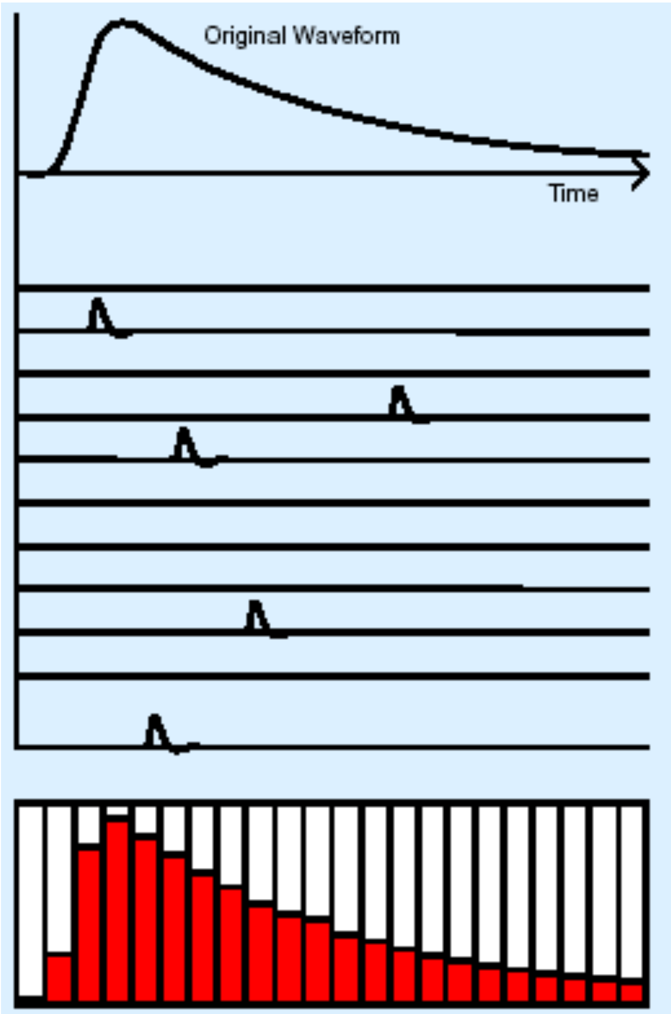
$$\lambda_{excitation} \leq \lambda_{fluorescence} < \lambda_{phosphorescence}$$

Stokes shift

E.g.: Corresponding spectra of triptophane



Excited-state lifetime

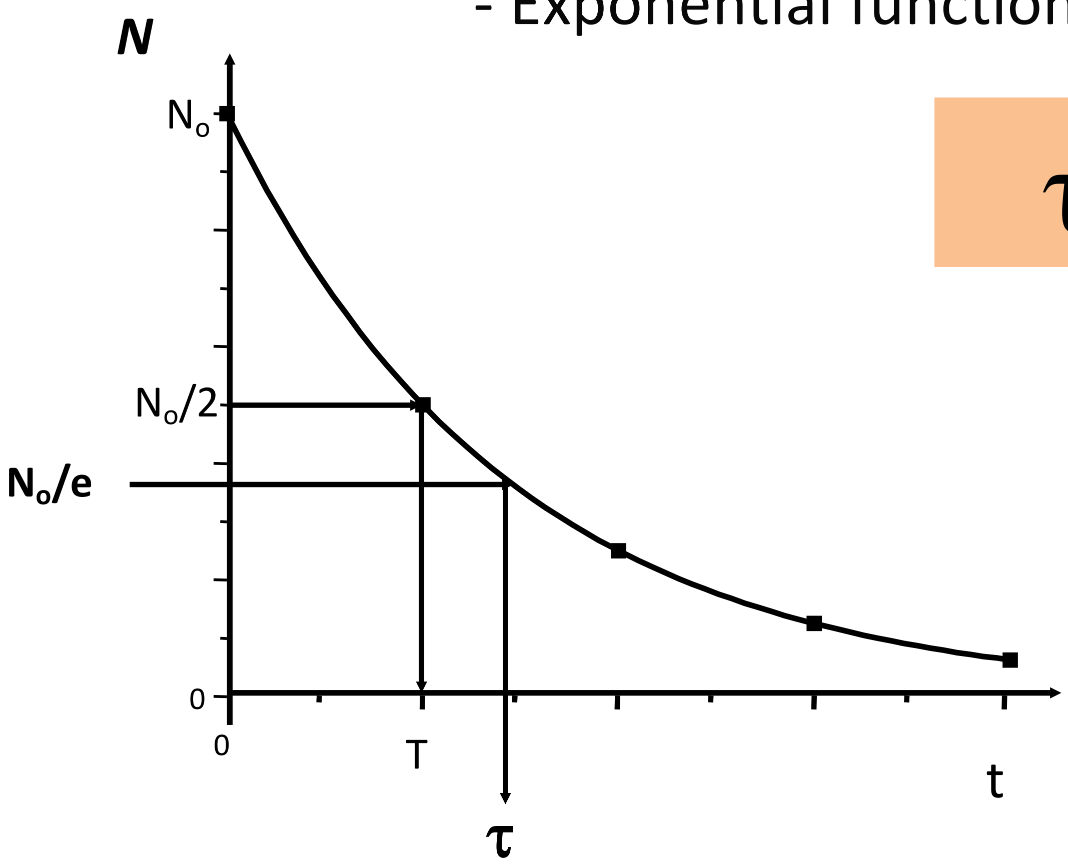


Single photon counting

Measuring of time gap between excitation and photon emission. Statistical analysis of large number of measurements.

Number of excited electrons → $N = N_0 e^{-\frac{t}{\tau}}$ ← time after excitation

- Exponential function

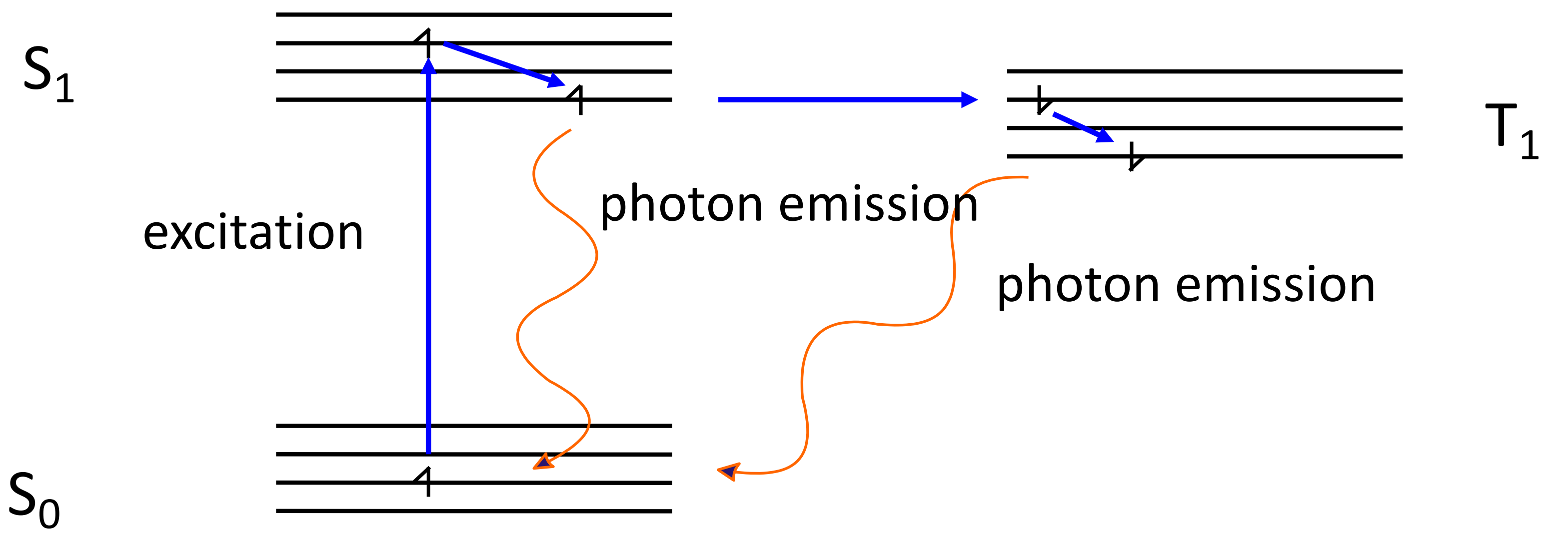


τ: life time

the time during which the number of excited electrons decreases to its e^{th}.

Typical excited-state lifetimes

Lifetime — the time during which the number of excited electrons decreases to its *e*th.



Fluorescence	Phosphorescence
short	long
$10^{-9} – 10^{-7}$ s	$10^{-3} – 10^{2}$ s

Is excitation always followed by photon emission?

- Excited state decay can be caused by mechanisms other than photon emission and are therefore often called "non-radiative rates„.

- These can include: chemical reaction, dynamic collisional quenching, near-field dipole-dipole interaction, internal conversion and intersystem crossing.

Is excitation <u>always followed</u> by photon emission?

Quantum yield

$$A \xrightarrow{h\nu} B$$

Reciprocal of the number of absorbed photons for one photon emission

Fluorescence quantum yield (Q_F)

$$Q_F = \frac{number.of.photons.emitted}{numbe.of.photons.absorbed}$$

$$Q_F \leq 1$$

<u>Types of luminescence:</u>

- fluorescence
- phosphorescence

<u>They can be characterized by:</u>

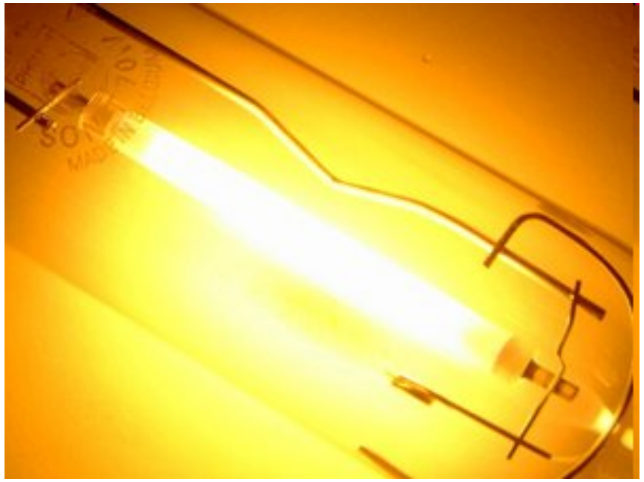
- emission spectrum:
  - Types
  - position of peaks
  - amplitude
- lifetime
- quantum yield

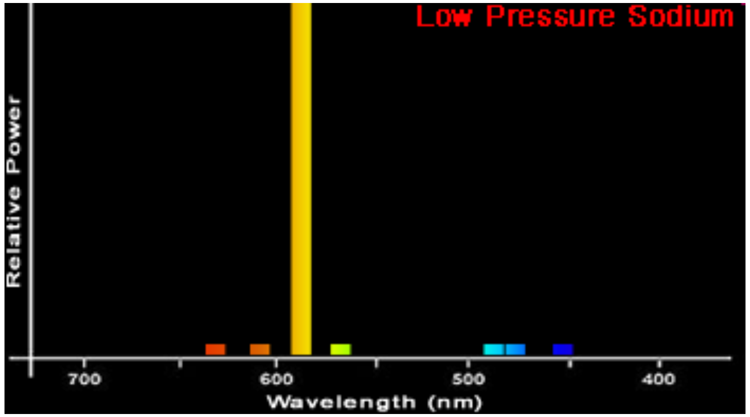
Application fields of luminescence

- Light sources (lightening, fertilization, sunbeds, photomedicine...)
- concentration determination (flame photometer)
- luminescence spectroscopy
- luminescence microscopy
- dosimetry (see later)
- archeology
- architecture
- safety control … many more

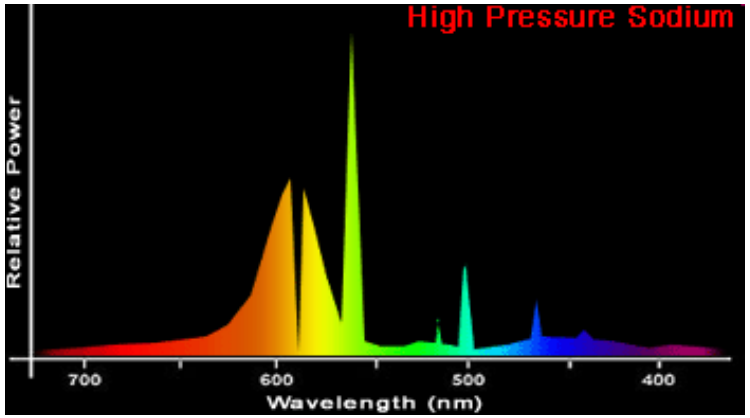
Luminescent light sources

Metal vapor lamps



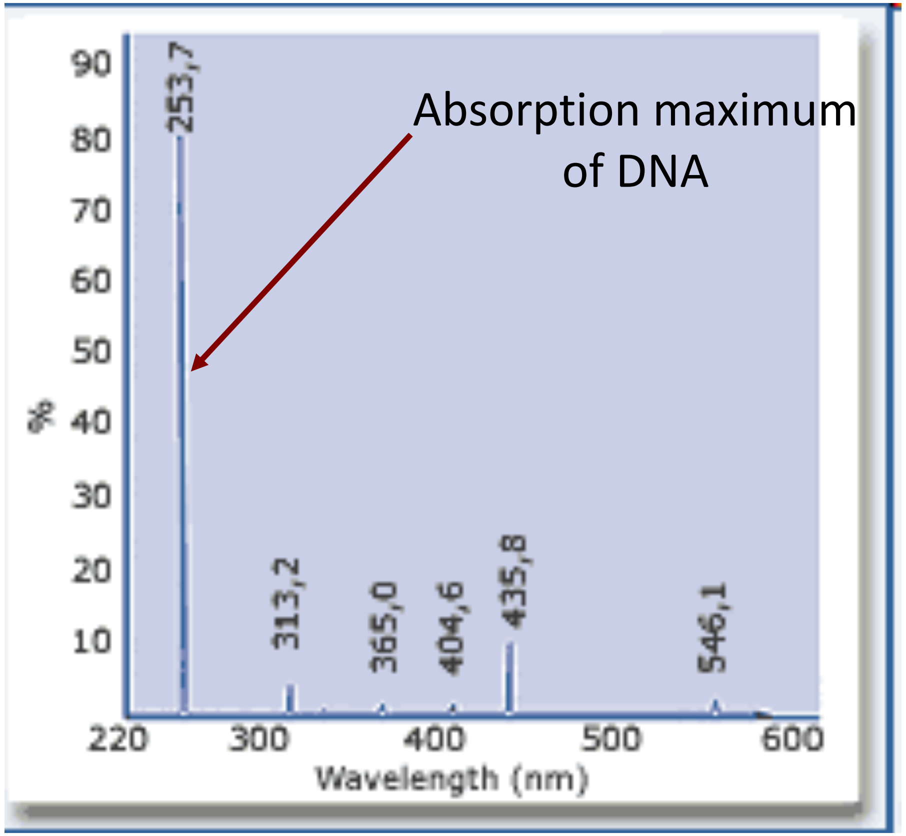


Low-pressure Na-vapor lamp

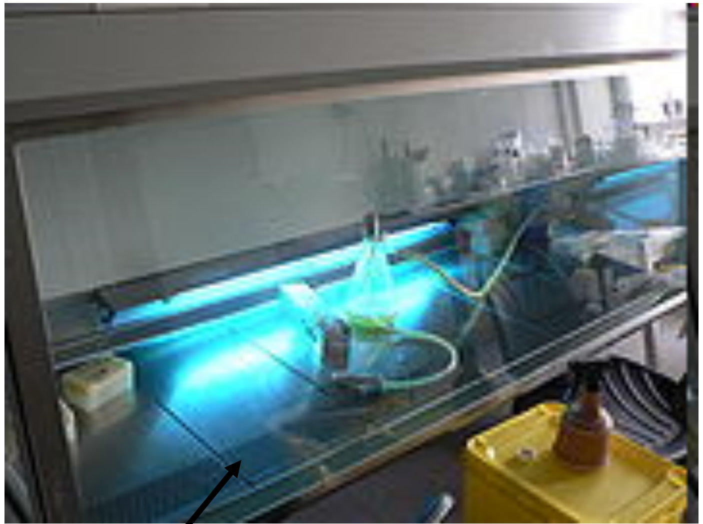


High-pressure Na-vapor lamp

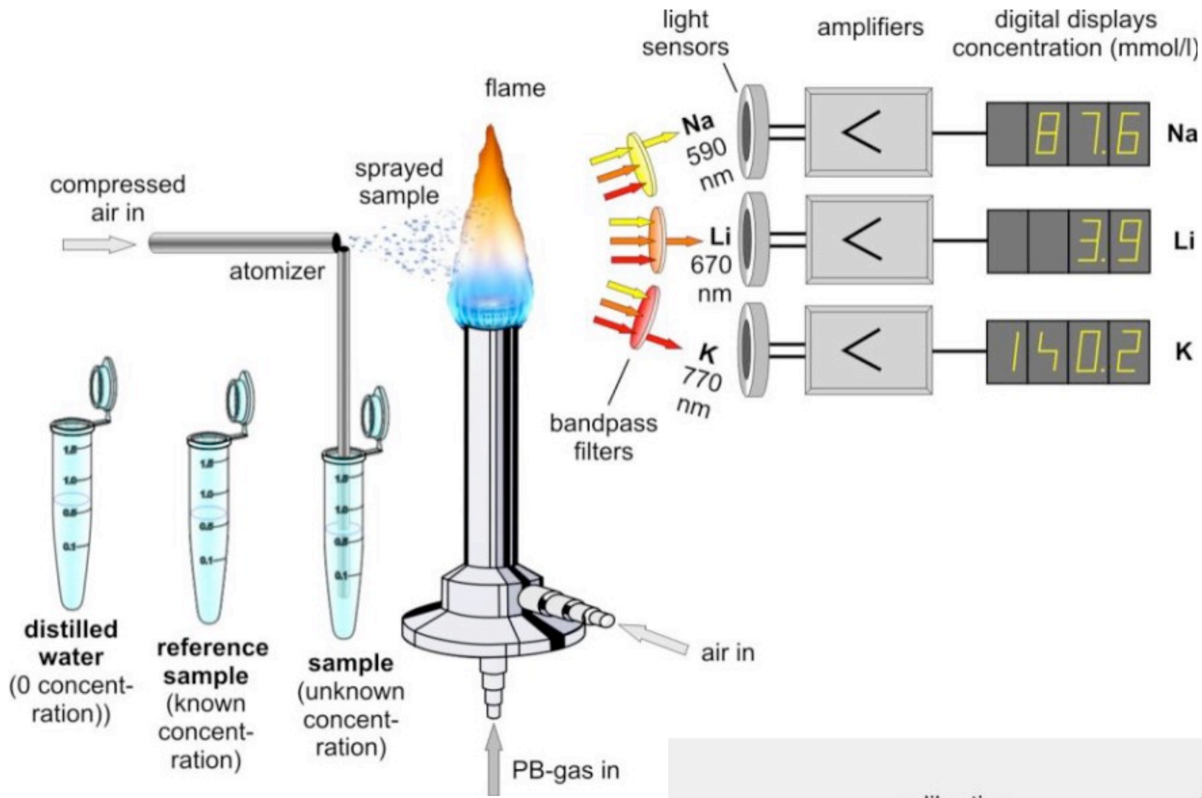
Low-pressure Hg-vapor lamp

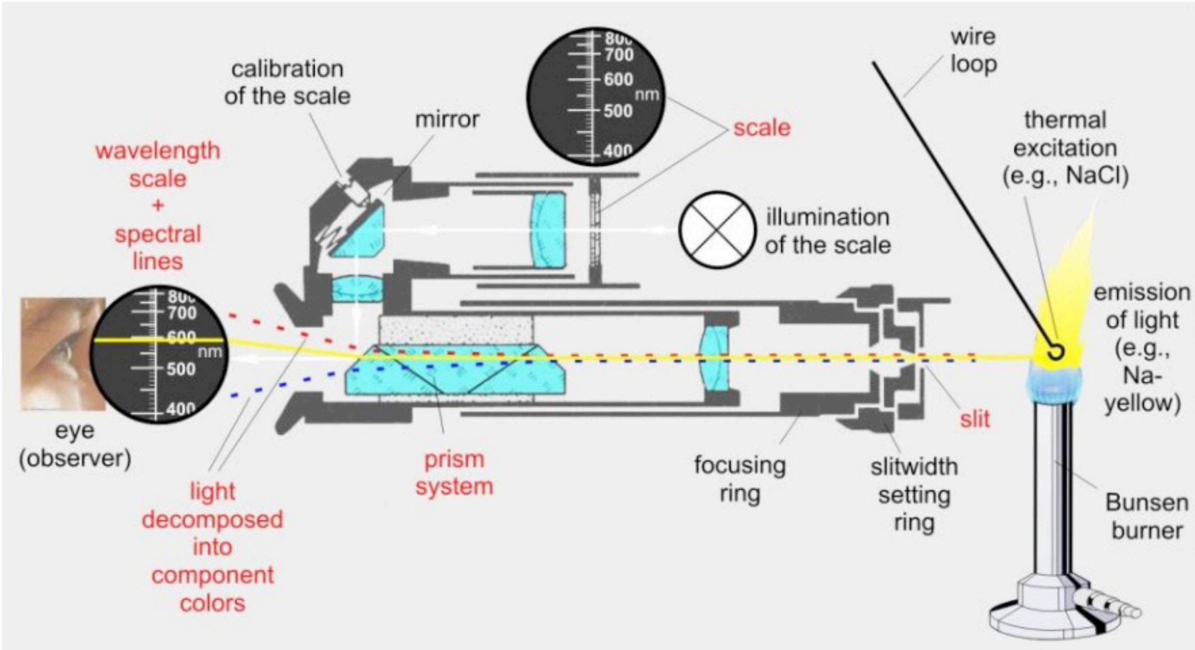


Emission spectrum

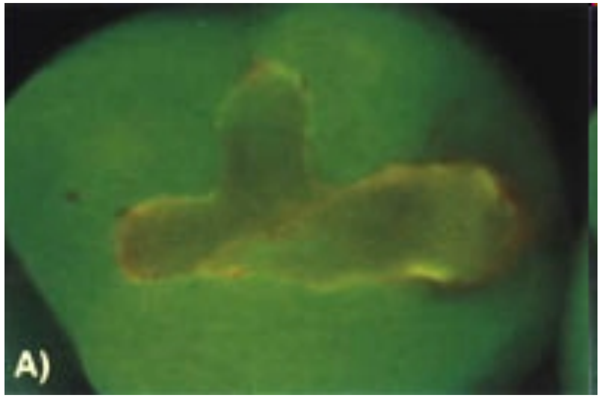


„germicid lamp”

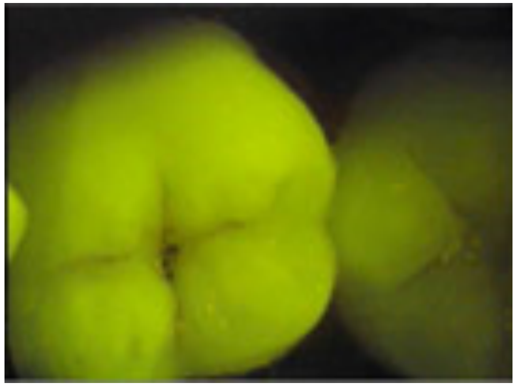

light sensors
amplifiers
digital displays concentration (mmol/l)
flame
Na 590 nm
87.6 Na
Li 670 nm
3.9 Li
K 770 nm
140.2 K
sprayed sample
compressed air in
atomizer
bandpass filters
distilled water (0 concentration))
reference sample (known concentration)
sample (unknown concentration)
air in
PB-gas in


wire loop
calibration of the scale
mirror
scale
thermal excitation (e.g., NaCl)
wavelength scale + spectral lines
illumination of the scale
emission of light (e.g., Na-yellow)
eye (observer)
light decomposed into component colors
prism system
focusing ring
slitwidth setting ring
slit
Bunsen burner

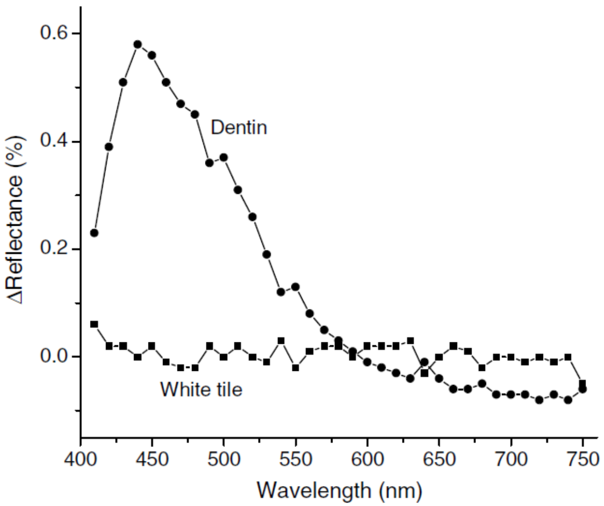
Application in dental medicine



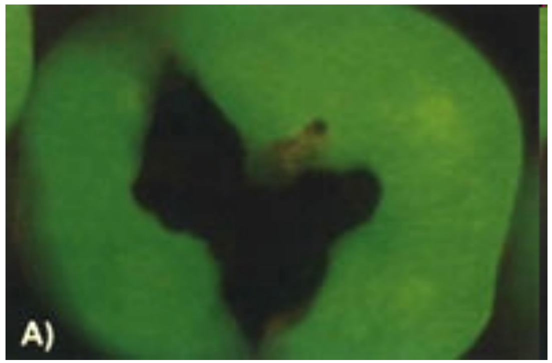
Red fluorescence indicates the activity of identifies cariogenic bacteria



Auto-fluorescence of teeth. When teeth are illuminated with high intensity blue light they will start to emit light in the green part of the spectrum.



Lee, Journal of Biomedical Optics 20(4), 040901 (April 2015)



amalgam restoration

0 – 14	No special measures.
15 – 20	Usual prophylactic measures.
21 – 30	More intensive prophylaxis or restoration: indication is dependent on: *Caries activity. *Caries risk. * Recall interval, etc.
from 30	Restoration and more intensive prophylaxis.

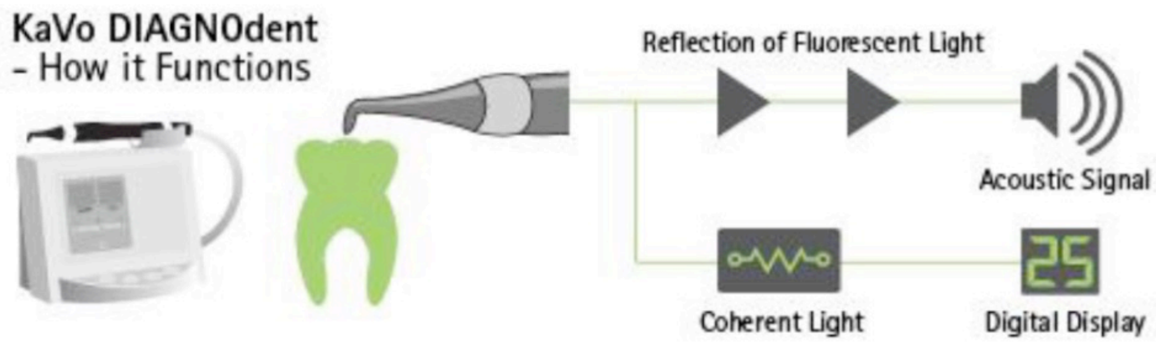
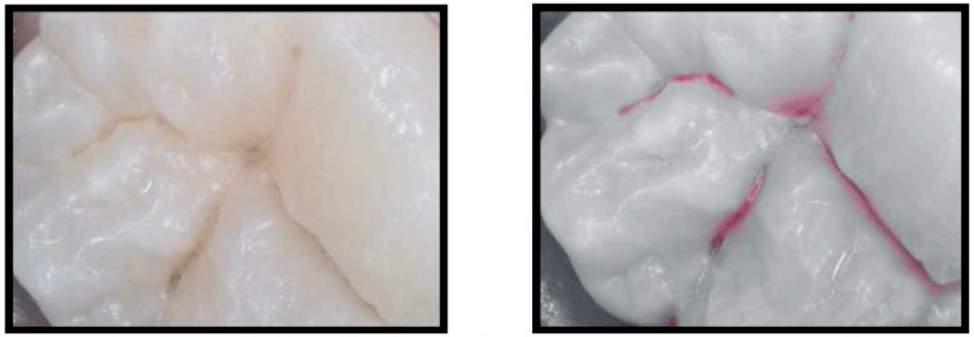


Figure (5) Spectra camera with spacer on (Kurtzman, 2010).

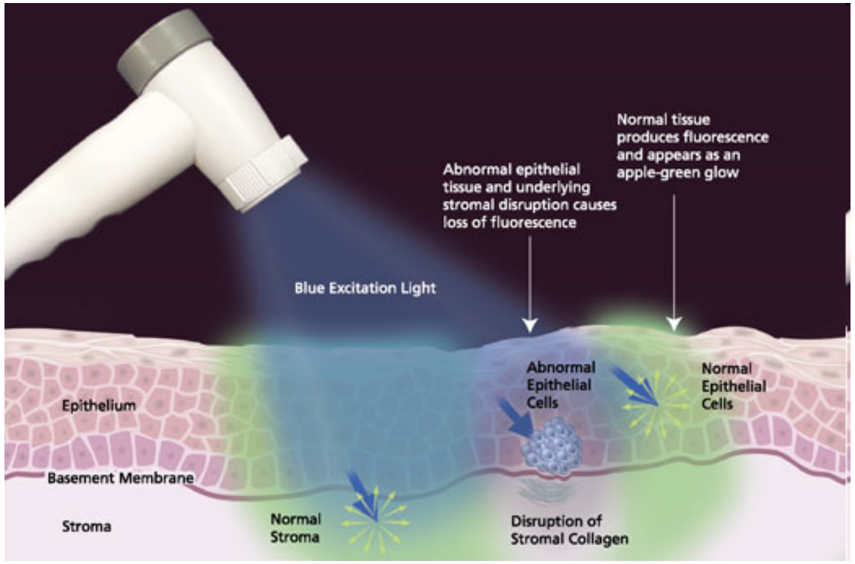
Table 2: Interpretation of Spectra data (Kurtzman, 2010).

Displayed Color	GREEN → BLUE → RED → ORANGE → YELLOW				
Displayed Number	1 ⟶ 5				
Depth of Involvement	Sound Enamel	Initial Enamel Caries	Deep Enamel Caries	Initial Dentin Caries	Deep Dentin Caries



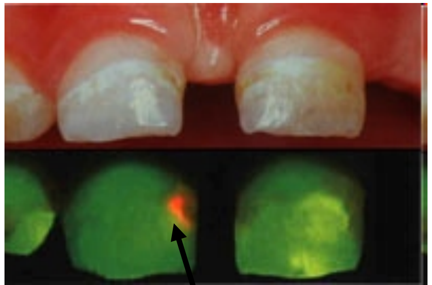
SOPROCARE. (A) Carious lesion invisible in DAYLIGHT mode. (B) Carious lesion visible in CARIO mode

Figure (8) Photos showed cavity illumination with Facelight before and after caries excavation (21).

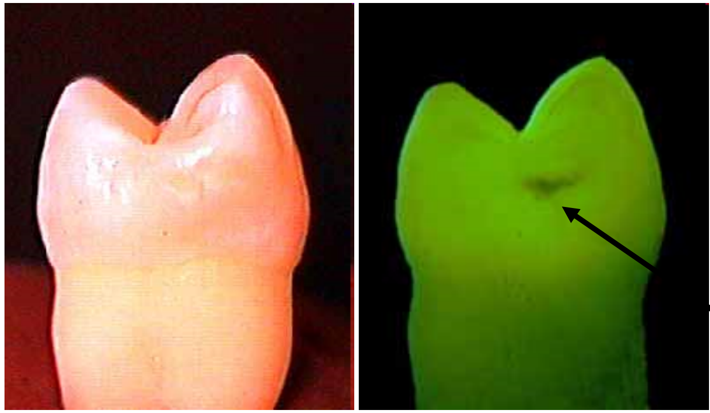


Healthy and malignant tissues
different fluorescent properties

Teeth
native and fluroescent
images



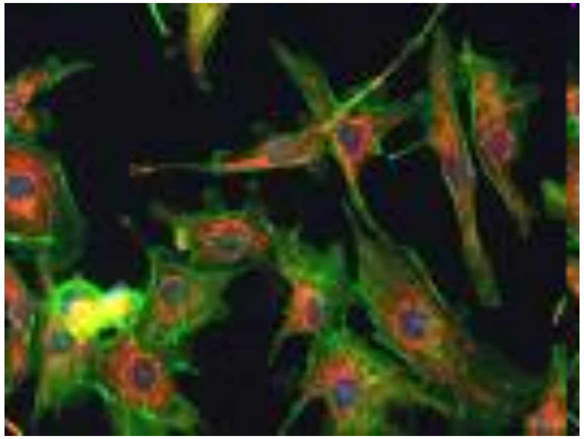
Active caries

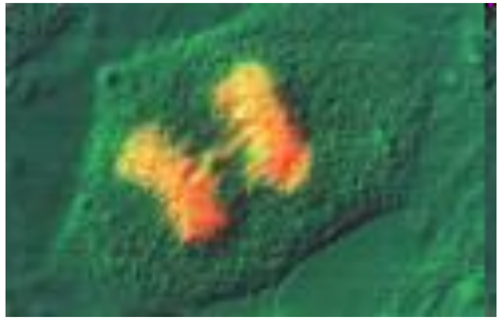


caries

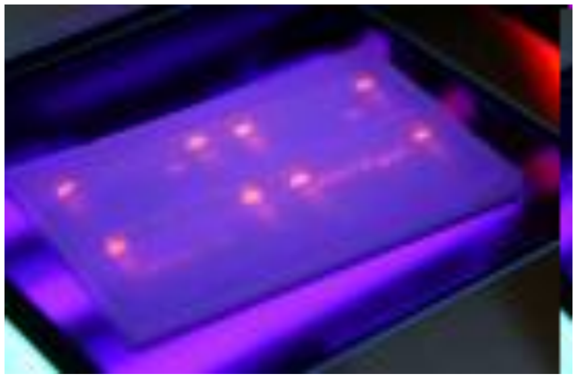
Tooth
native and fluroescent
image

Luminescent microscopy





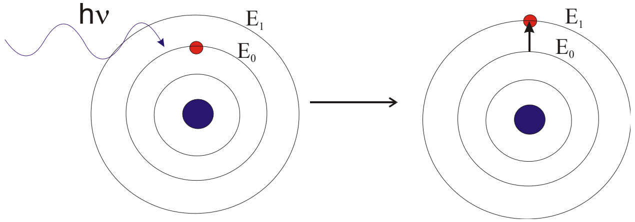
Laboratory application in many ways



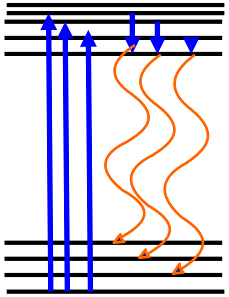
And more...

Checklist for the semifinal

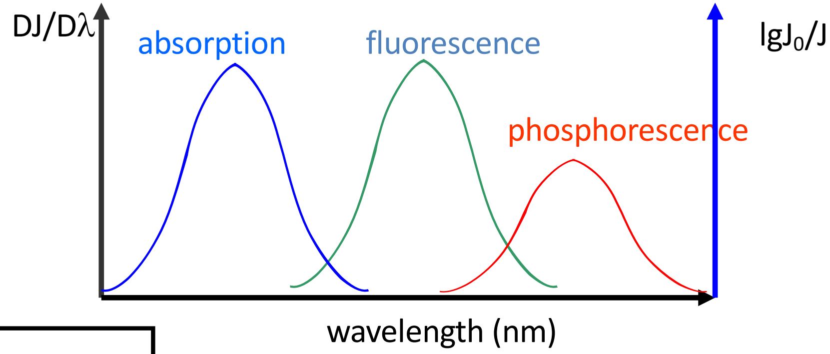
- ❑ Ground state-excited state



- ❑ Excitation methods
- ❑ Luminescence
- ❑ Jablonski diagram



- ❑ Fluorescence-Phosphorescence



- ❑ Kasha's rule
- ❑ Stokes shift

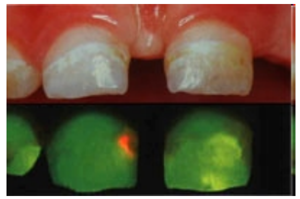
$$\lambda_{excitation} \leq \lambda_{fluorescence} < \lambda_{phosphorescence}$$

- ❑ Lifetime

$$N = N_0 e^{-\frac{t}{\tau}}$$

- ❑ Quantum yield

$$Q_F = \frac{number.of.photons.emitted}{numbe.of.photons.absorbed}$$



- ❑ Applications of luminescence effect in medical point of view

Damjanovich, Fidy, Szöllősi: Medical Biophysics

II. 2.2
- 2.2.4
- 2.2.6

VI.3.3
- 3.3.1
- 3.3.2 pp. 411-413
- 3.3.3