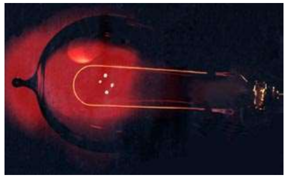
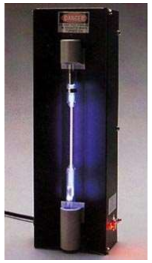
Generation of light – Light sources

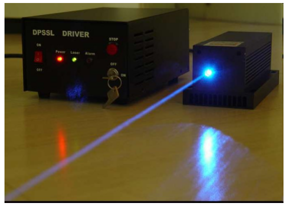




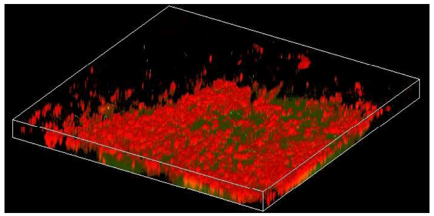
Luminescence

Laser

Black-body radiation



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

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

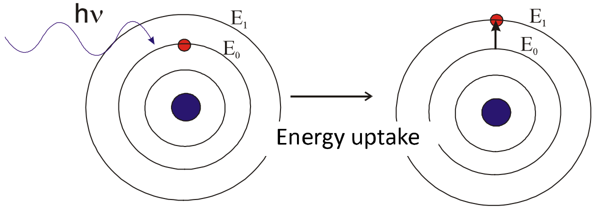
Scales of transition energies between different states are different:

$$E_e \;>\; E_v \;>\; E_r$$

Consider a **single atom**

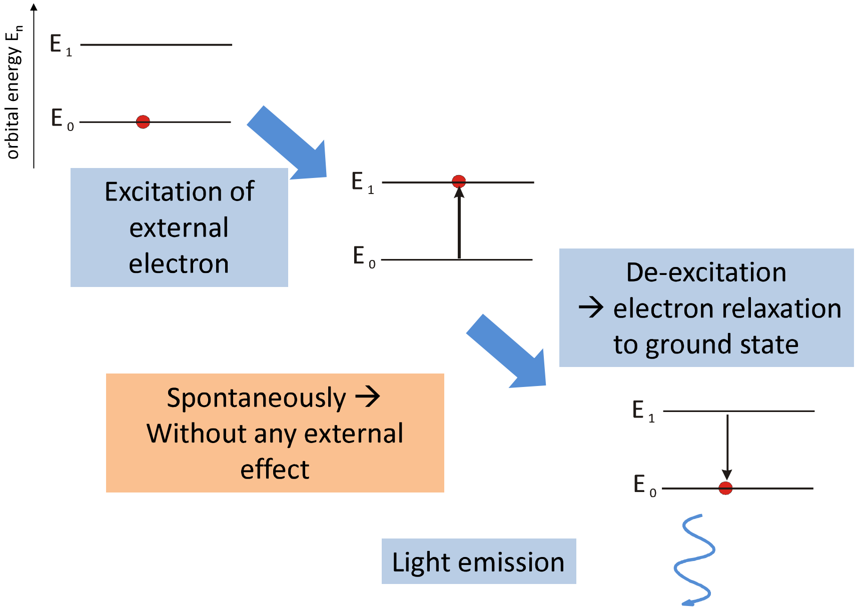
- Energy states are discrete
- Electrons occupy the lowest possible energy state (ground state)
- Pauli exclusion principle: no two identical fermions (particles with half-integer spin) may occupy the same quantum state simultaneously

Excitation energy



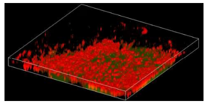
Ground state

Excited state



$hf=E_1-E_0$

Excitation modes



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

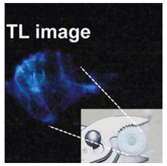
- chemical reaction: *chemo/bio-luminescence*

- Injection of charges: *electroluminescence*

- friction → mechanical deformation: *triboluminescence*

-thermally activated ion recombination: *thermoluminescence*

- Sound waves: *sonoluminescence*



Luminescence:

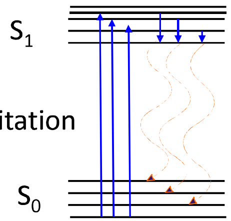
spontaneous light photon emission by electrons when they return from their excited state to their original (ground) state of lower energy

$hf=E_1-E_0$

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

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

Jablonski diagram



Non-radiant transitions

excitation

Light emission

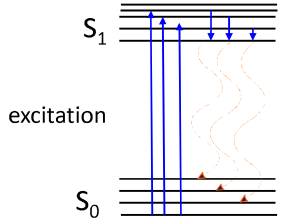
Fluorescence

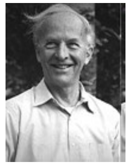
First excited singlet state

the spin states of the electrons

sum of all e⁻ spin quantum numbers=0

De-excitation by photon emission between singlet states





<u>Kasha's rule:</u>

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

Fluorescence

De-excitation by photon emission between singlet states

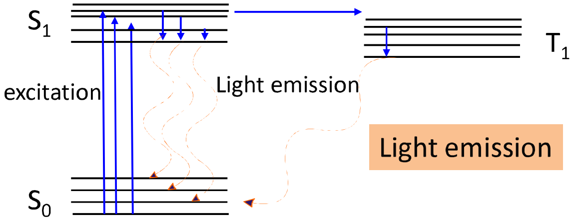
$E_{excitation} \geq E_{fluorescence}$

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

<u>Stokes-shift</u>

Intersystem crossing

Singlet->Triplet transition



Light emission

Phosphorescence

spontaneous light photon emission from metastable excited state

Triplet state

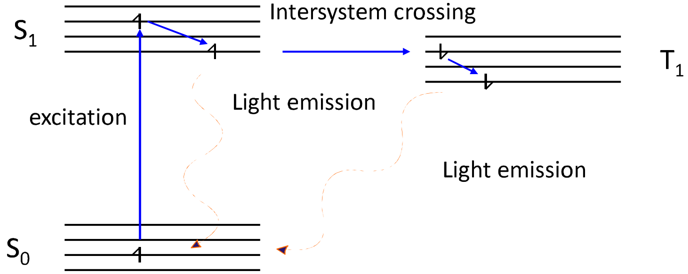
sum of all e⁻ spin quantum numbers=1

Metastable state

<u>Emitted photon energies</u>

Radiation-free transition

Intersystem crossing



Fluorescence

Phosphorescence

Stokes-shift

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

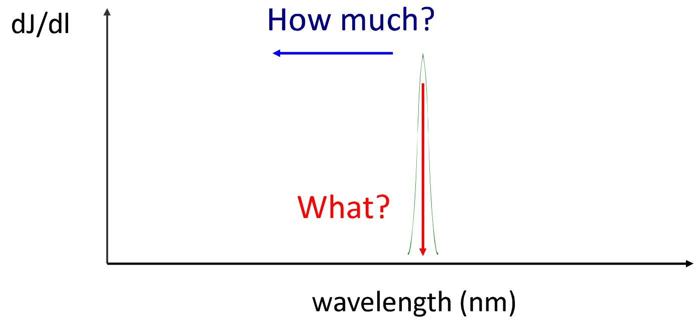
$\lambda_{excitation} \leq \lambda_{fluorescence} < \lambda_{phosphorescence}$

Characteristics of emitted light

Wavelength distribution of emitted light

Emission spectrum

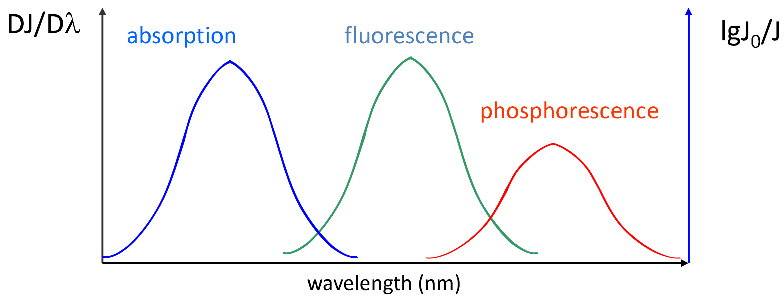
Atoms line spectrum



Wavelength distribution of emitted light

Emission spectrum

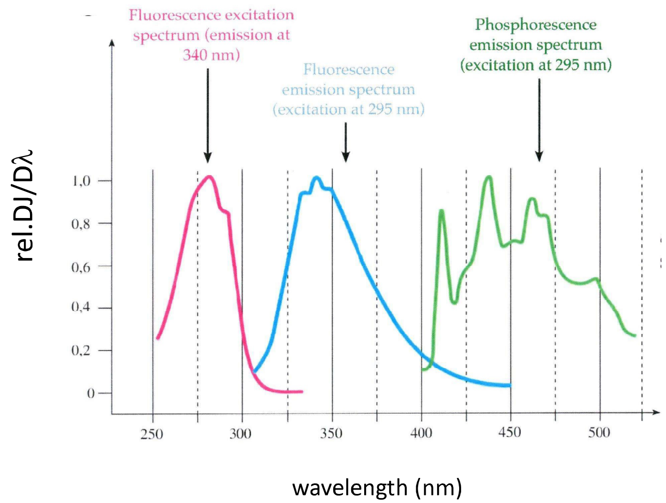
molecules: band spectrum



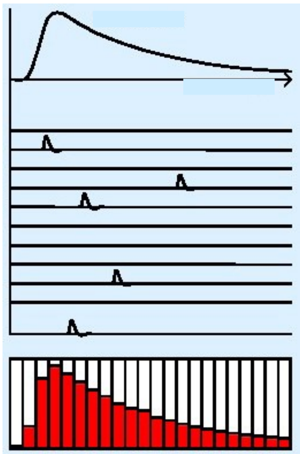
$\lambda_{excitation} \leq \lambda_{fluorescence} < \lambda_{phosphorescence}$

Stokes shift

E.g.: Corresponding spectra of triptophane



Excited-state lifetime

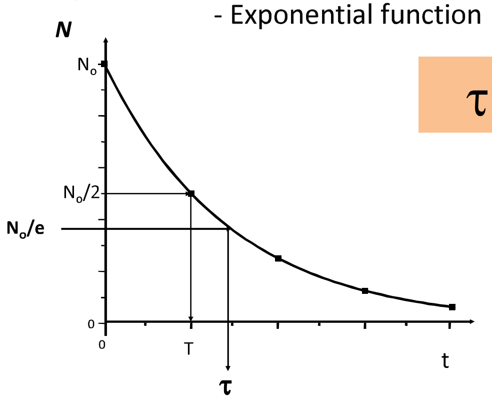


Single photon counting

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



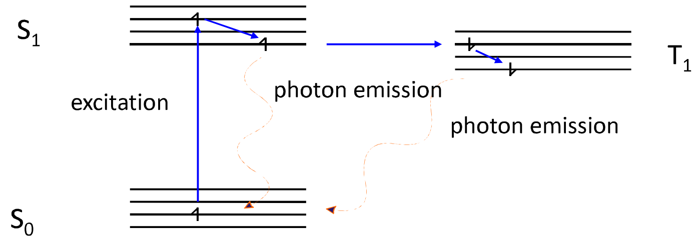
τ: life time

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 always followed 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)

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

$$Q_F \leq 1$$

Types of luminescence:

- fluorescence
- phosphorescence

They can be characterized by:

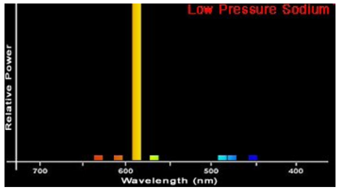
- emission spectrum:
  - Types
  - position of peaks
  - amplitude
- lifetime
- quantum yield

Application fields of luminescence

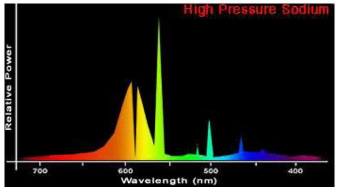
- Light sources (lightning, fertilization, sunbeds, photomedicine...)
- concentration determination (flame photometer)
- luminescence spectroscopy
- luminescence microscopy
- dosimetry (see later)
- archeology
- architecture
- safety control … many more

Luminescent light sources

Metal vapor lamps

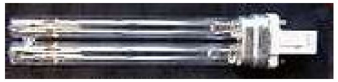


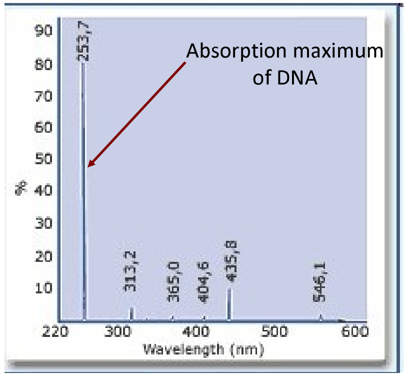
Low-pressure Na-vapor lamp



High-pressure Na-vapor lamp

Low-pressure Hg-vapor lamp

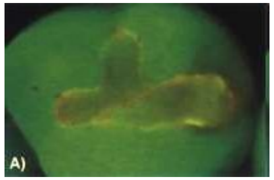




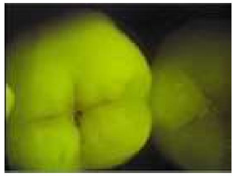
Emission spectrum

„germicid lamp"

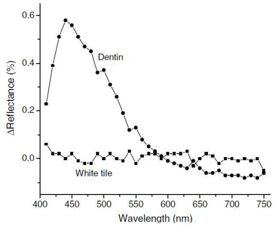
Application in dental medicine



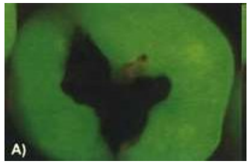
Red fluorescence indicates the activity of identifies cariogenic bacteria



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.

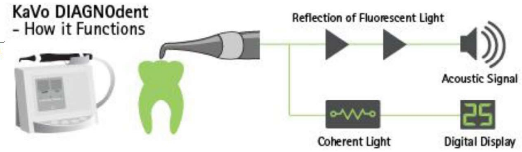


Lee, Journal of Biomedical Optics 20(4), 040901 (April 2015)



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.



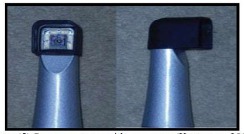
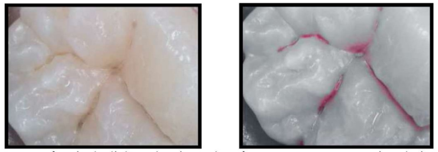


Figure (5) Spectra camera with spacer on (Kurtzman, 2010).

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

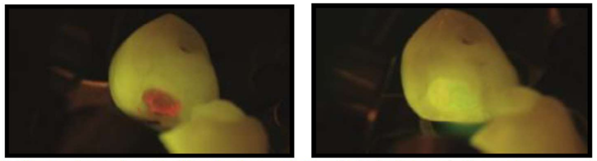
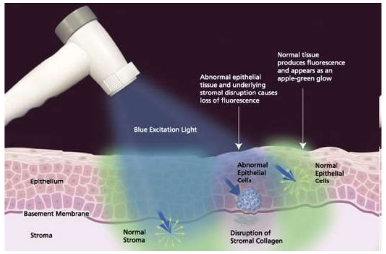


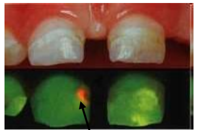
Figure (8) Photos showed cavity illumination with Facelight before and after caries excavation (21).

Mualla, Journal of Dental and Medical Sciences. 15:3, 2016, PP 65-75

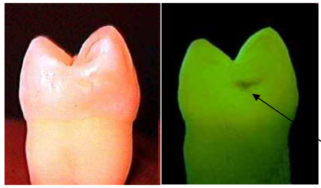


Healthy and malignant tissues different fluorescent properties

Teeth
native and fluroescent images



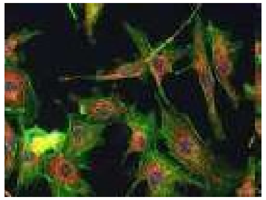
Active caries

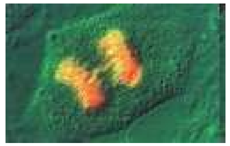


caries

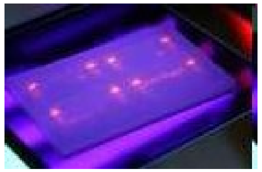
Tooth
native and fluroescent image

Luminescent microscopy





Laboratory application in many ways



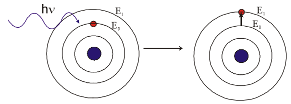
And more...

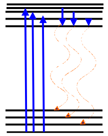
Damjanovich, Fidy, Szöllősi: Medical Biophysics

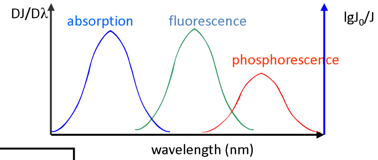
II. 2.2
- 2.2.4
- 2.2.6

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

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 $Q_F = \frac{\text{number .of .photons .emitted}}{\text{numbe .of .photons .absorbed}}$
- ❑ Applications of luminescence effect in medical point of view