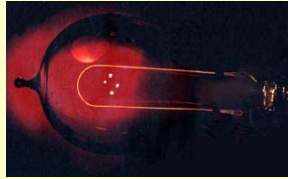


## Generation of light - Light sources



Black-body radiation

Luminescence

Laser



## 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)

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

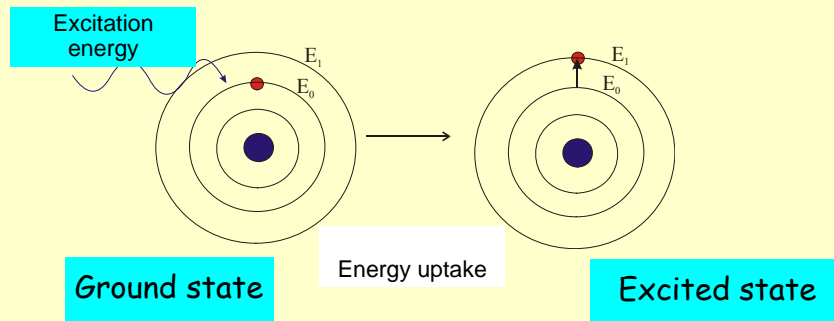
Scales of transition energies between different states are different:

$$E_e > E_v > E_r$$



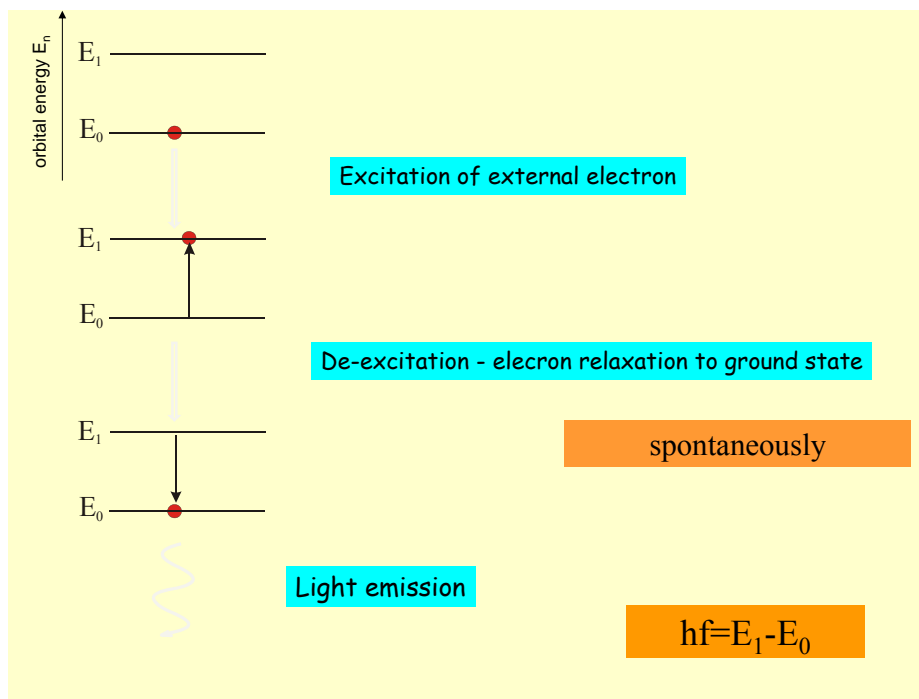
## Consider a single atom

- 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 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*

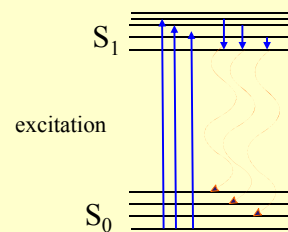
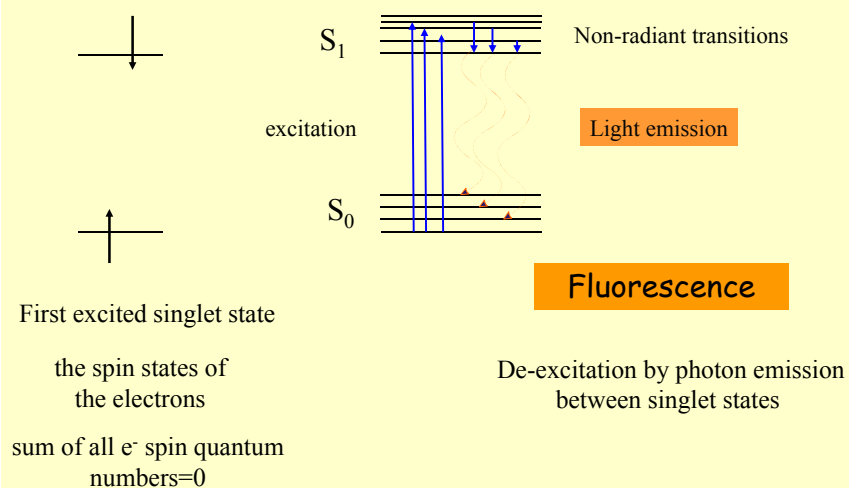


**Luminescence:** spontaneous light photon emission by electrons when they return from their excited state to their original (ground) state of lower energy

$$hf = E_1 - E_0$$

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



**Kasha's rule:**

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



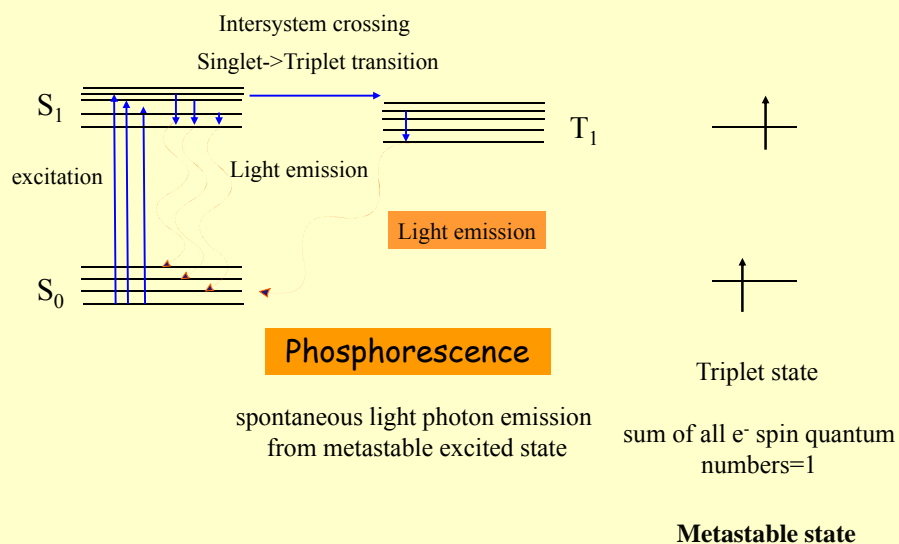
**Fluorescence**

De-excitation by photon emission between singlet states

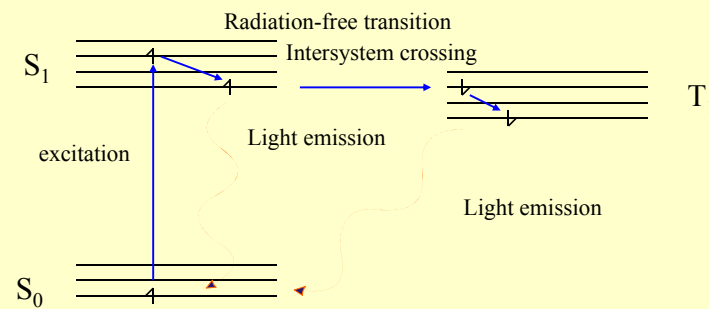
$$E_{\text{excitation}} \geq E_{\text{fluorescence}}$$

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

**Stokes-shift**



Emitted photon energies



**Fluorescence**

**Phosphorescence**

**Stokes-shift**

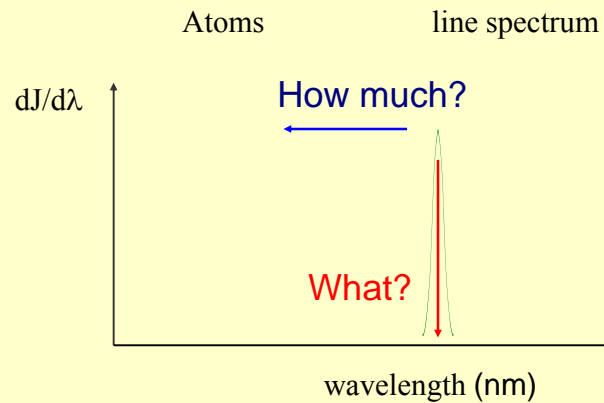
$$E_{\text{excitation}} \geq E_{\text{fluorescence}} > E_{\text{phosphorescence}}$$

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

## Characteristics of emitted light

Wavelength distribution of emitted light

### Emission spectrum

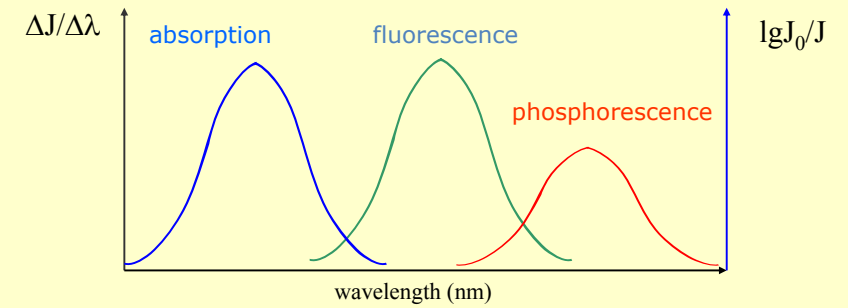


Wavelength distribution of emitted light

### Emission spectrum

molecules:

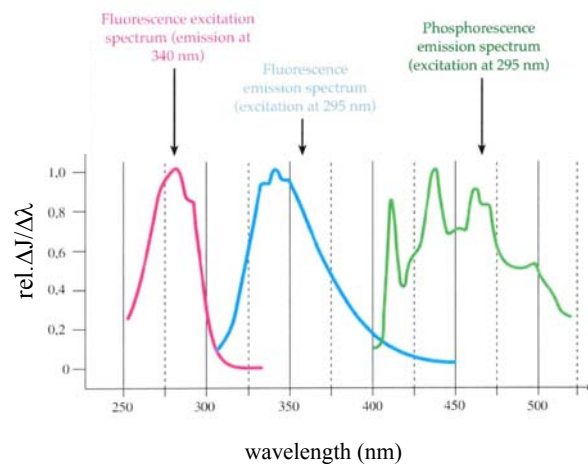
band spectrum



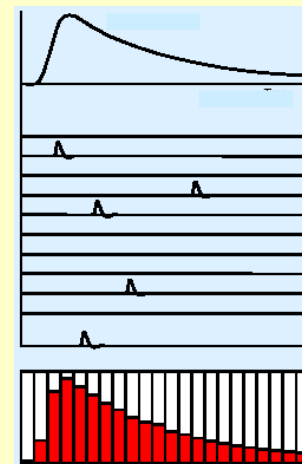
$$\lambda_{\text{excitation}} \leq \lambda_{\text{fluorescence}} < \lambda_{\text{phosphorescence}}$$

Stokes shift

E.g.: Corresponding spectra of triptophane

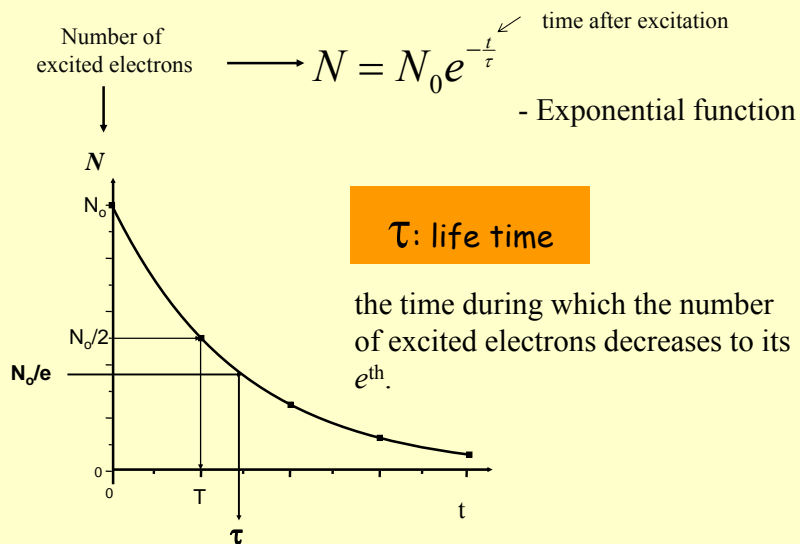


Excited-state lifetime



Single photon counting

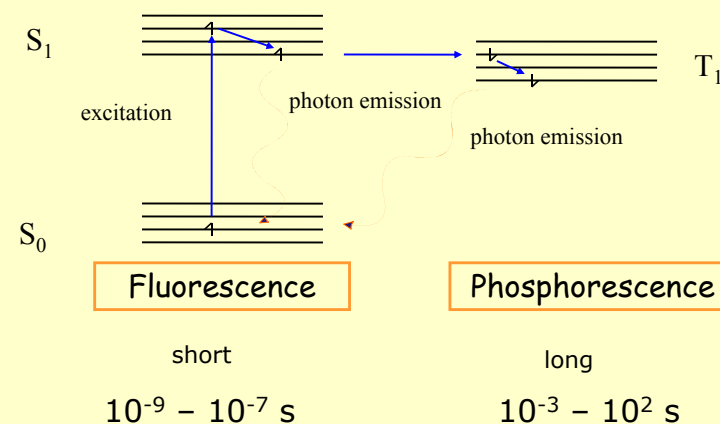
Measuring of time gap between excitation and photon emission. Statistical analysis of large number of measurements.



## Typical excited-state lifetimes

### Lifetime

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



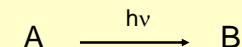
Is excitation always followed by photon emission?

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



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)

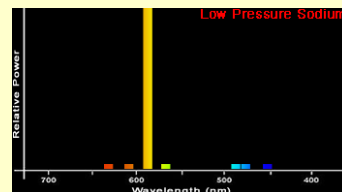
archeology

architecture

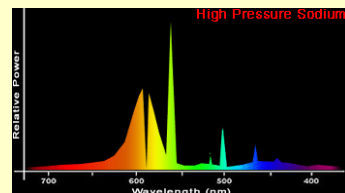
safety controll ... many more

## Luminescent light sources

### Metal vapor lamps

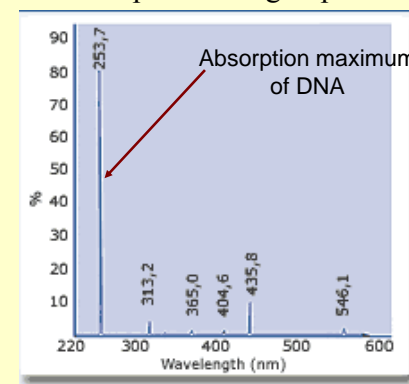


Low-pressure Na-vapor lamp



High-pressure Na-vapor lamp

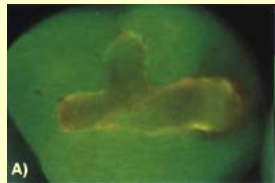
### Low-pressure Hg-vapor lamp



Emission spectrum



## Application in dental medicine



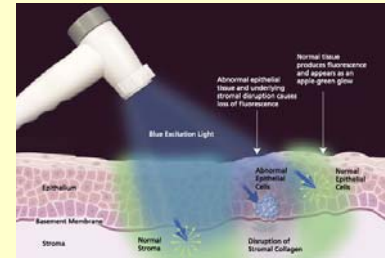
Red fluorescence indicates the activity of identifies cariogenic bacteria



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.



amalgam restoration

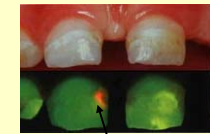


Healthy and malignant tissues different fluorescent properties



Tooth native and fluorescent image

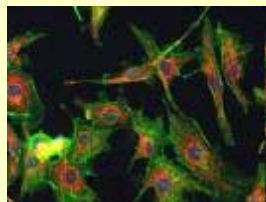
Teeth native and fluorescent images



Active caries

caries

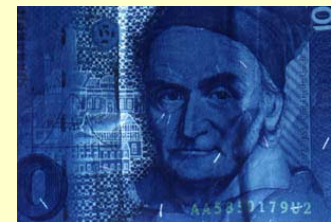
## Luminescent microscopy



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