



Thermal radiation Luminescence

Medical Biophysics I. 5 November, 2025

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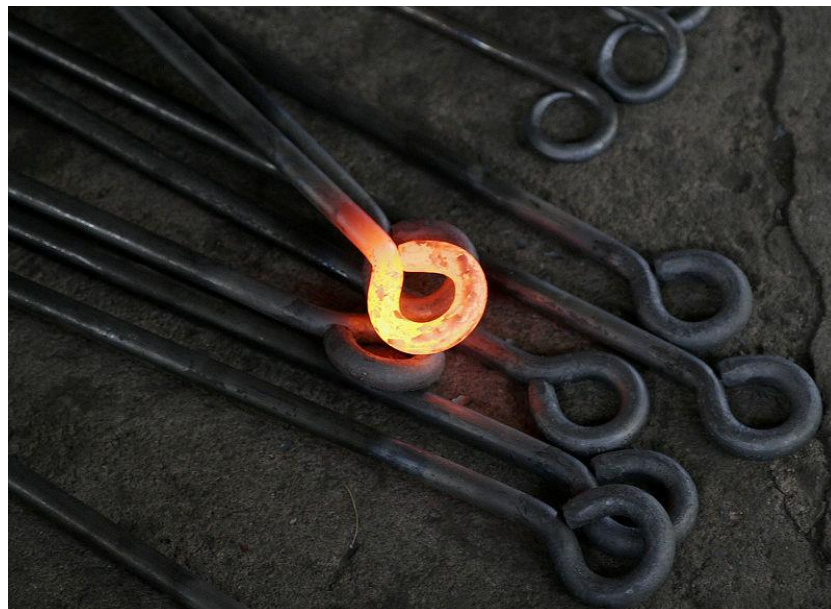
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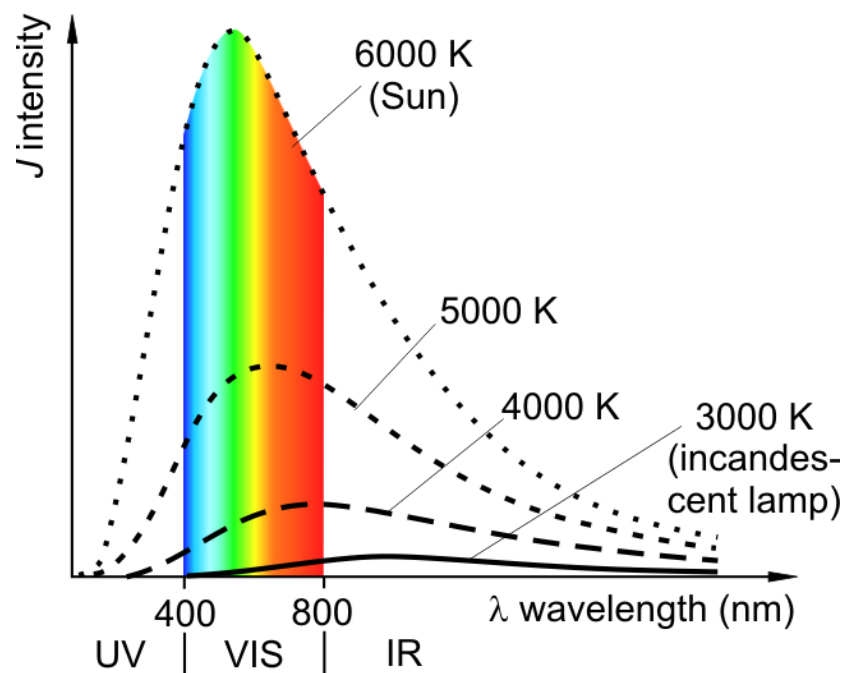
Sources of light emission

1. Thermal (black body) radiation

Mechanism: thermal motion of atoms, molecules

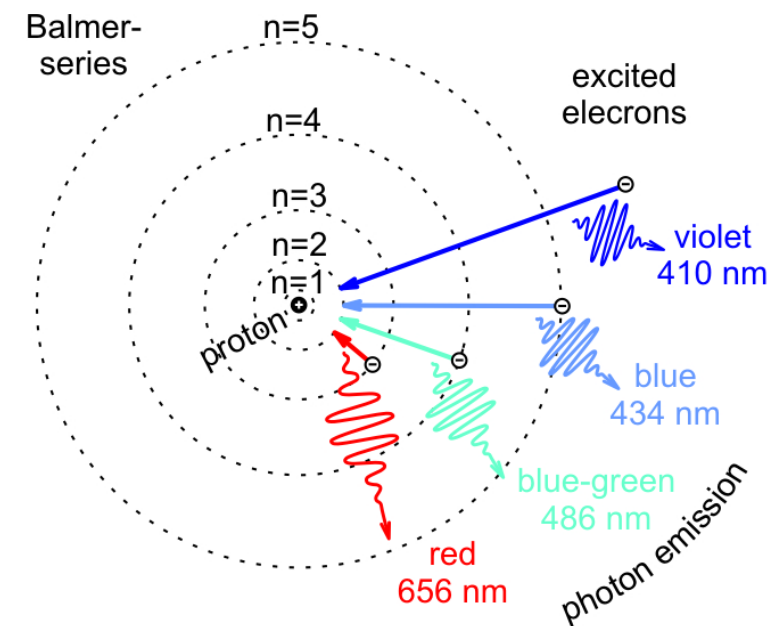


Source of light energy: **internal energy** of the system

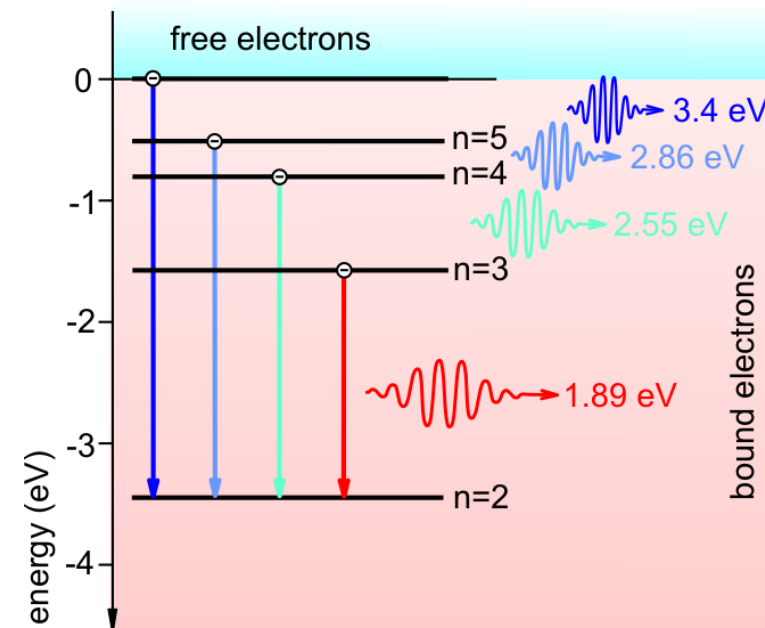


2. Luminescence

Mechanism: emission of excited-state energy

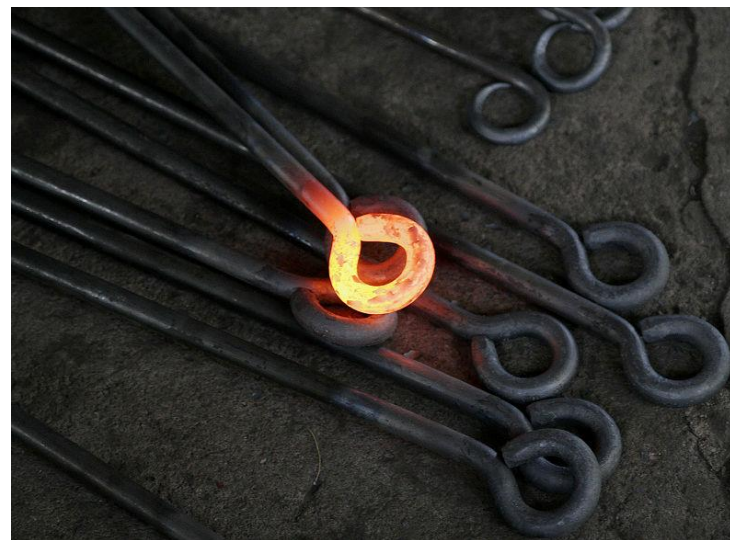
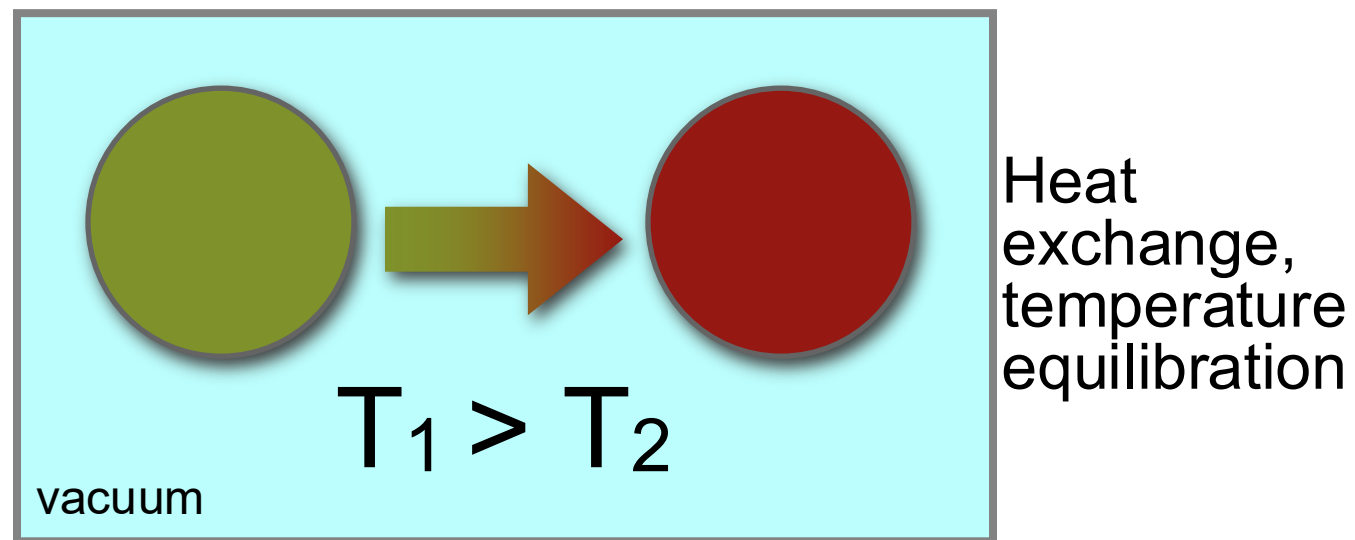


Source of light energy: energy of **excited state**



“Black-body” (Thermal) radiation

- One way of generating of light (besides *luminescence*)
- **Electromagnetic radiation** emitted from all matter due to its possessing **thermal energy**



- High-temperature objects emit light.
- The greater the temperature of the body, the smaller the wavelengths that appear in its emission spectrum.

... what is a “black body”...?

Black body absorbs all light falling on it

Objects not only emit radiation but absorb it as well.

Ratio of spectral emissive power (M) and absorptivity (α) is constant (Kirchoff's law):



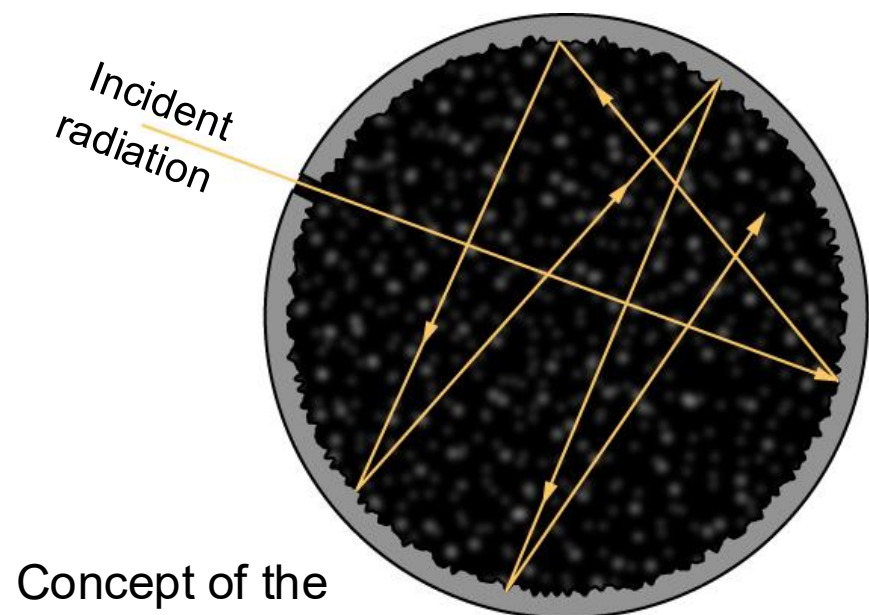
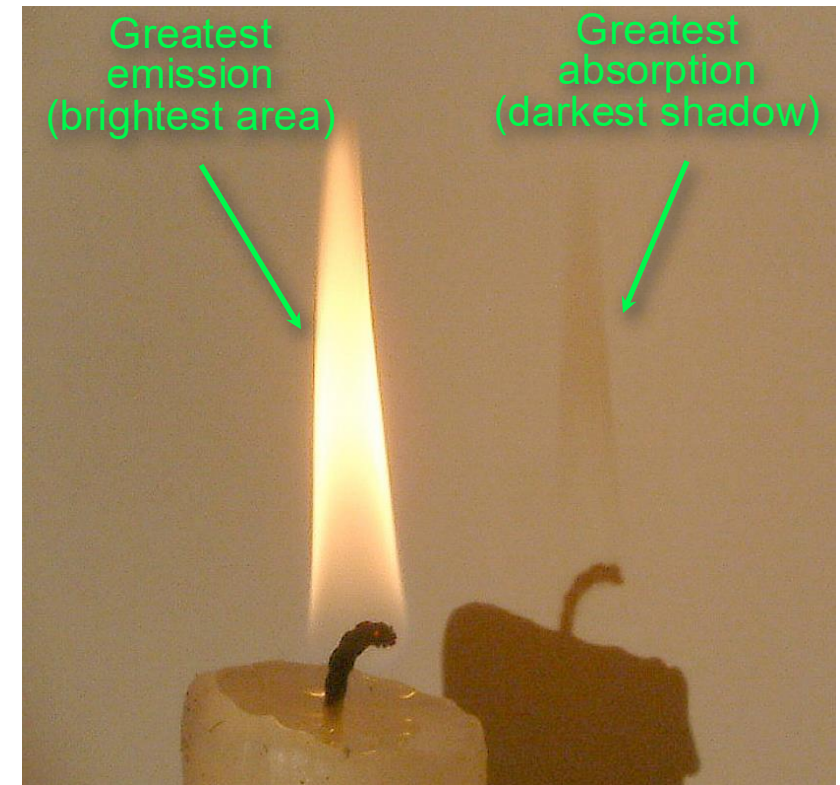
Gustav Robert Kirchoff
(1824-1887)

$$\frac{M_{\lambda_i}}{\alpha_{\lambda_i}} = \frac{M_{\lambda_j}}{\alpha_{\lambda_j}}$$

For a black body (BB):

$$\alpha_{\lambda_{BB}} = 1$$

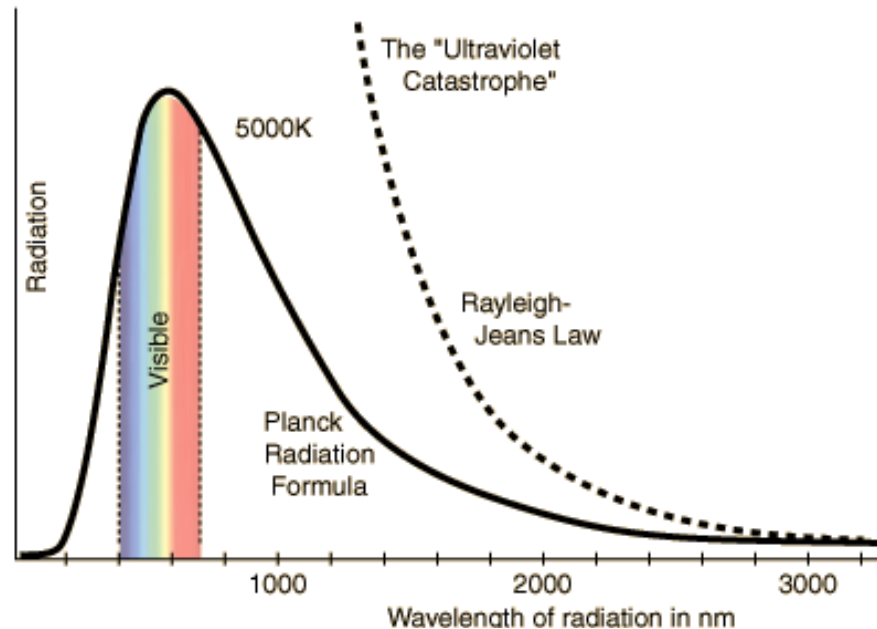
- That is, the black body absorbs all light that it is exposed to (nothing is reflected).
- The black body is an ideal object for investigating temperature-dependent emission.



Concept of the absolute black body

Black-body radiation

Properties and inferences



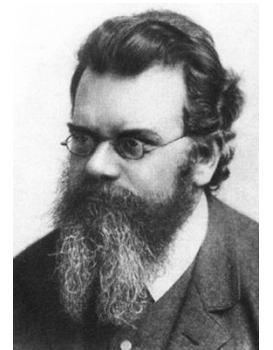
Stefan-Boltzmann law:

$$M_{BB}(T) = \sigma T^4$$

M_{BB} = emissive power, area under emission spectrum.



Jozef Stefan (1835-1893)



Ludwig Eduard Boltzmann (1844-1906)

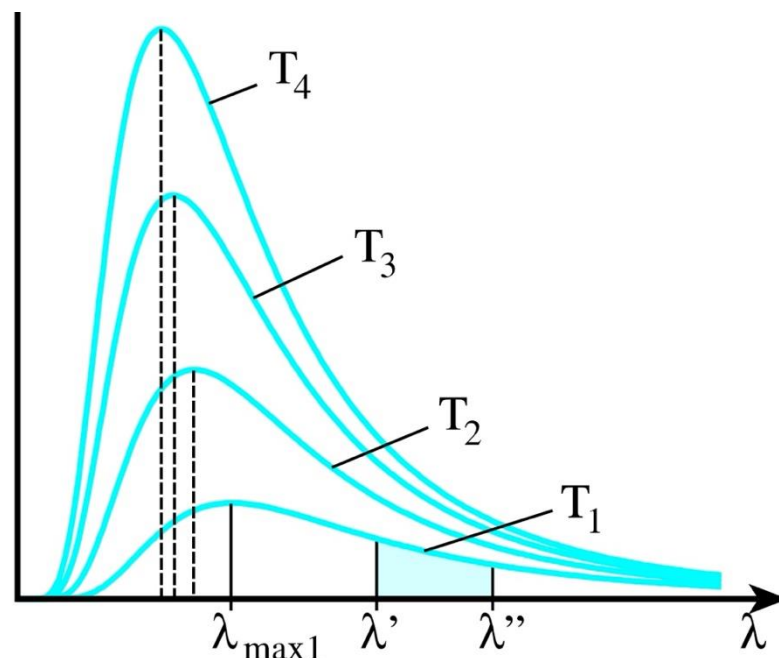
Wien's displacement law:

$$\lambda_{\max} T = \text{const}$$



Wilhelm Wien (1864-1928)

spectral emissive power

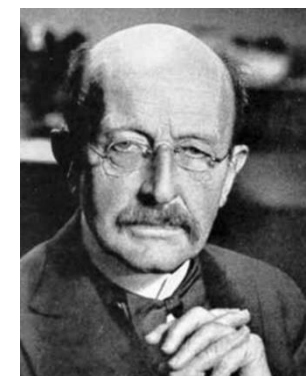


Planck's law of radiation:

$$E = hf$$

h = Planck's constant (6.626×10^{-34} Js).

Meaning: energy is absorbed and emitted in discrete packets (*quanta*).

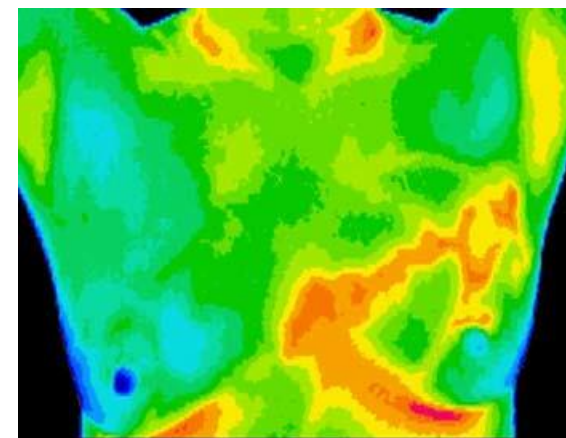


Max Karl Ernst Ludwig Planck (1858-1947)

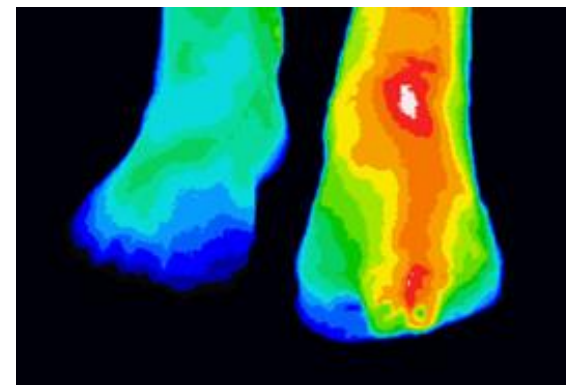
Applications of thermal radiation

Thermography, infradiagnostics

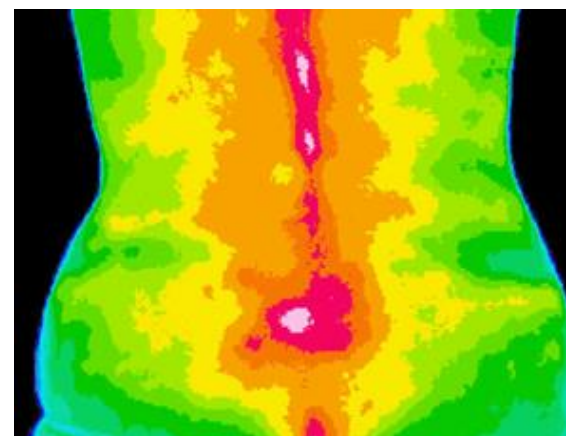
“Seeing through” a non-absorbing layer



Breast carcinoma



Inflammation



Chronic musculoskeletal stress (pain)

Airport thermography



Detection of febrile condition, prevention of epidemics

Luminescence

- Relaxation from **excited state** followed by light emission
- Radiation emitted by matter in excess of thermal emission
- “Cold light”
- Processes of fluorescence and phosphorescence

Luminescence is everywhere

Photoluminescence

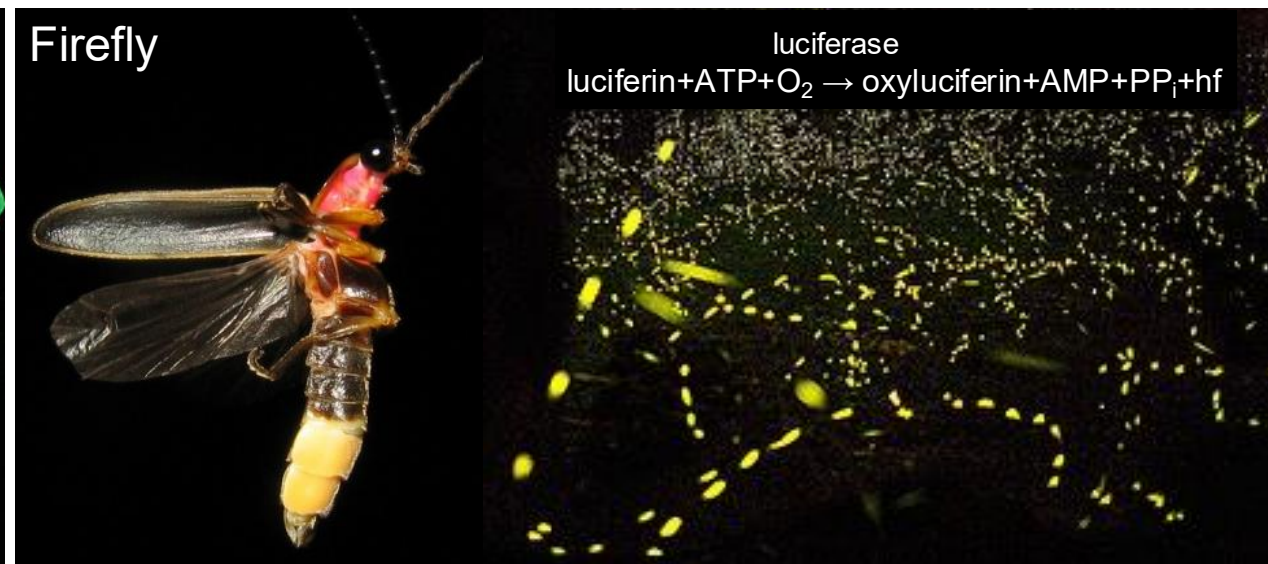


Luminescence is everywhere

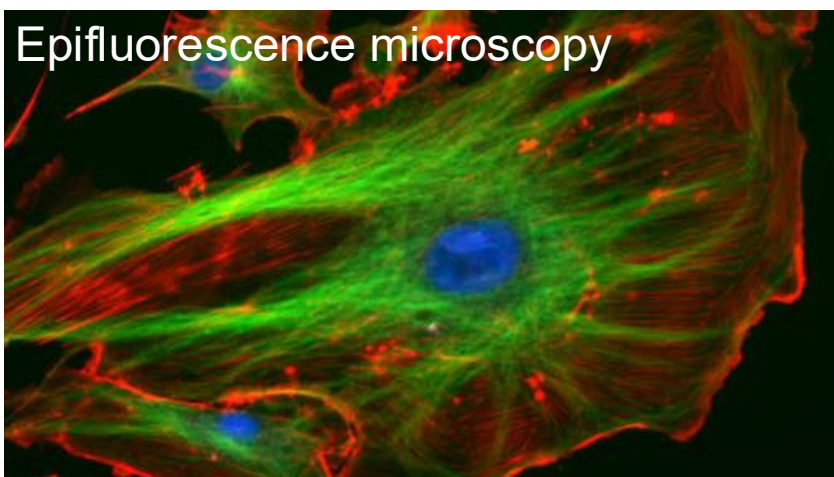
Radio-luminescence



Bio-/chemi-luminescence



Fluorescence applications



Types of luminescence

(a) Excitation Mode

Luminescence Type

absorption of radiation (UV/VIS)

photoluminescence

chemical reaction

chemiluminescence, bioluminescence

thermally activated ion recombination

thermoluminescence

injection of charge

electroluminescence

high energy particles or radiation

radioluminescence

friction

triboluminescence

sound waves

sonoluminescence

(b) Excited State (Assuming Singlet State)

Luminescence Type

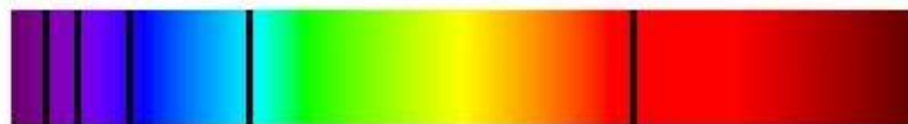
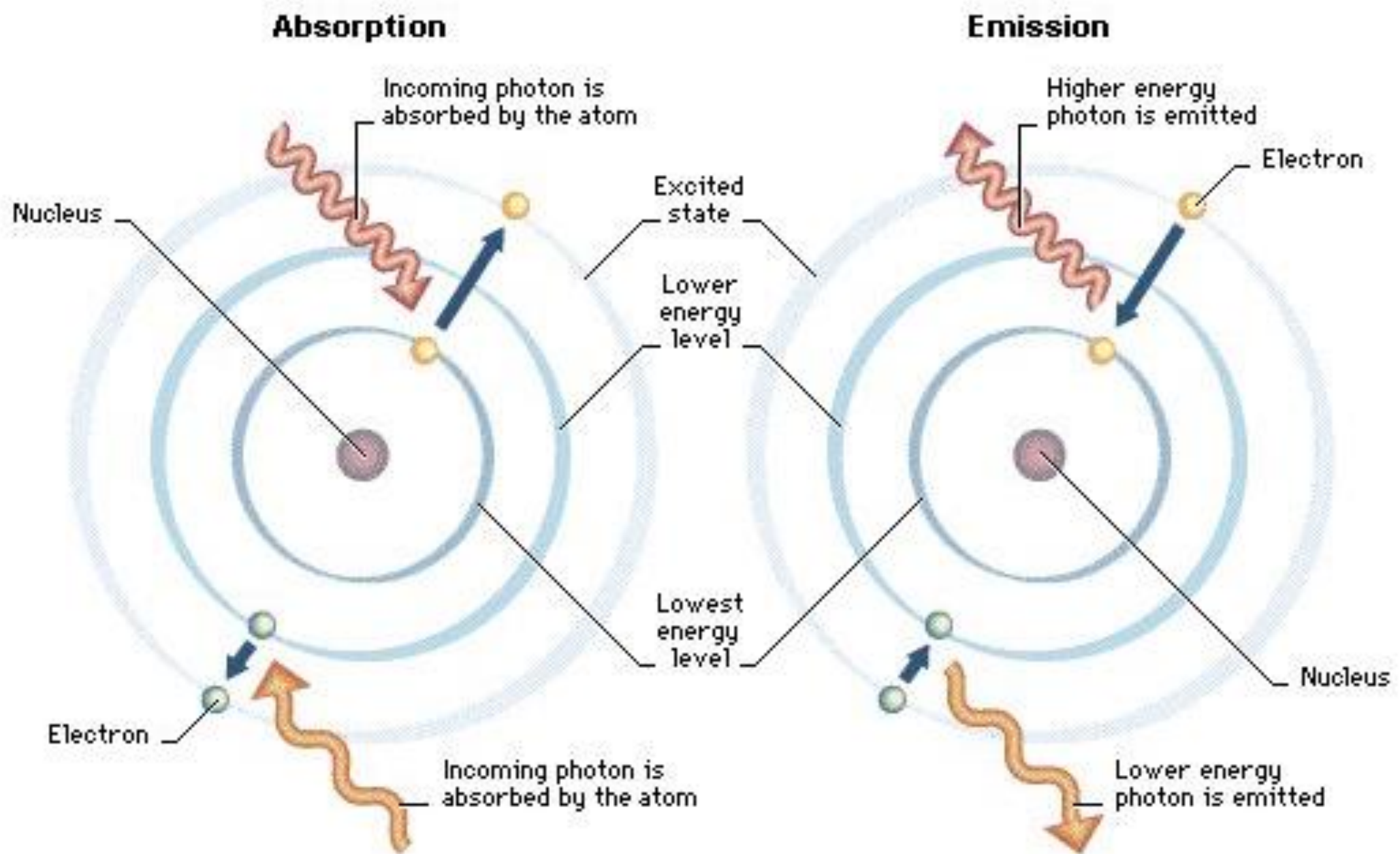
first excited singlet state

fluorescence, delayed fluorescence

lowest triplet state

phosphorescence

Absorption and emission by an atom



Absorption line spectrum



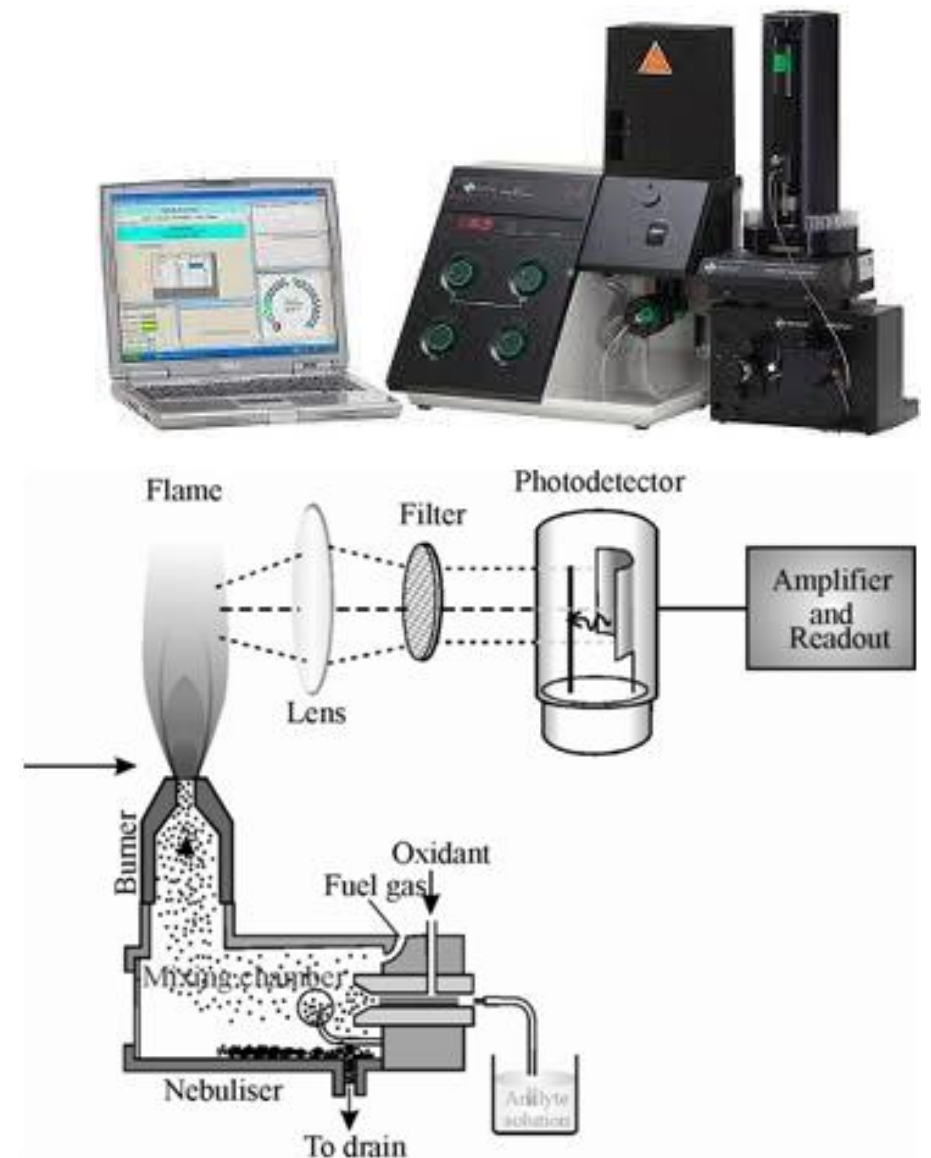
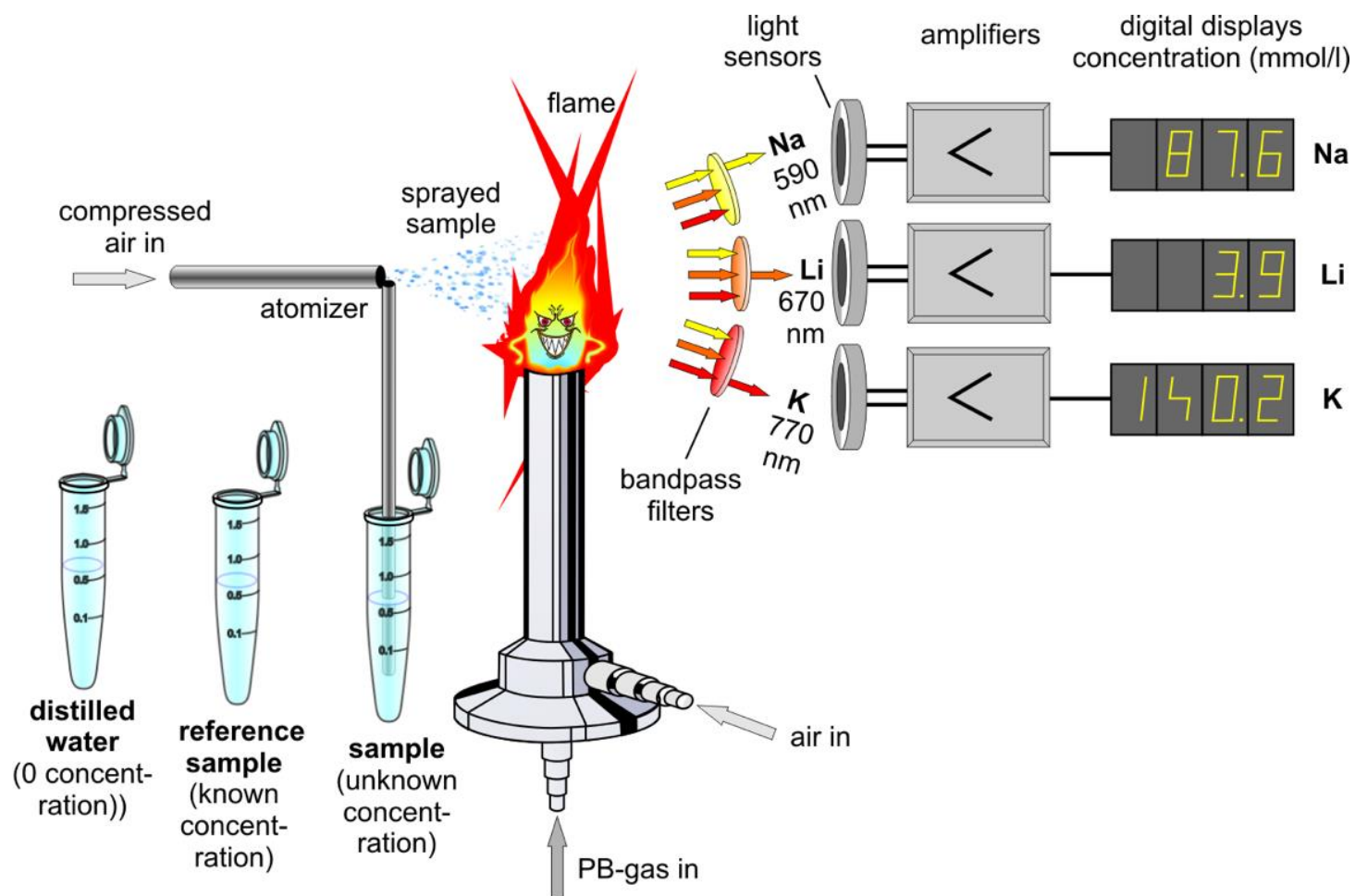
Emission line spectrum

Application of emission spectroscopy

Flame photometry

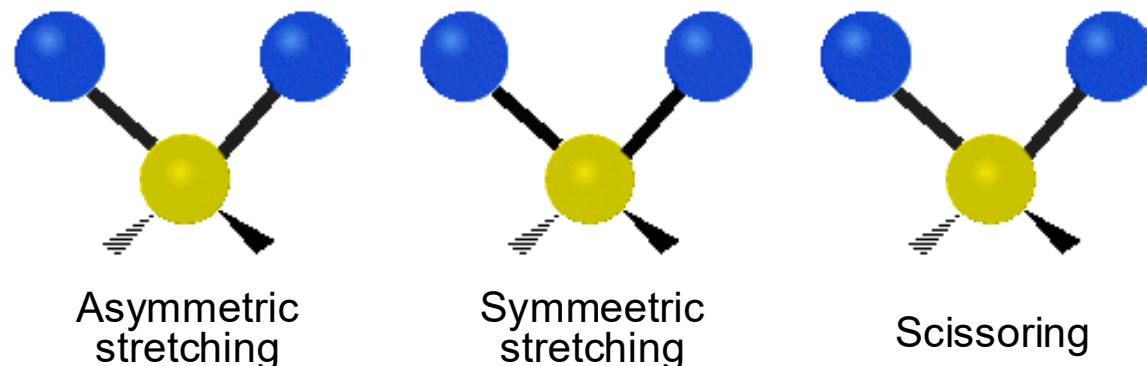
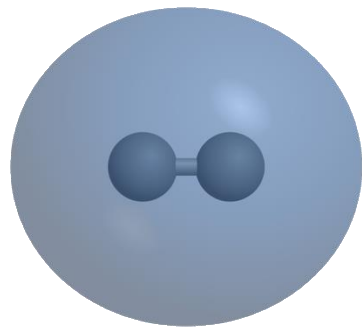
Qualitative and quantitative analysis of alkali metals

Clinical practice:
determination of serum ions
(Na⁺, K⁺)



The emission by an excited **molecule** is non-linear, because its energy levels are complex

Molecule: atoms connected by chemical bonds
Simplest case: diatomic molecule (e.g., hydrogen molecule)



Molecules **vibrate** and **rotate**!

Vibration: periodic motion *along* the axis of the covalent bond
Rotation: periodic motion *around* the axis of the covalent bond

Energy of a molecule: Born-Oppenheimer - approximation:

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

- Types of energy states are independent (not coupled)
- Energy states are non-continuous, but discrete
- Transition between states involves packets (quanta) of energy
- Scales of transition energies between different states are different.

Scaling of transition energies:

$$E_e \overset{\sim 100x}{>} E_v \overset{\sim 100x}{>} E_r$$

$$\sim 3 \times 10^{-19} \text{ J } (\sim 2 \text{ eV}) > \sim 3 \times 10^{-21} \text{ J } > \sim 3 \times 10^{-23} \text{ J }$$

(Rule of thumb: ultraviolet (UV) > visible > infrared)

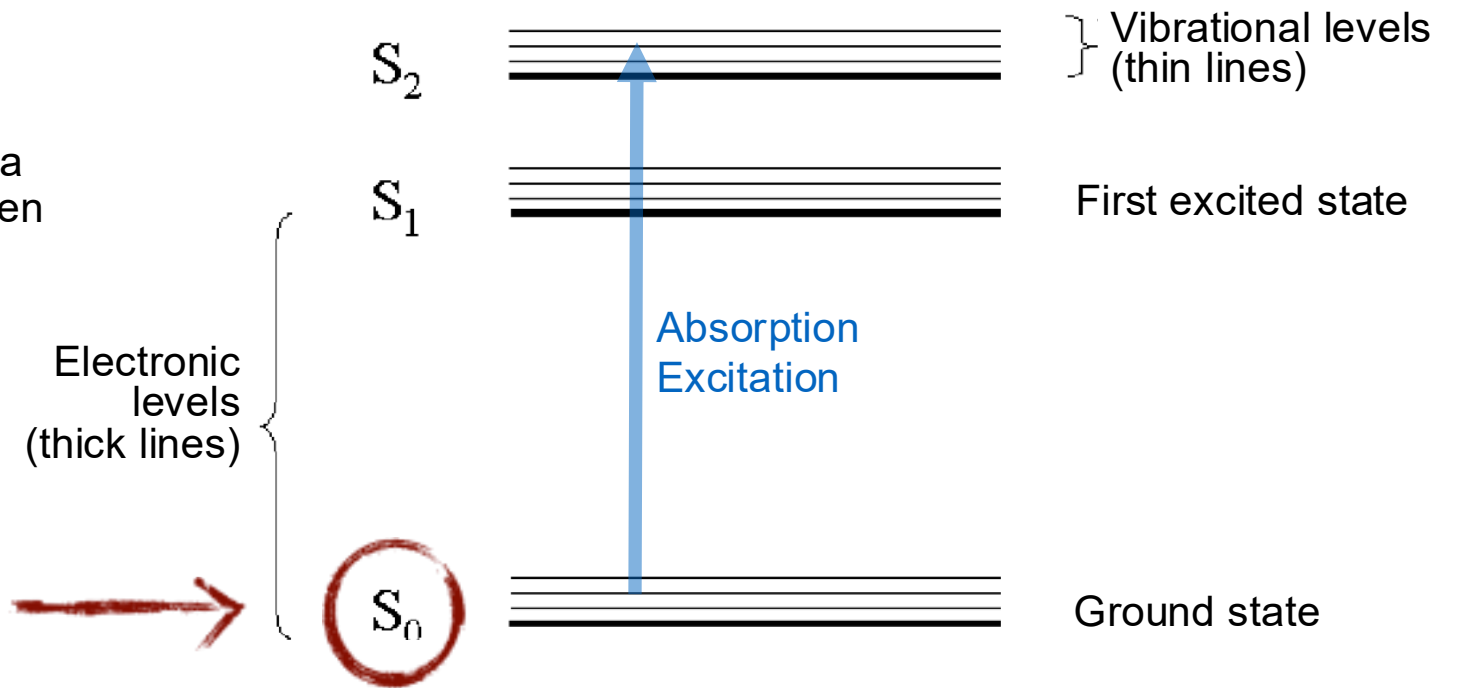
Representation of energy states



Alexander Jabłoński
(1898-1980)

Jabłoński diagram:

illustrates the electronic states of a molecule and the transitions between them (with arrows)



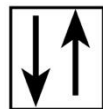
What is this "S" (singlet) state?

Spin states – Pauli's exclusion principle

Wolfgang Pauli
(1900-1958)



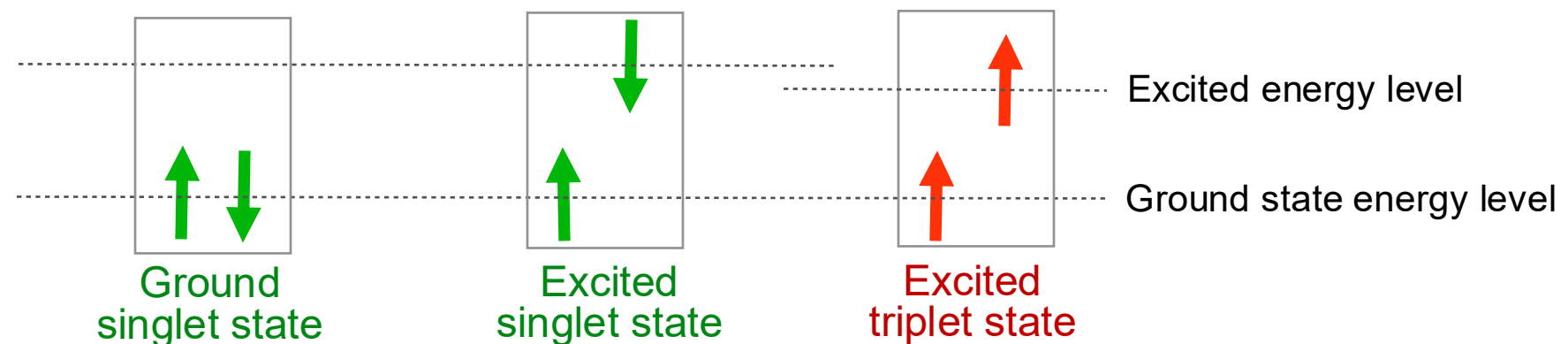
- Each quantum state can be occupied by a single electron.
- Within an atom there cannot be two electrons for which all four quantum numbers are identical.

 fully occupied subshell:
spin pairing
(opposite-spin electrons pair)

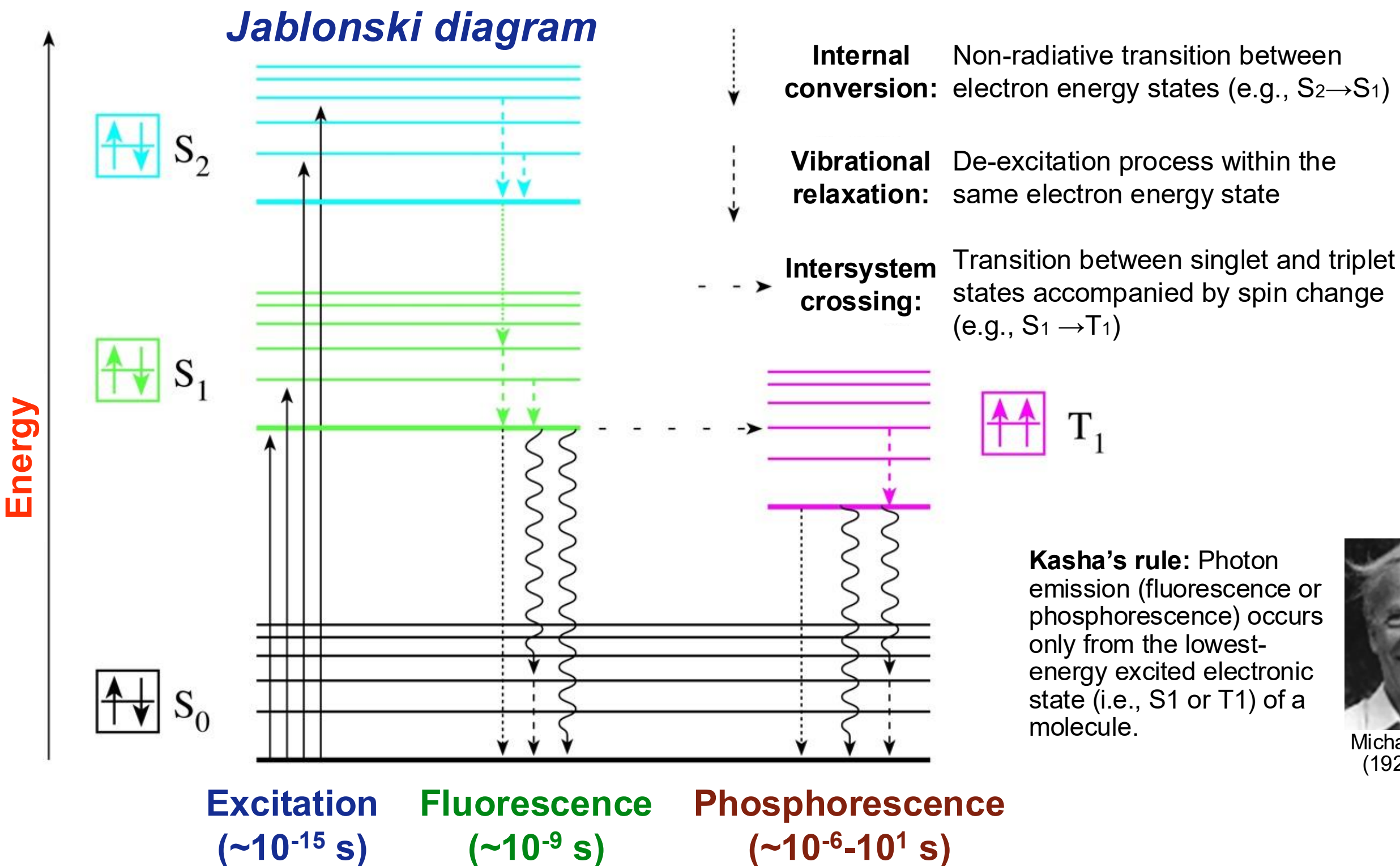
Singlet and **triplet** states: *number of orientations* of magnetic moment associated with net spin state (in magnetic field) = $2S+1 = 1$ (*singlet*) or 3 (*triplet*). (S = net spin, e.g., in fully occupied subshell $(+1/2)+(-1/2) = 0$)

S: singlet state: paired electrons with opposite spins, net spin (S) = 0, *number of orientations* ($2S+1$) = 1.

T: triplet state: there are identical spin-state electrons in the molecule, net spin = 1 (e.g., $(+1/2)+(+1/2) = 1$), *number of orientations* ($2S+1 = 2+1$) = 3.



Processes of luminescence



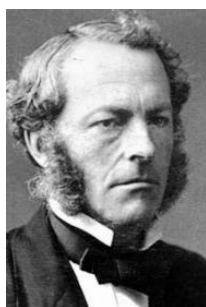
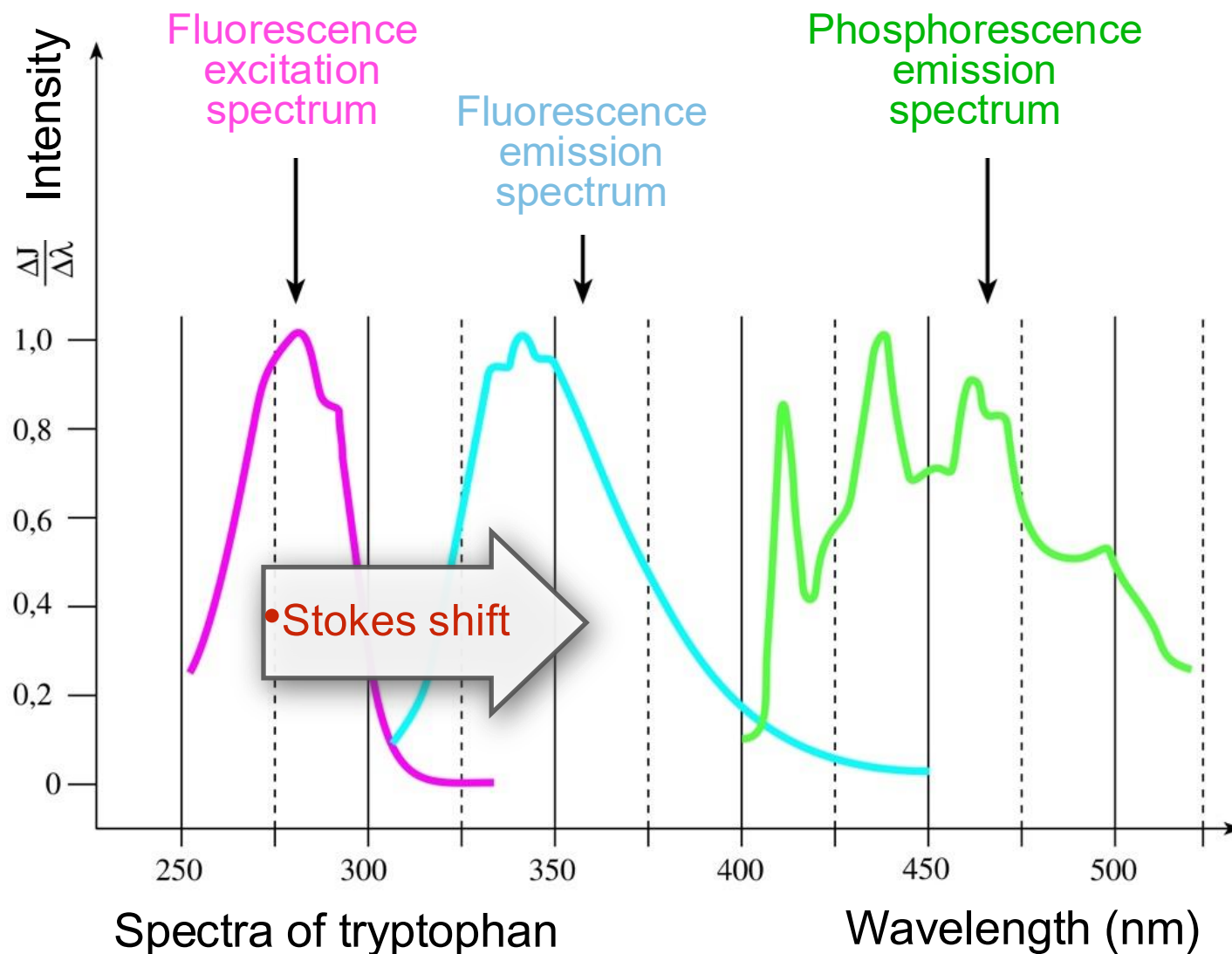
Michael Kasha
(1920-2013)

Characterization of luminescence

1. Spectra

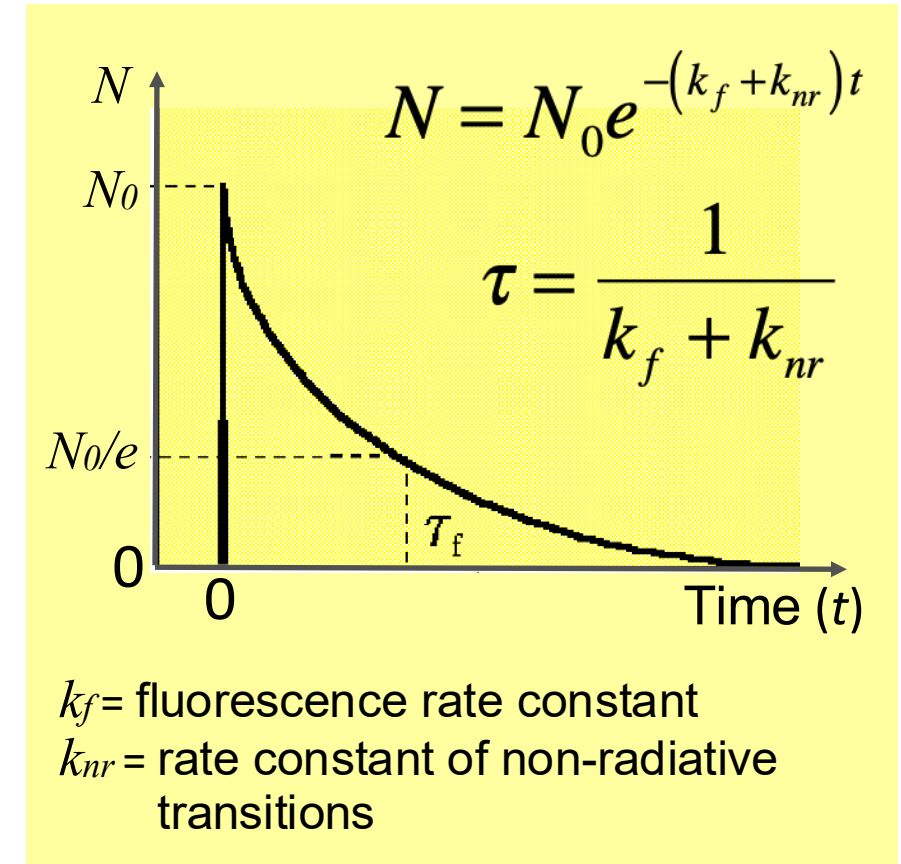
• Band spectra

• Excitation-emission are mirror-symmetric



George Stokes
(1819-1903)

2. Excited-state lifetime (τ)

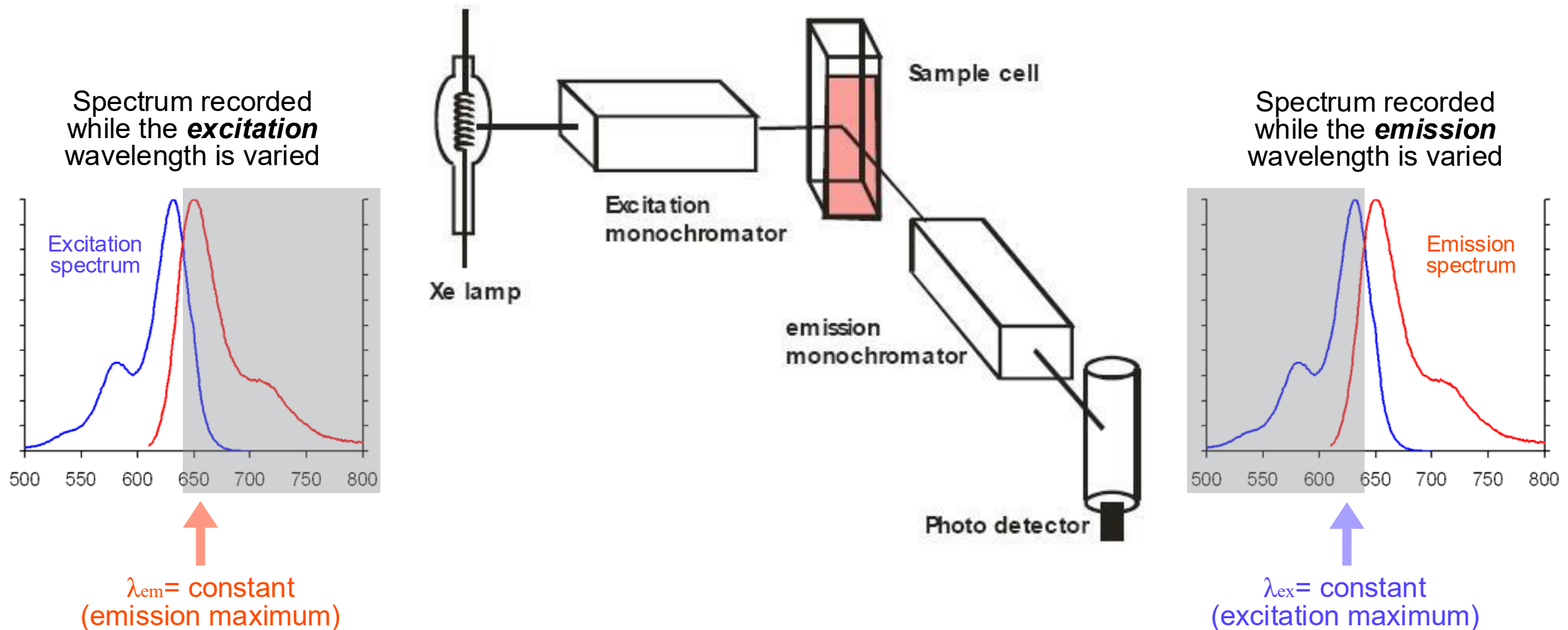


3. Quantum yield (Φ)

$$\Phi = \frac{k_f}{k_f + k_{nr}} = \frac{N_{emitted\ photons}}{N_{absorbed\ photons}} \leq 1$$

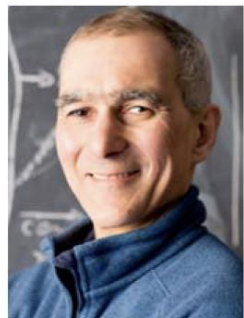
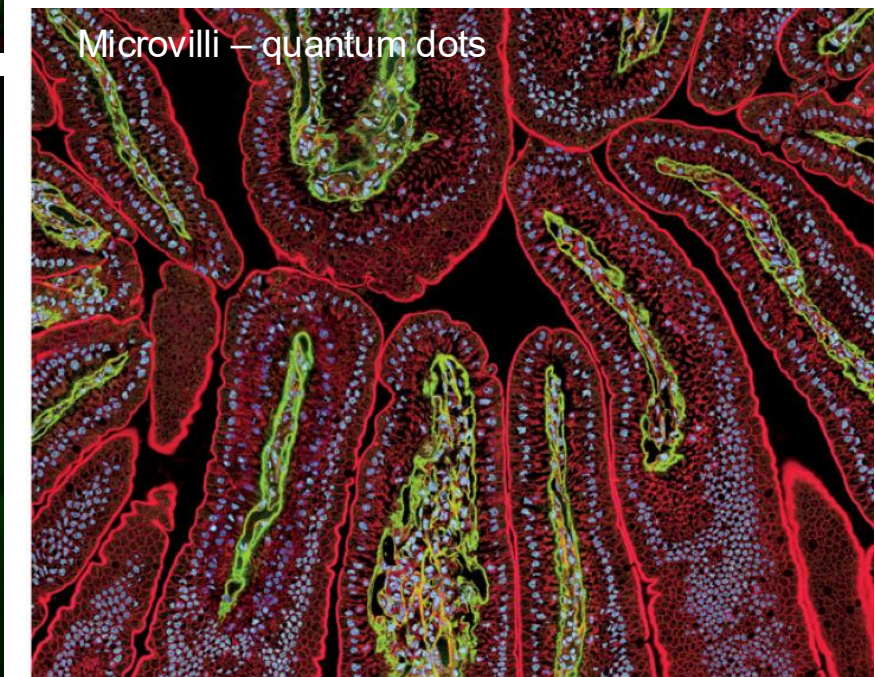
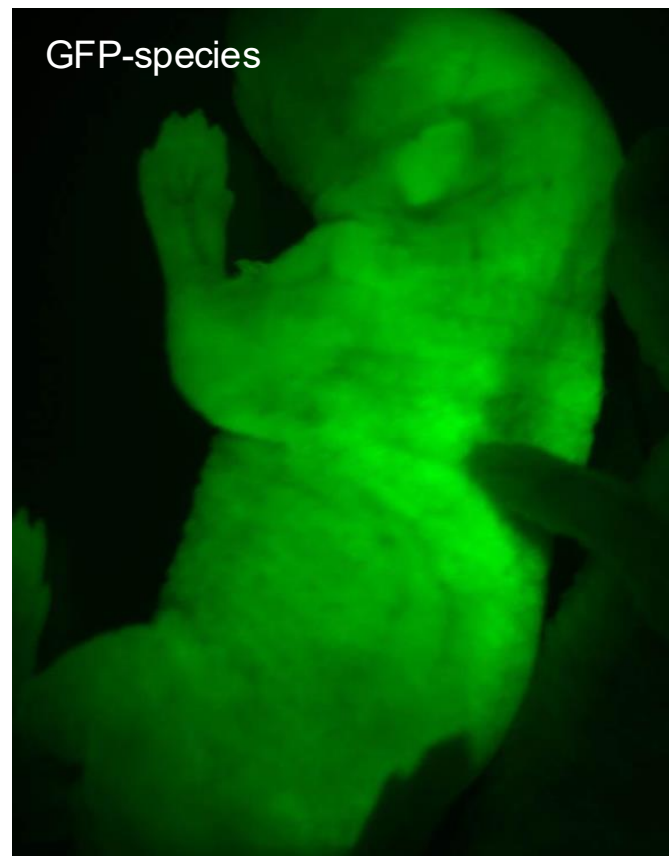
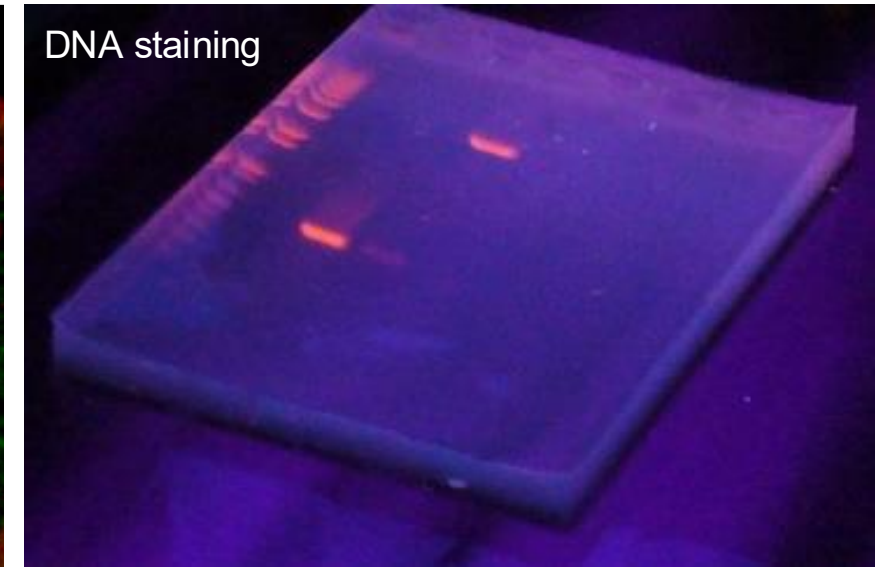
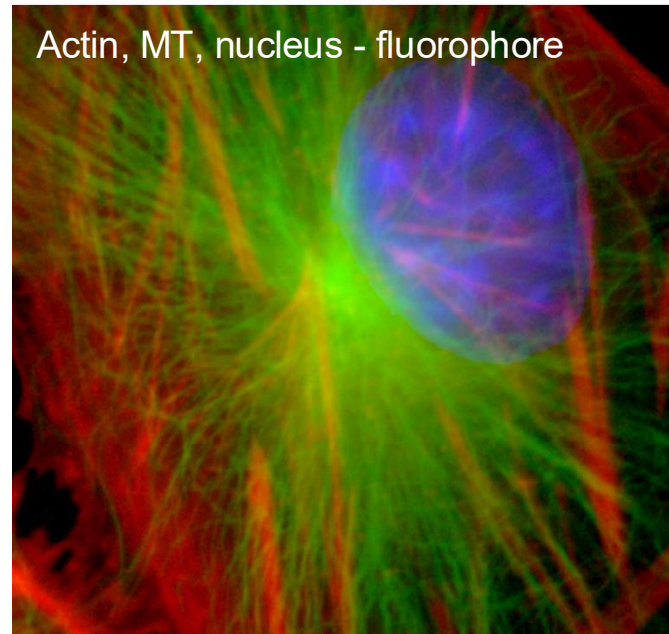
Measurement of luminescence

Fluorescence spectrometer (*"Steady-state" spectrofluorometer*)

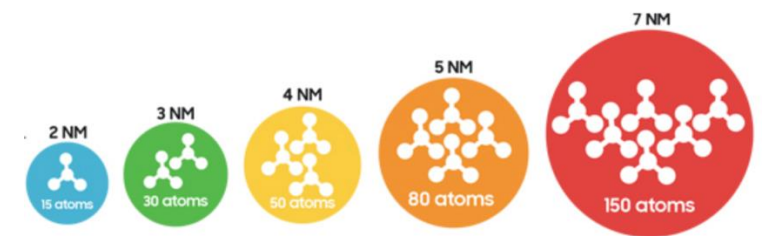


Biomedical applications of fluorescence

- Fluorescent labeling with fluorophores
- DNA sequencing (chain termination), DNA staining (EtBr), DNA microarray technology
- Immunofluorescence
- Fluorescent protein conjugation techniques (GFP)
- FRET (Fluorescence Resonance Energy Transfer)
- FRAP (Fluorescence Recovery After Photobleaching)
- FACS (Fluorescence Activated Cell Sorting)
- Quantum-dot labeling
- Etc., etc.

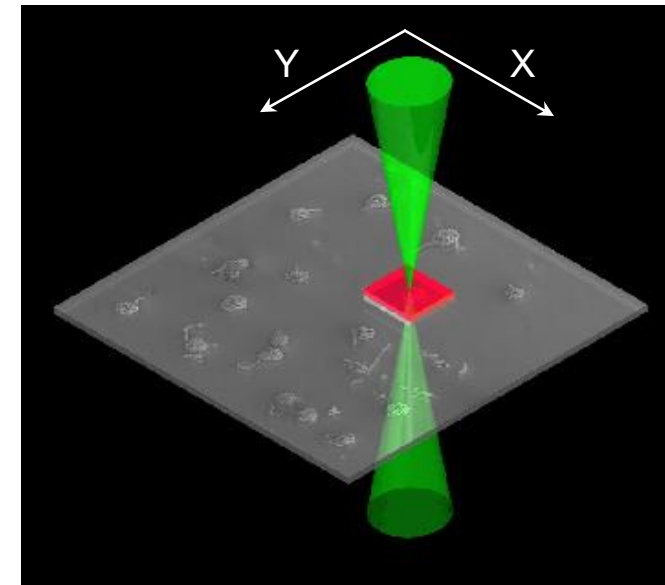
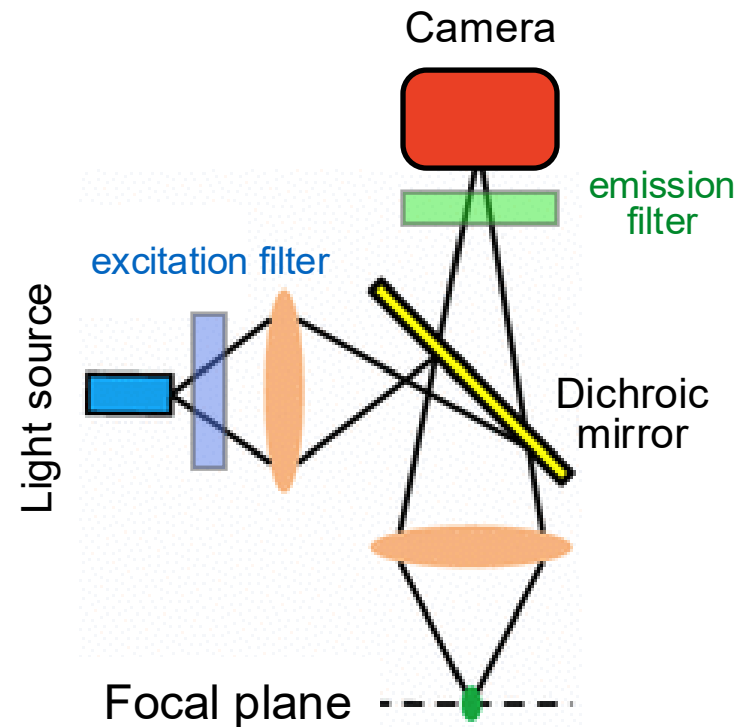


Moungi G. Bawendi, Louis E. Brus, Alexei I. Ekimov
kémiai Nobel-díj 2023



Epifluorescence microscope and Laser scanning confocal microscope

„Epi“:
from above

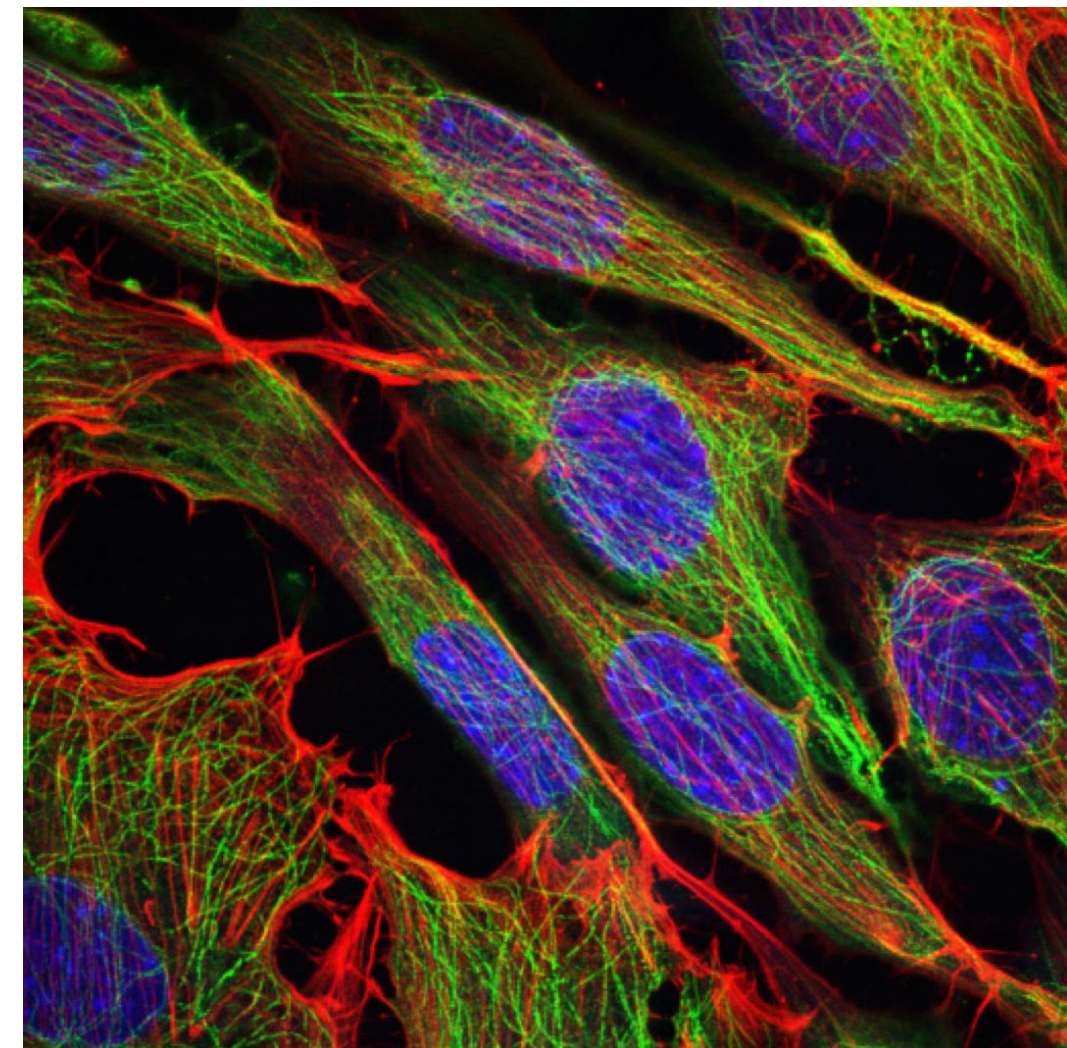
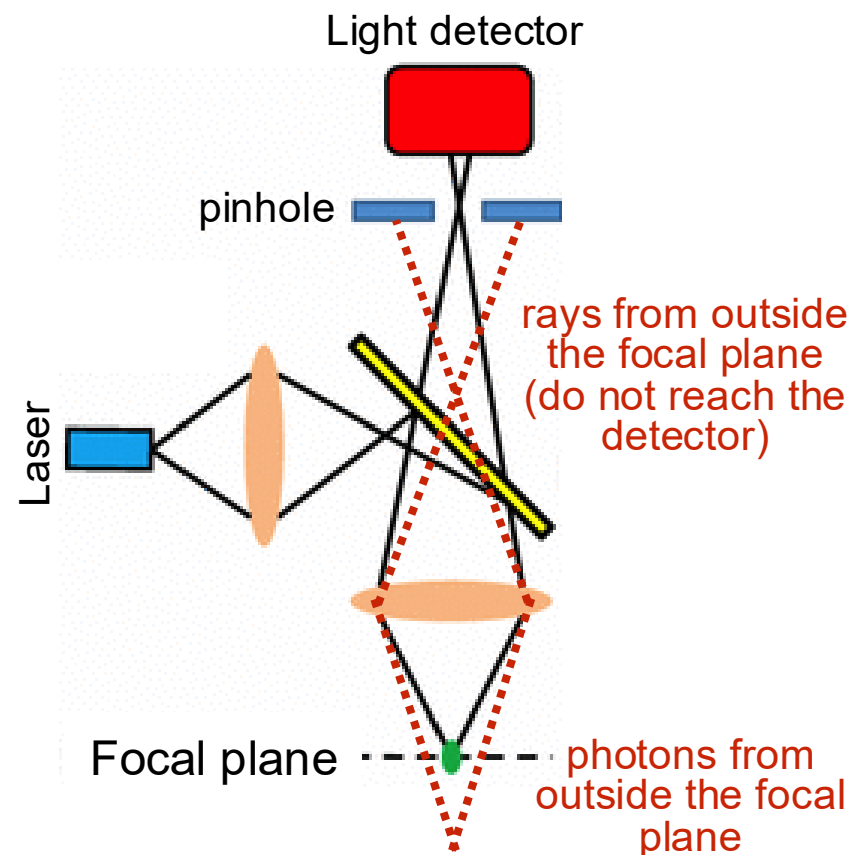


Scanning,
point-by-point
data collection

Green: microtubules;
Red: actin;
Blue: nucleus

Confocality:
focal points of the
excitation- and
emission-side
geometric optics are
identical.

Confocal principle:
photons that are not
from the focal point can
be filtered by using a
„pinhole“.



Super-resolution microscopy

Chemistry Nobel-prize, 2014



Eric Betzig



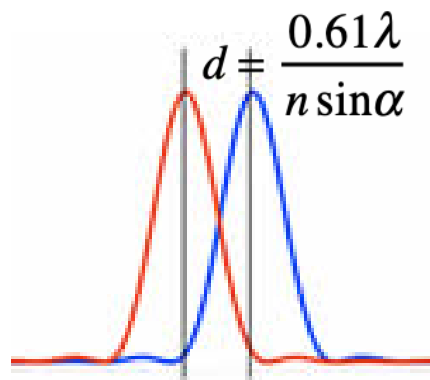
Stefan Hell



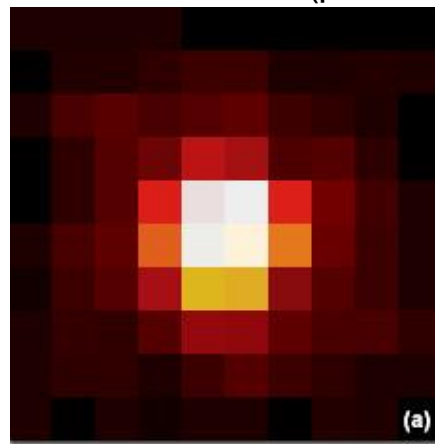
William E. Moerner

Resolution problem is converted into position-determination problem

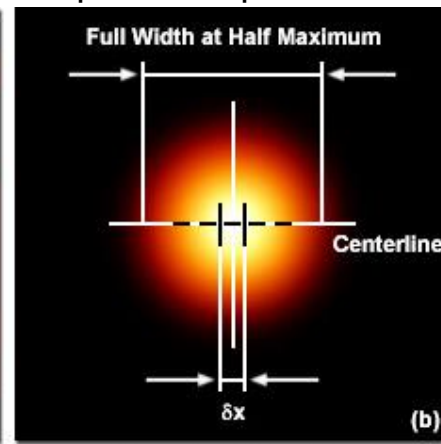
Resolution problem (Abbé)



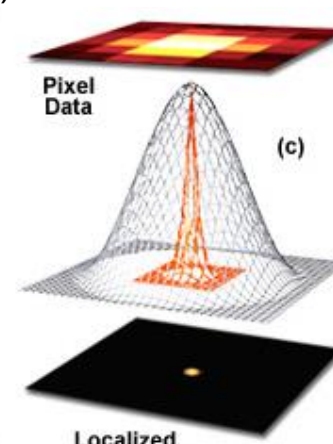
Position determination problem (precision depends on photon count)



Raw Data

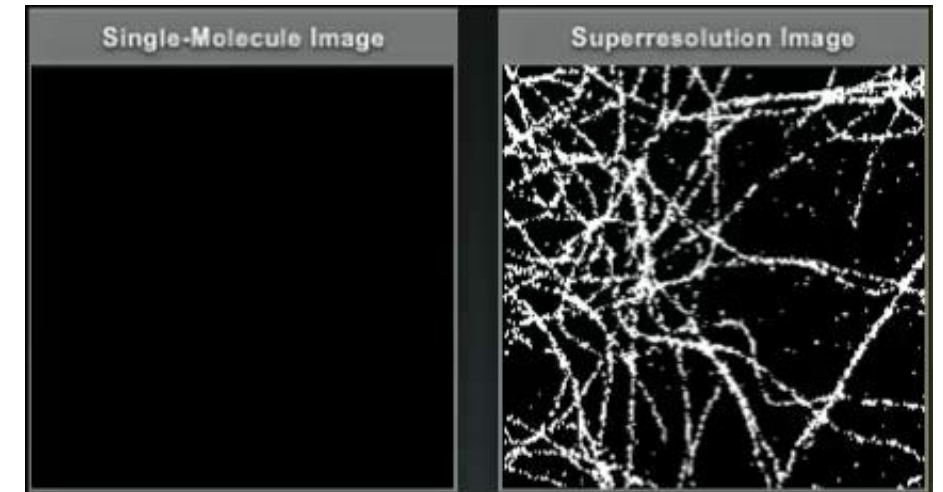


Gaussian Fit Function

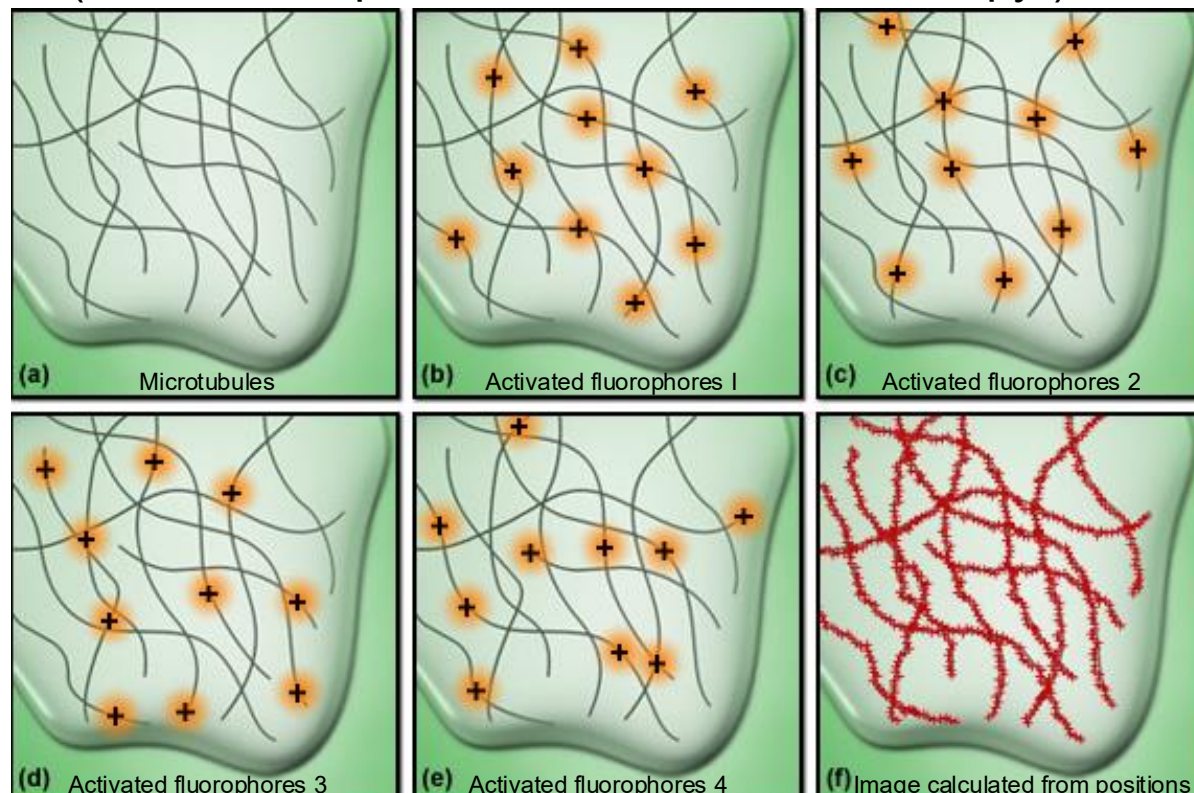


Localized Data Point

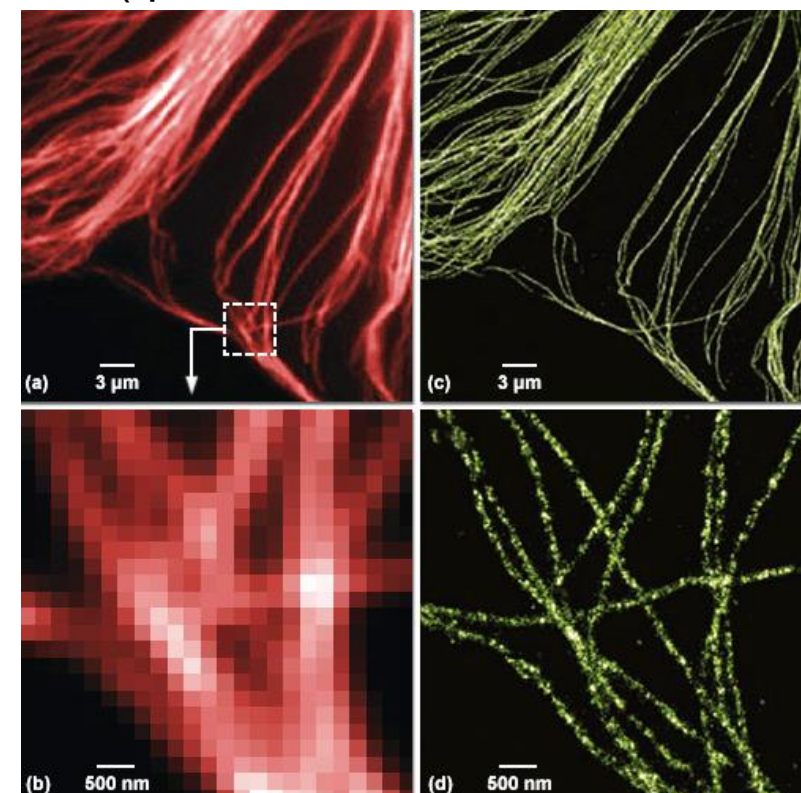
“Stochastic” data collection, single fluorophores



STORM (“stochastic optical reconstruction microscopy”); PALM (“photoactivated localization microscopy”)



Data collection process



Microtubular system

Feedback



<https://feedback.semmelweis.hu/feedback/index.php?feedback-qr=MAEQF7H7HE7O3ZW9>