

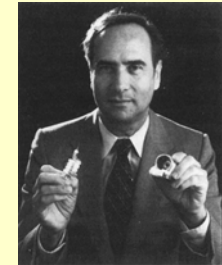
# Laser

light **a**mplification by **s**timulated **e**mission of **r**adiation

## Brief laser history

**1917 - Albert Einstein:** theoretical prediction of stimulated emission

**1954 - N.G. Basow, A.M. Prochorow, C. Townes:** ammonia maser\*



**1960 - Theodore Maiman:** first laser  
(ruby laser)

\***M**icrowave **A**mplification by **S**timulated **E**mission of **R**adiation

## Brief laser history



**Alexander Prokhorov**



**Charles H. Townes**



**Nicolay Basov**

Nobel prize in Physics 1964  
for work in quantum electronics leading to lasers and masers



**Denes Gabor**

Nobel prize in Physics 1971  
for invention of holography

## Brief laser history



**Steven Chu**



**William D. Phillips**

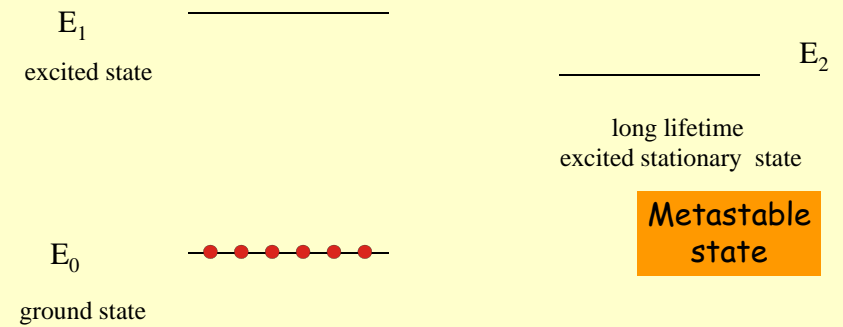


**Claude Cohen-Tannoudji**

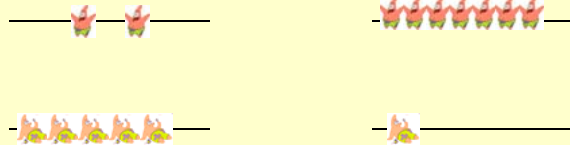
Nobel prize in Physics 1997  
for development of methods to cool and trap atoms with laser light.

## Fundamentals of Laser Operation

### Special electronic energy states - precondition for laser action



### Occupancy in energy levels



*Thermal equilibrium*  
according to Boltzmann  
distribution:

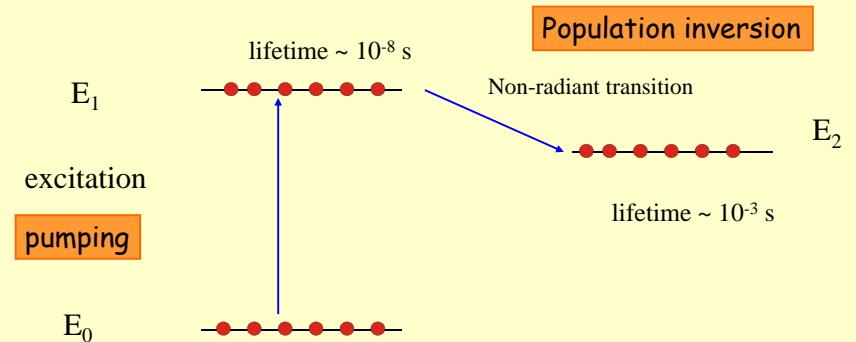
$$N_2 = N_1 e^{-\frac{\Delta E}{RT}}$$

The relative number of atoms  $N_1$  and  $N_2$  in two energy levels separated by  $\Delta E$  energy difference

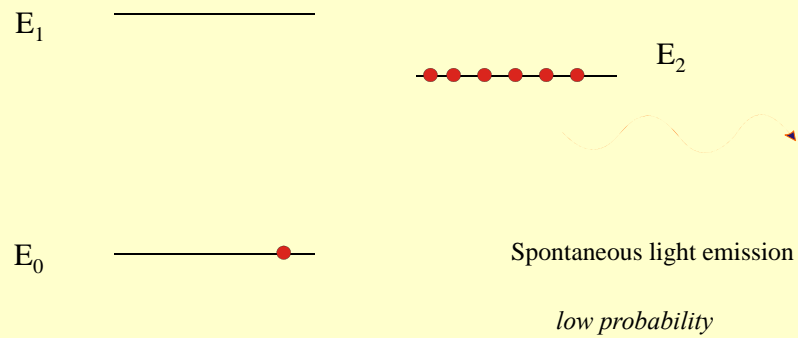
### **Population inversion**

“opposite” distribution –  
more electrons in excited  
than in ground state

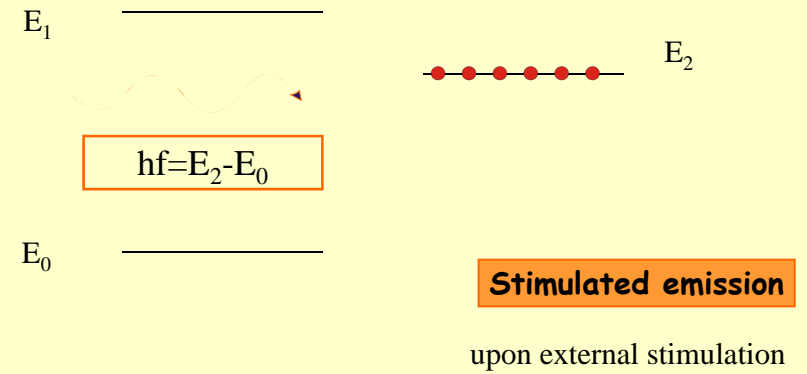
### Elementary radiative processes:



### Spontaneous photon emission

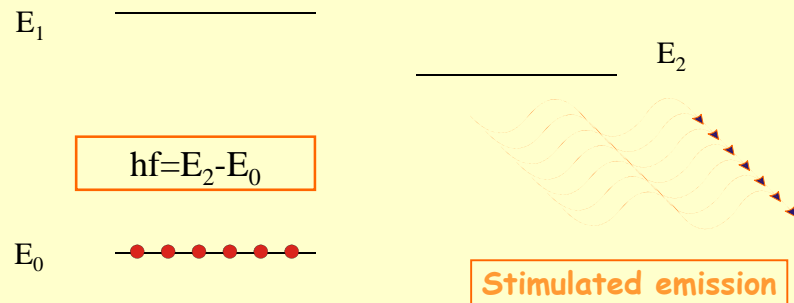


Induction of atomic transition – relaxation of electrons in metastable state



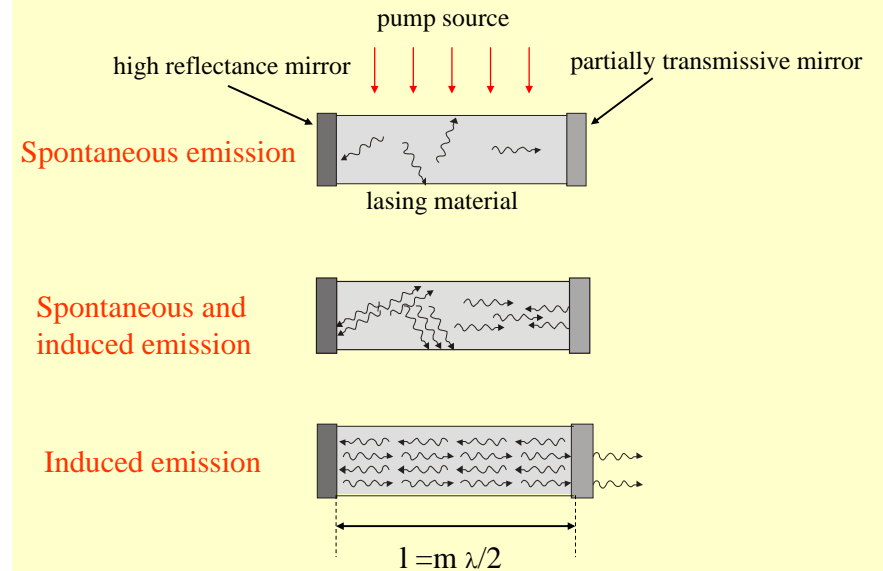
Electron interacting with an electromagnetic wave, may drop to a lower energy level.

Induction of atomic transition – relaxation of electrons in metastable state



Phase, polarisation, direction and frequency of emitted and inducing photons are identical.

### Operating a laser – optical resonator



Photons emitted by stimulated emission and inducing photons are identical

frequency  
phase,  
polarization  
and direction.

Consequently laser light is

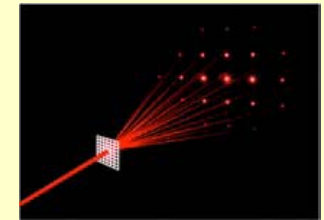
monochromatic  
coherent  
polarized  
parallel, collimated beam

Light generated by stimulated emission

monochromatic – small spectral width

coherent – phase equivalency in space  
and in time  
ability for interference

polrized,  
can provide large spatial density due to small divergence.



Possibility of very short pulses –  $ps$ ,  $fs$

Possibility of high power –  $kW$  -  $GW$

### Conditions of laser light production

pumping energy  
population inversion  
induced emission  
optical resonance

### Properties of laser light

monochromatic  
coherent  
polarized  
collimated  
facilitate a high power density

## Types of laser

*Based on active medium:*

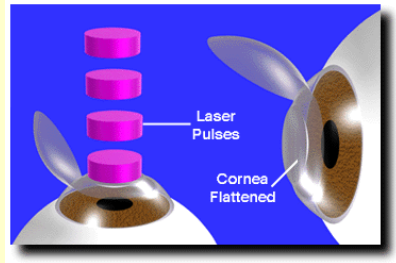
solid state lasers – Crystals or glasses doped with metal ions;  
Ruby, Nd-YAG, Ti-sapphire  
Red - infrared spectral range; possibility of high power  
gas lasers – He-Ne laser (10 He/Ne). CO<sub>2</sub> laser: CO<sub>2</sub>-N<sub>2</sub>-He  
mixture;  
dye lasers – Dilute solution of organic dyes (e.g., rhodamine,  
coumarine); pumped with another laser  
Large power (in Q-switched mode); Tunable

semiconductor lasers – At the junction of p- and n-type, doped  
semiconductors.  
No need for resonator mirrors (internal reflection)

## Excimer laser – *excited dimer*

Alapállapotban monomerek, gerjesztett állapotban stabilis komplexek vagy dimerek

Pl. nemesgázok vagy nemesgáz és halogén keverékek

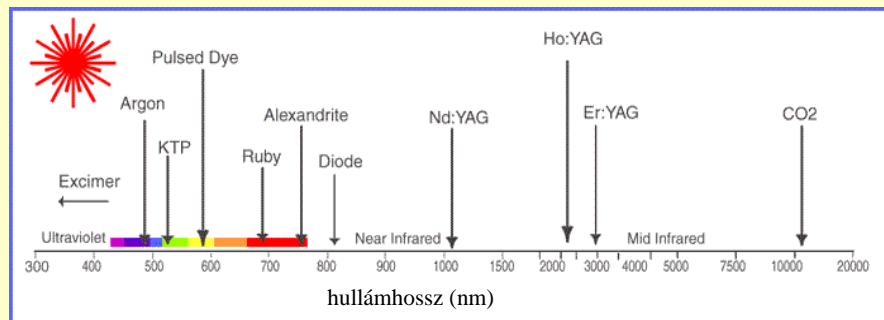


Ar <sub>2</sub>	126 nm
Kr <sub>2</sub>	146 nm
F <sub>2</sub>	157 nm
Xe <sub>2</sub> <sup>*</sup>	172 & 175 nm
ArF	193 nm
KrF	248 nm
XeBr	282 nm
XeCl	308 nm
XeF	351 nm
CaF <sub>2</sub>	193 nm
KrCl	222 nm
Cl <sub>2</sub>	259 nm

## Types of laser

### Depending on power:

- 5 mW – CD-ROM drive
- 5–10 mW – DVD player or DVD-ROM drive
- 100 mW – High-speed CD-RW burner
- 250 mW – Consumer DVD-R burner
- 1–20 W – output of the majority of commercially available solid-state lasers used for micro machining
- 30–100 W – typical sealed CO<sub>2</sub> surgical lasers
- 100–3000 W (peak output 1.5 kW) – typical sealed CO<sub>2</sub> lasers used in industrial laser cutting



## Application of lasers

### Criteria for selection

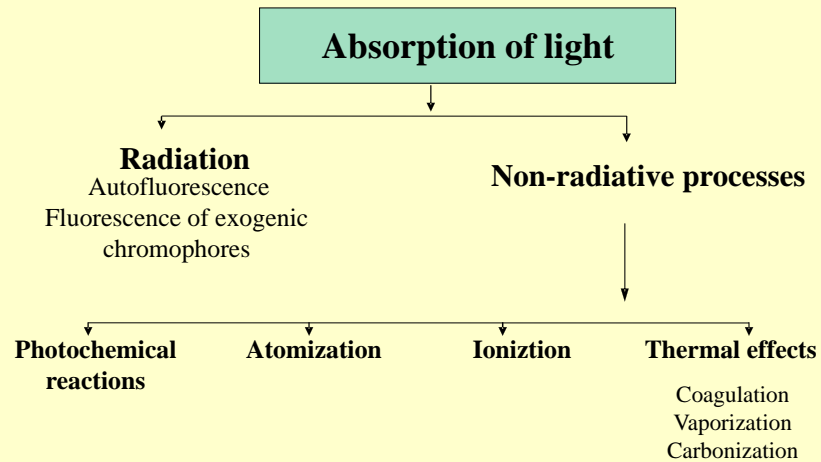
- wavelength
- power
- continuous/pulse mode

### Fields of application

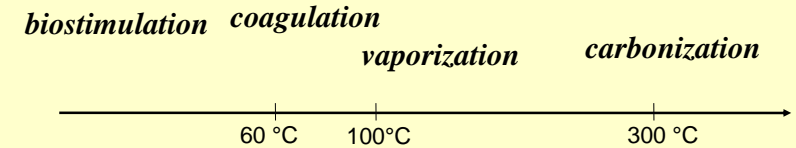
- Medicine** (health and beauty) – diagnostic and therapy
- Industry:** Cutting, welding, material heat treatment, marking parts
- Defense:** Marking targets, guiding munitions, missile defence, electrooptical countermeasures (EOCM), alternative to radar
- Research:** spectroscopy, laser ablation, Laser annealing, laser scattering, laser interferometry, LIDAR, Laser capture microdissection
- Product development/commercial:** laser printers, CDs, barcode scanners, thermometers, laser pointers, holograms.
- Laser lighting displays:** Laser light shows

## Biomedical applications of laser

### Light induced processes in tissues



## Thermal effects



## Light induced processes in tissues

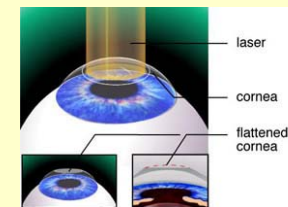
Selectivity of processes: getting the right amount of the right wavelength of laser energy to the right tissue to damage or destroy only that tissue, and nothing else.

## Photoablation - volatilization of tissue by UV radiation

Mechanism: atomization/vaporization

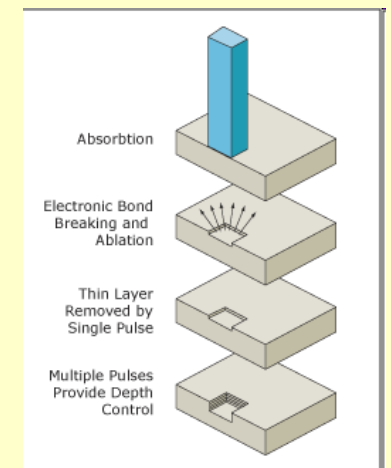
UV laser pulse ( $10 \text{ MW/cm}^2$  -  $10 \text{ GW/cm}^2$ )

Excimer laser (193 nm-351 nm), 10-20 ns pulse

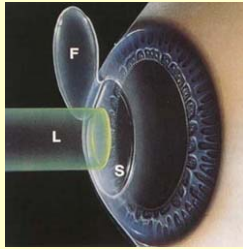


### Photorefractive Keratectomy (PRK):

myopic eye is too big compared to the refraction of its lens



## Corneal reshaping: LASIK (Laser in situ Keratomileusis)



The epithelium is surgically peeled back and the underlying stroma is ablated. LASIK allows correction of even severe myopia because it is not limited by the finite thickness of the epithelium.

## Photodisruption

Focused, high intensity ns pulses

Kavitation

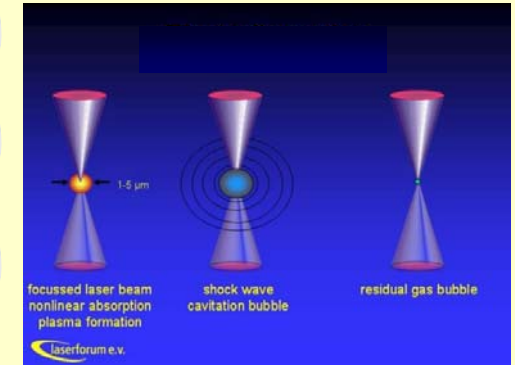
Water evaporation and  $\text{CO}_2$

generation in the cavity

Shock wave

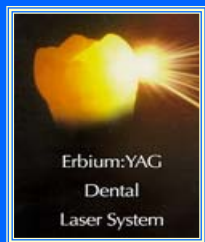
Distruction of surrounding

tissues



## Applications in dentistry:

Er:YAG laser  
2940 nm



Absorption in water and  
hydroxyapatite

Vaporization and mechanical  
shockwave

caries removal



caries removal



caries removal



Argon laser  
488, 514 nm



A rubber dam is put over your  
teeth to protect the gums



Teeth whitening

Nd: YAP\* laser

930, 1080,  
1340 nm



frenectomy

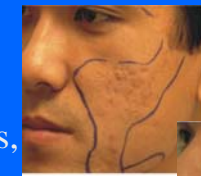
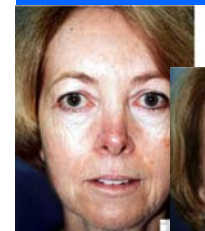


gingivectomy

\*YAlO<sub>3</sub>:Nd

## Dermatological applications:

„resurfacing” – ablation technic for renewal of epidermis



wrinkles,  
damages,  
acnes ...

Er:YAG laser (2940 nm) or CO<sub>2</sub> laser (10600 nm)



Nd:YAG laser

1064 nm

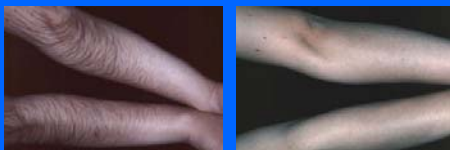
Removal of superficial blood vessels, veins



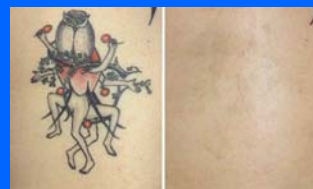
Photocoagulation based correction of veins



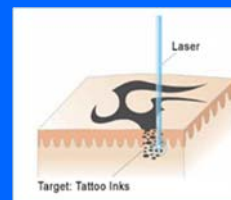
Hair removal



Tattoo removal

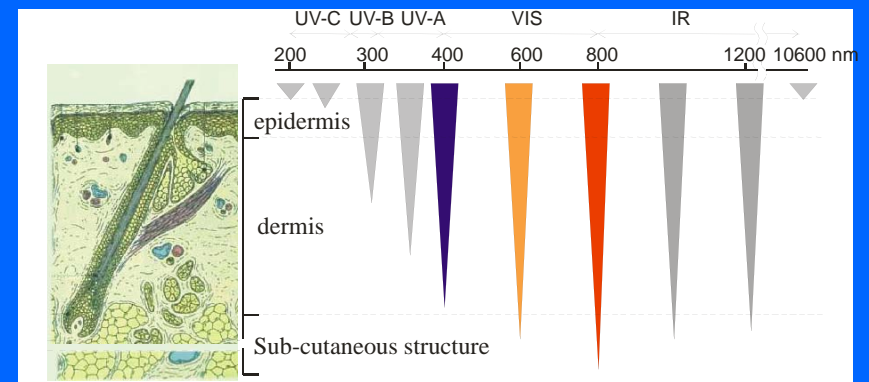


before after



ruby laser (694 nm) is specifically absorbed by the color pigments in the tattoo

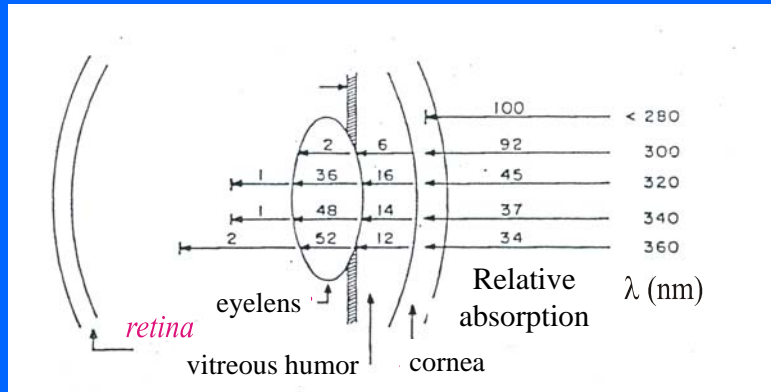
Penetration of light into the skin



*Light intensity is attenuated due to absorption, reflection, refraction.*

*Penetration depth depends on the wavelength.*

## Penetration of light into the skin

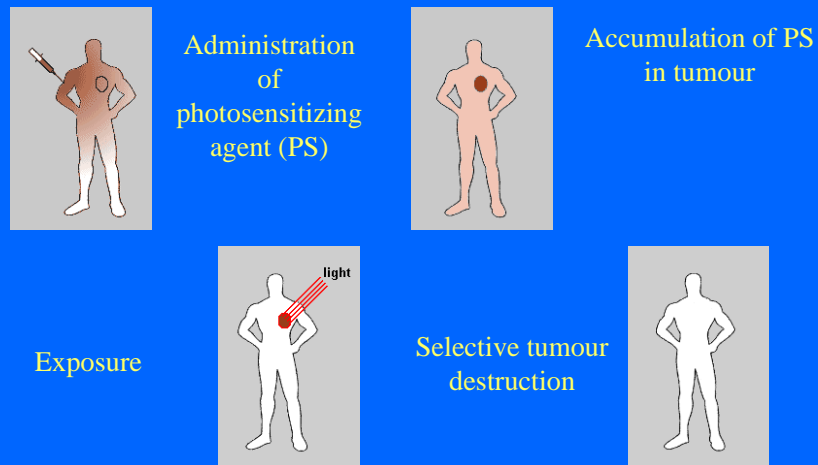


## Photodynamic therapy (PDT)

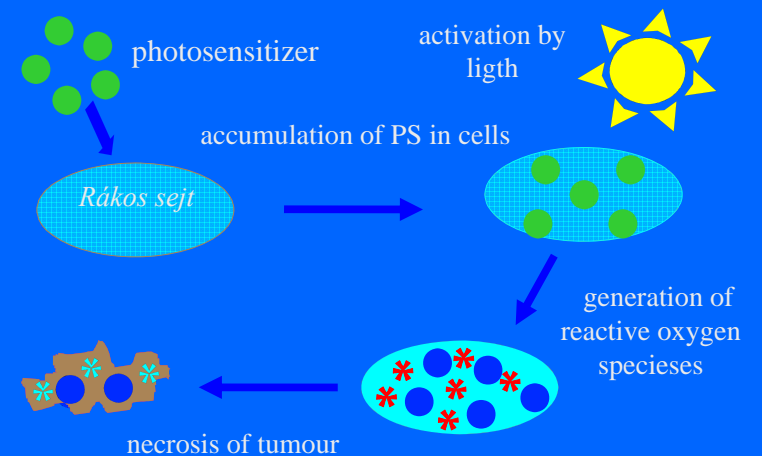
**Combined application of light and photosensitizer**  
in oxygen rich environment.

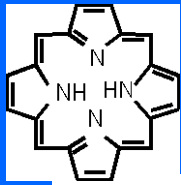
T. Dougherty: Activated dyes as antitumor agents.  
J. Natl. Cancer. Inst. 1974

## Steps of the treatment

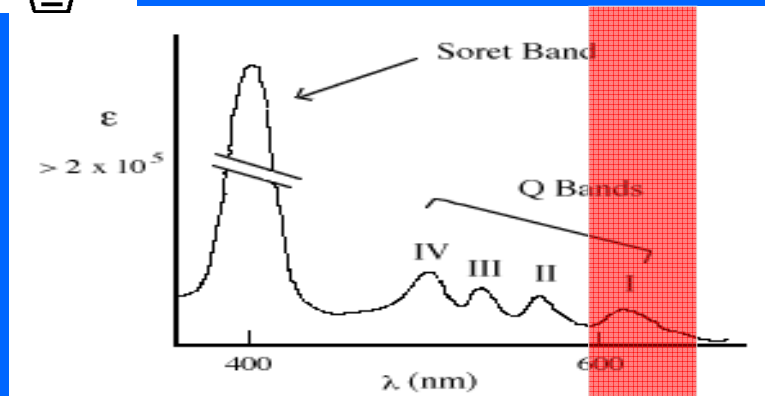


## Mechanism of action

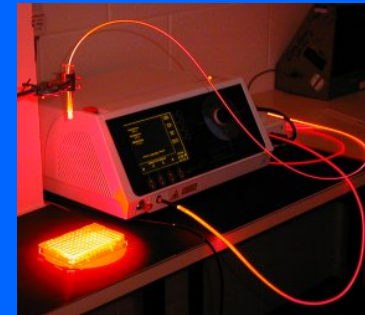




## Typical absorption of porphyrins



## Selection of light source



Monochromatic – red

high intensity



laser

## Application fields of PDT

- *destruction of malignant tissues*
- *removal of non-malignant structures*
- *inactivation of microorganisms*
  - in dentistry
  - dermatology
  - sterilization of blood products
  - sterilization of water reserves

## Question of the week

Why are excimer lasers and not Nd-YAG lasers used in corneal refractive surgery to remove anterior corneal tissues?

*Damjanovich, Fidy, Szöllősi: Medical Biophysics*

II. 2.2

2.2.5

2.2.7

2.2.8

IX. 1.1

IX. 1.2