

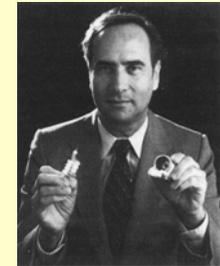
Laser

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)

*Microwave **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

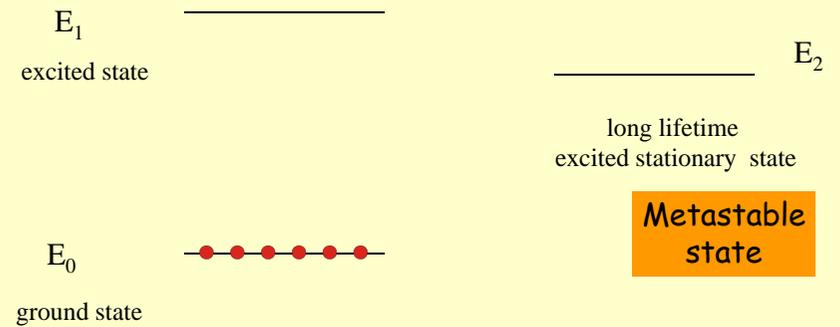


Claude Cohen-Tannoudji

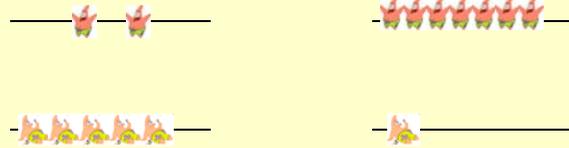
Nobel prize in Physics 1997
for development of methods to cool and trap atoms with laser light.

Fundamentals of Laser Operation

Special electronic energy states - precondition for laser action



Occupancy in energy levels



Thermal equilibrium according to Boltzmann distribution:

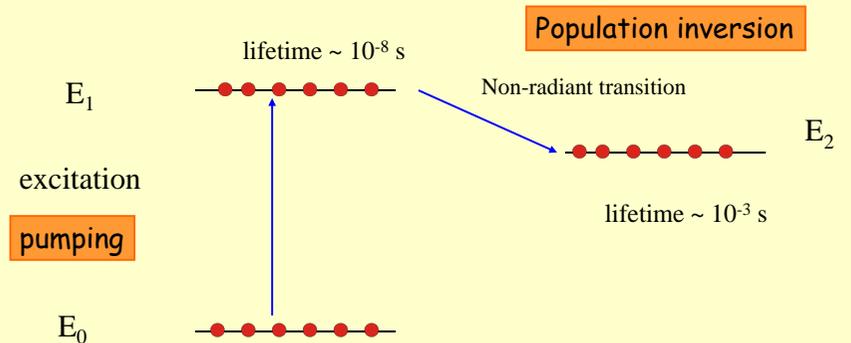
$$N_2 = N_1 e^{-\frac{\Delta E}{RT}}$$

The relative number of atoms N_1 and N_2 in two energy levels separated by ΔE energy difference

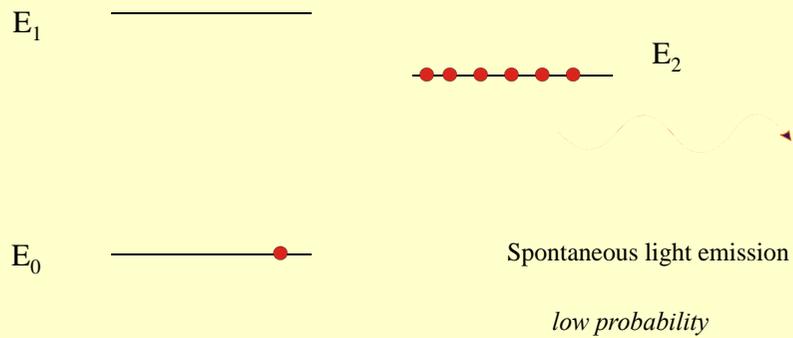
Population inversion

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

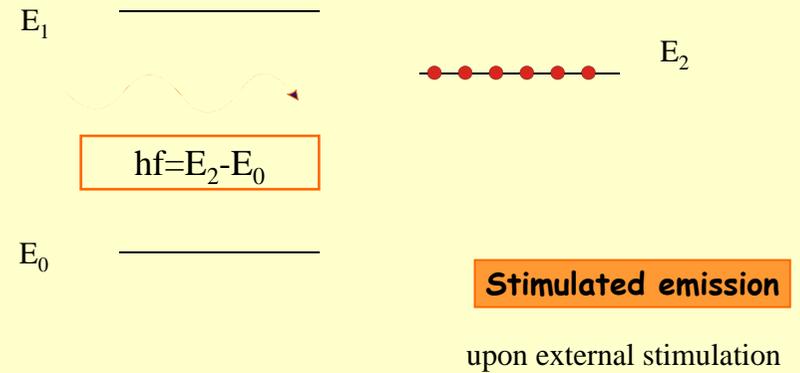
Elementary radiative processes:



Spontaneous photon emission

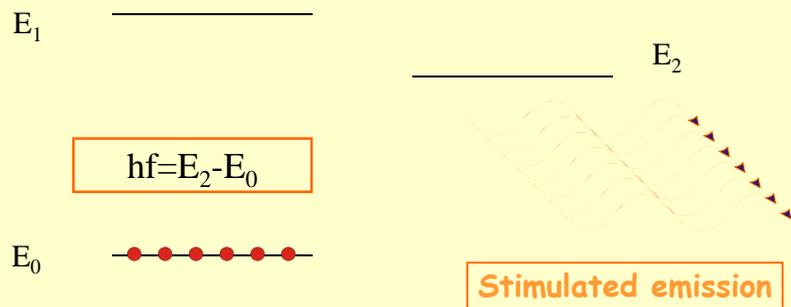


Induction of atomic transition – relaxation of electrons in metastable state



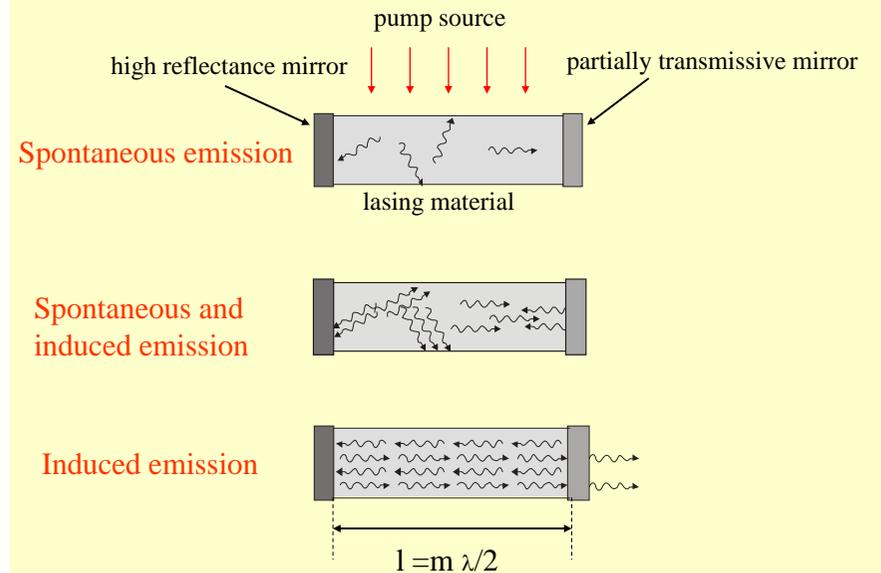
Electron interacting with an electromagnetic wave, may drop to a lower energy level.

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

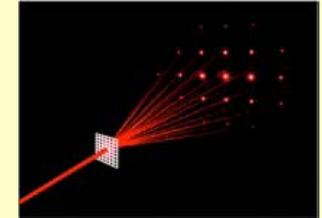
Light generated by stimulated emission

monochromatic – small spectral width

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

polarized,

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). CO₂ laser: CO₂-N₂-He
mixture;

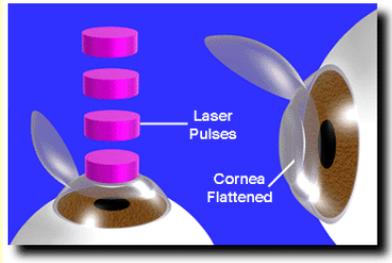
dye lasers – Dilute solution of organic dyes (e.g., rhodamine,
coumarine); pumped with another laser
Large power (in Q-switched mode); Tunable

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

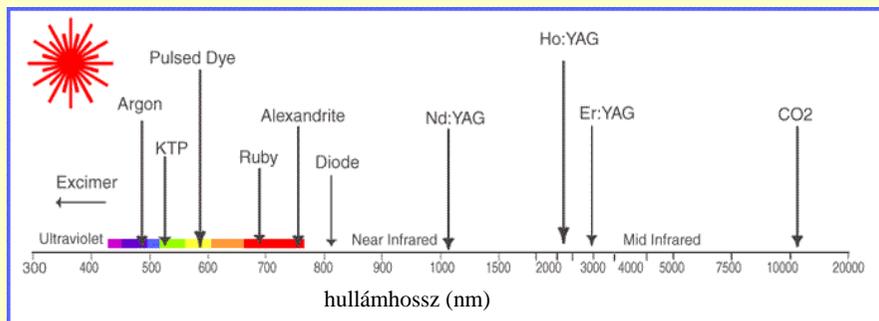


Ar ₂	126 nm
Kr ₂	146 nm
F ₂	157 nm
Xe ₂ [*]	172 & 175 nm
ArF	193 nm
KrF	248 nm
XeBr	282 nm
XeCl	308 nm
XeF	351 nm
CaF ₂	193 nm
KrCl	222 nm
Cl ₂	259 nm

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 CO₂ surgical lasers
- 100–3000 W (peak output 1.5 kW) – typical sealed CO₂ lasers used in industrial laser cutting



Application of lasers

Criteria for selection

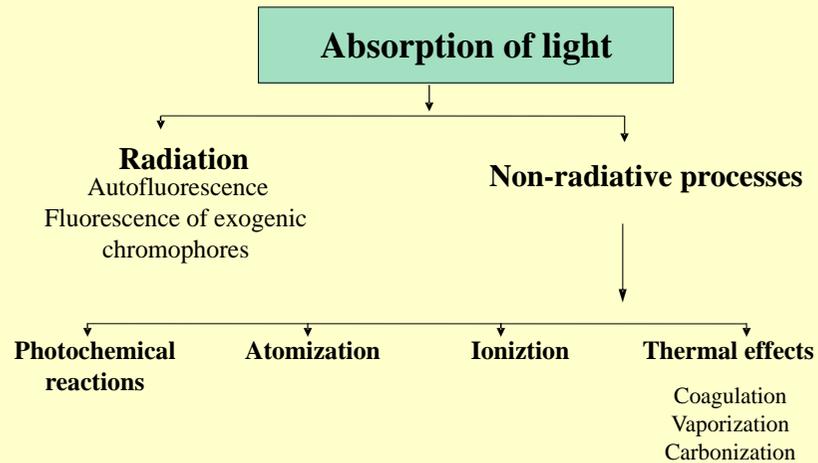
- wavelength
- power
- continuous/pulse mode

Fields of application

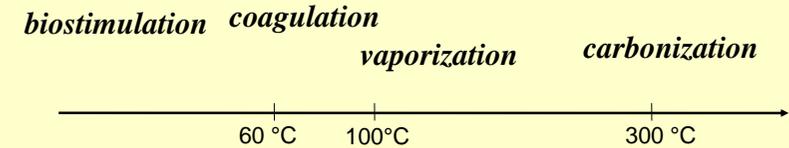
- Medicine** (health and beauty) – diagnostic and therapy
- Industry:** Cutting, welding, material heat treatment, marking parts
- Defense:** Marking targets, guiding munitions, missile defence, electrooptical countermeasures (EOCM), alternative to radar
- Research:** spectroscopy, laser ablation, Laser 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

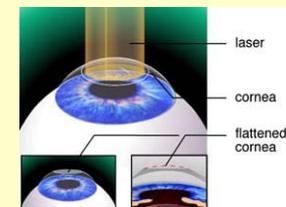
Selectivity of processes: getting the right amount of the right wavelength of laser energy to the right tissue to damage or destroy only that tissue, and nothing else.

Photoablation - volatilization of tissue by UV radiation

Mechanism: atomization/vaporization

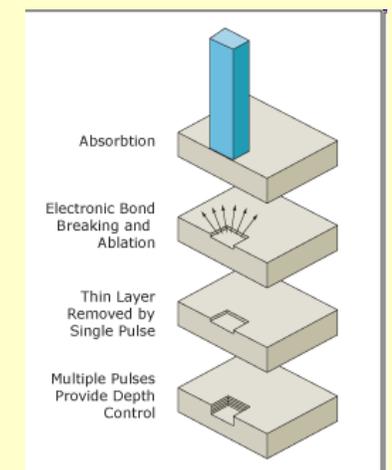
UV laser pulse (10 MW/cm² - 10 GW/cm²)

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

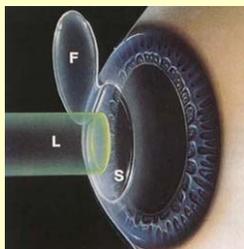


Photorefractive Keratectomy (PRK):

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

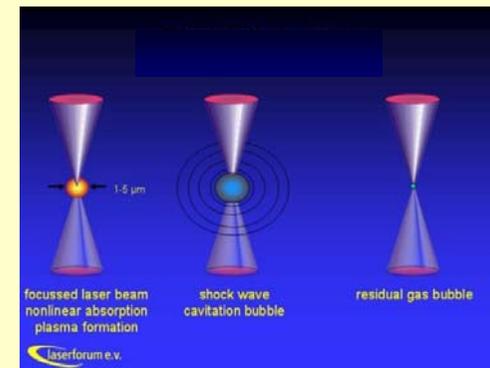
Focused, high intensity ns pulses

Kavitation

Water evaporation and CO₂ generation in the cavity

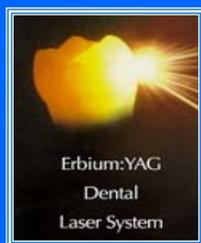
Shock wave

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

*YAIO₃:Nd

Dermatological applications:

„resurfacing” – ablation technic for renewal of epidermis



wrinkles,
damages,
acnes ...

Er:YAG laser (2940 nm) or CO₂ laser (10600 nm)

Nd:YAG laser

1064 nm

Removal of superficial blood vessels, veins



Photocoagulation based correction of veins



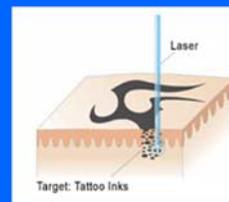
Hair removal



Tattoo removal

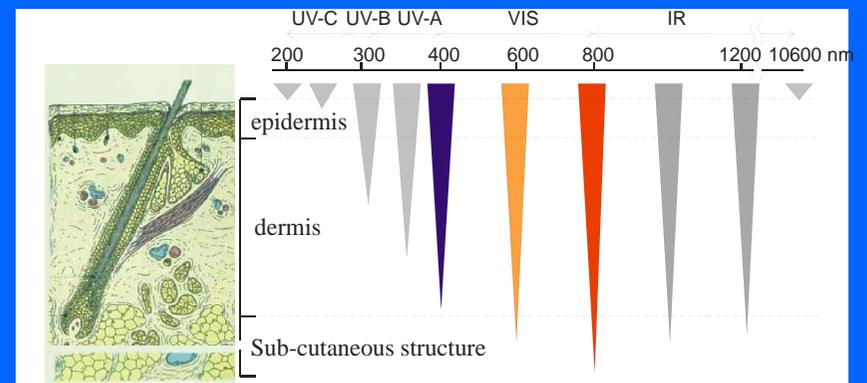


before after



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

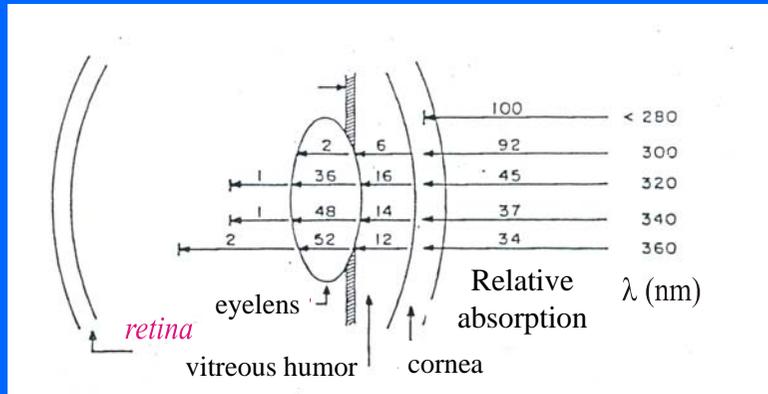
Penetration of light into the skin



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

Penetration depth depends on the wavelength.

Penetration of light into the skin

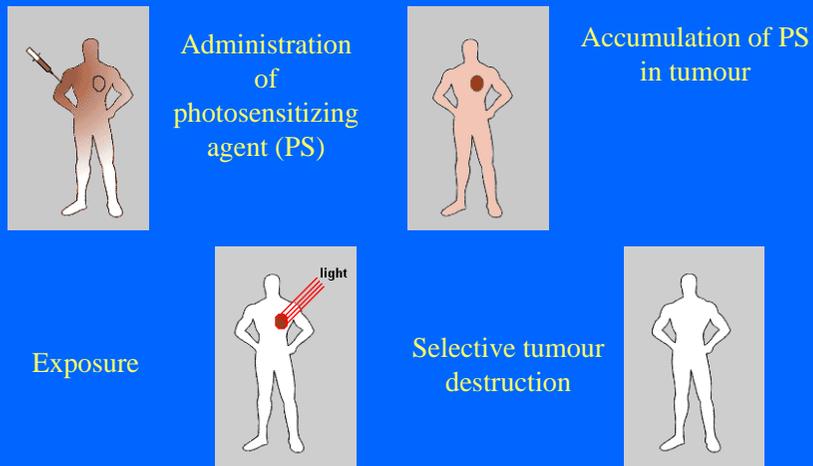


Photodynamic therapy (PDT)

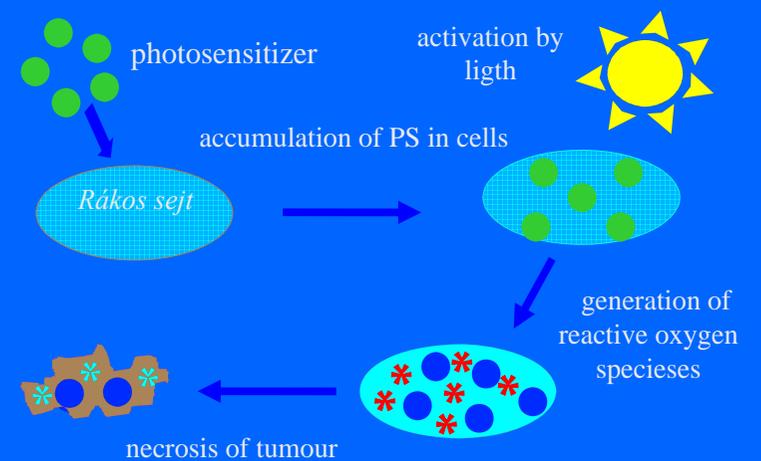
Combined application of light and photosensitizer
in oxygen rich environment.

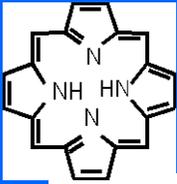
T. Dougherty: Activated dyes as antitumor agents.
J. Natl. Cancer. Inst. 1974

Steps of the treatment

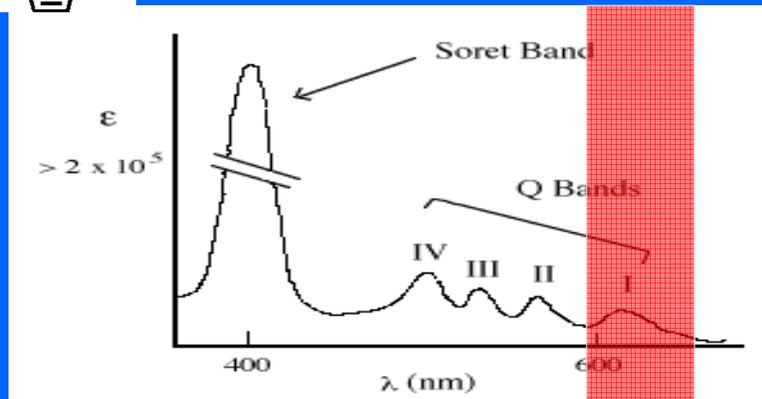


Mechanism of action

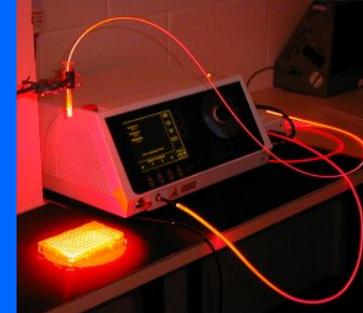




Typical absorption of porphyrins



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