LAMELIS 2019

Lasers in Medicine and Life Sciences

5 Jul **Fri**

▶ 9^{00}–10^{30} • **Zsolt Tóth,**

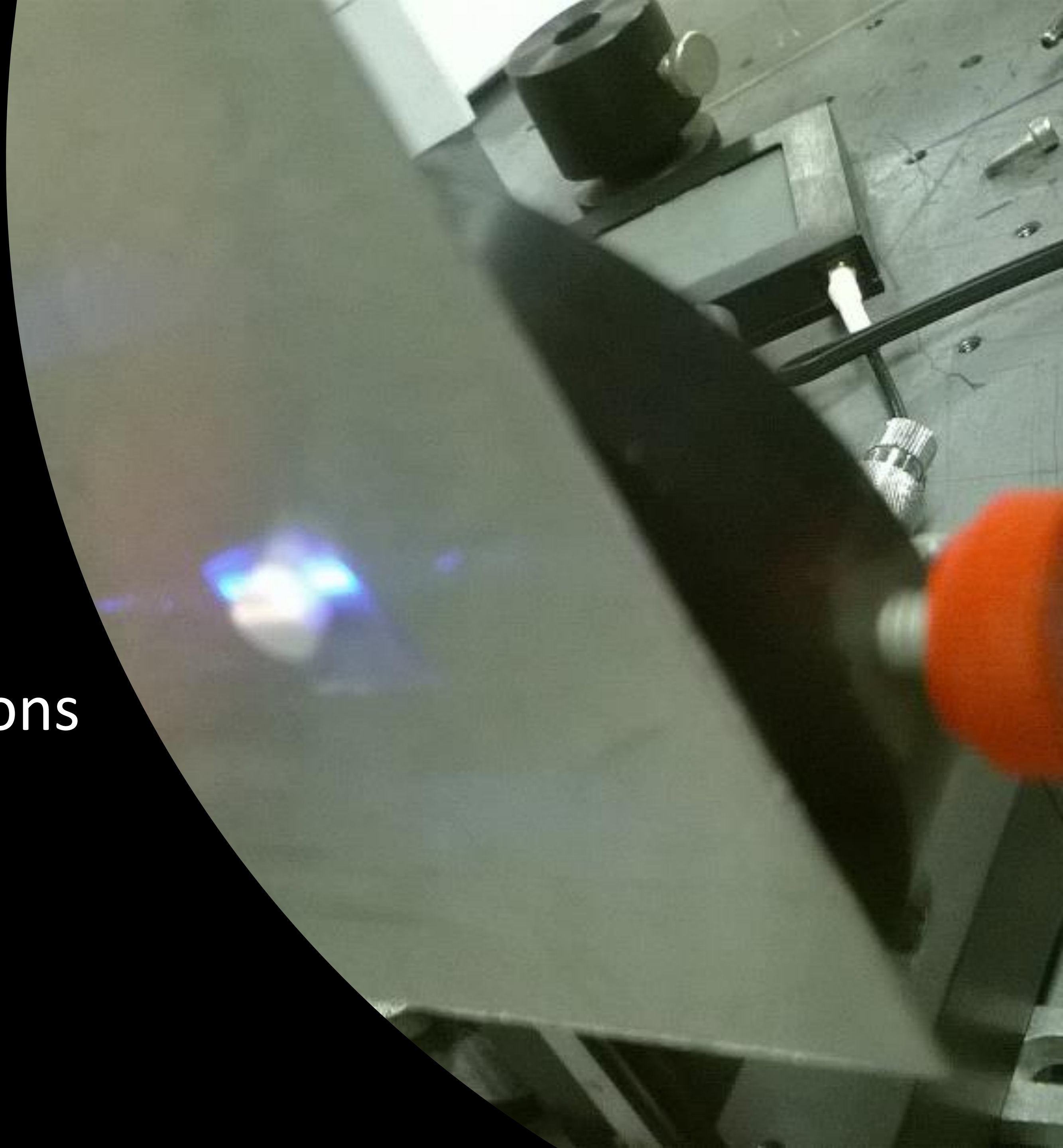
Lasers for dental applications

University of Szeged, Faculty of Dentistry

Department of Oral Biology and Dental Research

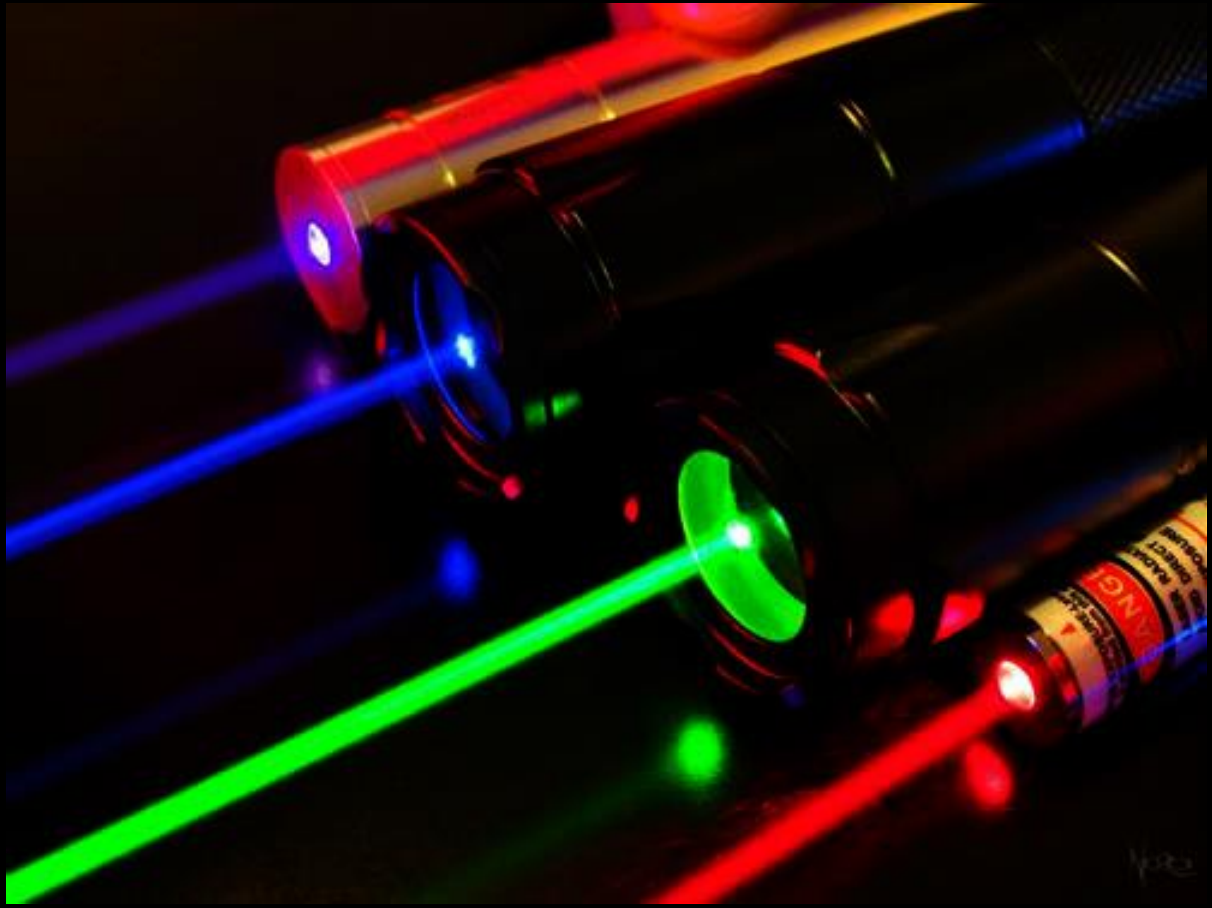
Contents of this talk

- Lasers
- Light – material interactions
- Overview of dental applications



Lasers

Light Amplification by Stimulated Emission of Radiation



Lasers are unique light sources. Many important parameters of laser light are substantially different from those of the light emitted by classical (thermal or fluorescent) light sources

"a solution looking for a problem,"

Short history of Laser development

Article (PDF Available) *in* Applied Optics 49(25):F99-122 · September 2010

DOI: 10.1117/1.3483597 · Source: PubMed

Jeff Hecht
32.32 · Institute of Electrical and Electronics Engineers

Abstract

Half a century has passed since Theodore Maiman's small ruby rod crossed the threshold of laser emission. The breakthrough demonstration earned headlines, but in the early years the laser was called "a solution looking for a problem," and there was a germ of truth in the joke. Years of development since then have vastly improved laser performance,and tremendously increased their variety, earning lasers important roles in scientific research, consumer products, telecommunications,engineering, medicine, materials working, and a host of other applications. This article reviews the highlights of those developments and puts them into context, showing how laser technology has evolved to meet application requirements.

Optical spectrum

range name, sign	subrange name, sign		λ (nm)	ν [1/cm]	f (THz)	E (eV)
Ultraviolet (UV)	Vacuum UV VUV	UV-C	100 - 200	$5\cdot10^4$-10^5	1498-2997	6,2 - 12,4
	Far UV FUV		200 - 280	35700-$5\cdot10^4$	1070-1498	4,43 - 6,2
	UV-B		280 - 315	31700-35700	951-1070	3,94 - 4,43
	UV-A		315 - 400	25000-31700	749 -951	3,1 - 3,94
Visible (VIS)	VIS		400 - 800	12500-25000	375-749	1,55 - 3,1
Infrared (IR)	Near IR NIR	IR-A	800 - 1400	7100-12500	214-375	0,89 - 1,55
		IR-B	1400 - 3000	3300-7100	99-214	0,41 - 0,89
	Mid IR MIR	IR-C	3000 – $5\cdot10^4$	200-3300	6-99	0,025 - 0,41
	Far IR FIR		$5\cdot10^4$ - 10^6	10-200	0,3-6	0,00124-0,025

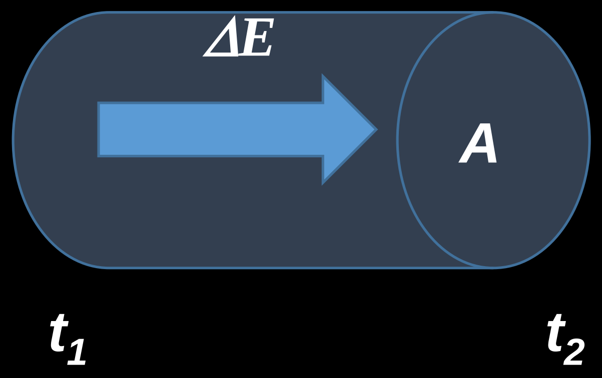
Different spectral ranges, and the associated λ wavelengths, ν wave numbers, f frequencies, and E photon energy values.

Definition of power of radiation

The quantity of energy reaching the surface during a unit time gives the current of light or power of light.

In a time interval Δt

energy in an amount of ΔE is transported through an area A



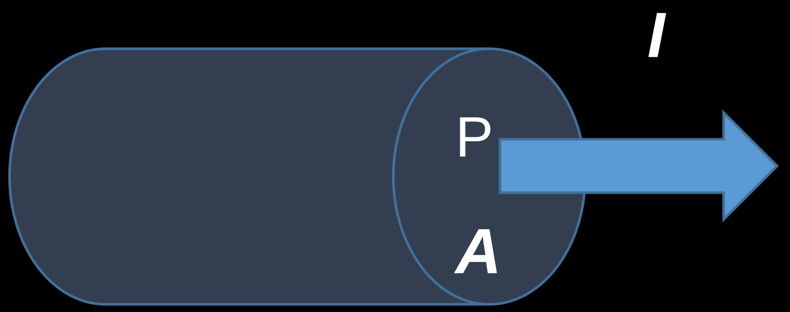
$$P = \frac{\Delta E}{\Delta t}$$

unit: J/s=W

$$\Delta t = t_2 - t_1$$

Intensity

The strength of phototermal, or photochemical effects depends on the *I* **intensity, or power density** of the light. This is the light power which falls to a unit area:

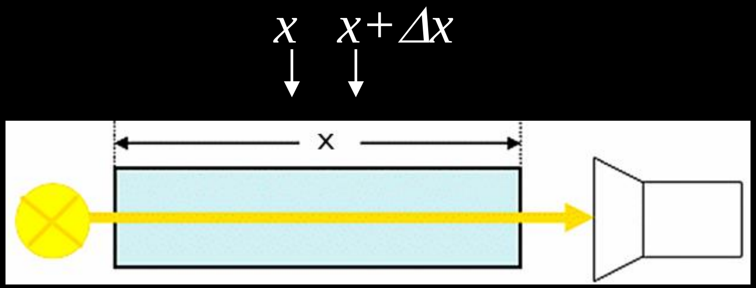


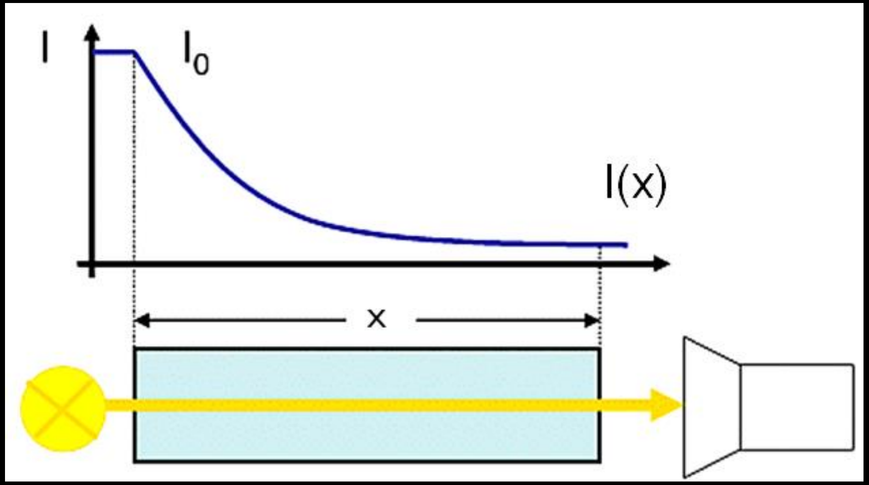
$$I = \frac{\Delta P}{\Delta A}$$

unit: W/m^2

Light absorption

$I(0) \quad I(x) \; I(x+\Delta x)$





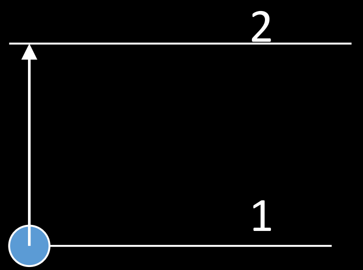
ΔI is directly proportional to both I and Δx

$$\Delta I = -\alpha(\lambda) \cdot I \cdot \Delta x \quad ,$$

$$I(x) = I_0 \cdot e^{-\alpha(\lambda) \cdot x}$$

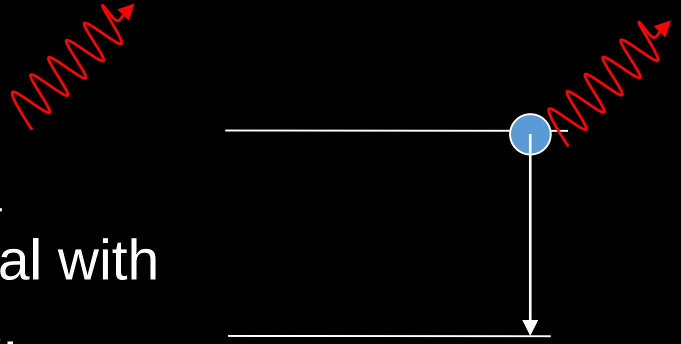
Due to absorbtion the light intensity exponentially decreases as a function of depth. This is *Lambert-law*.

Principles of operation



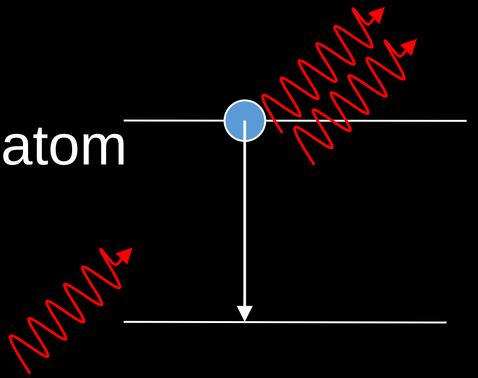
Absorption

electron moves from an enery level E_0 to a higher level E_1 by absorbing a photon with a probability B_{12}



Emission

When an excited electron returns to its ground level, it emits a photon with a probability A_{21}. The energy of this photon is equal with the difference of energies of the excited and the ground levels.

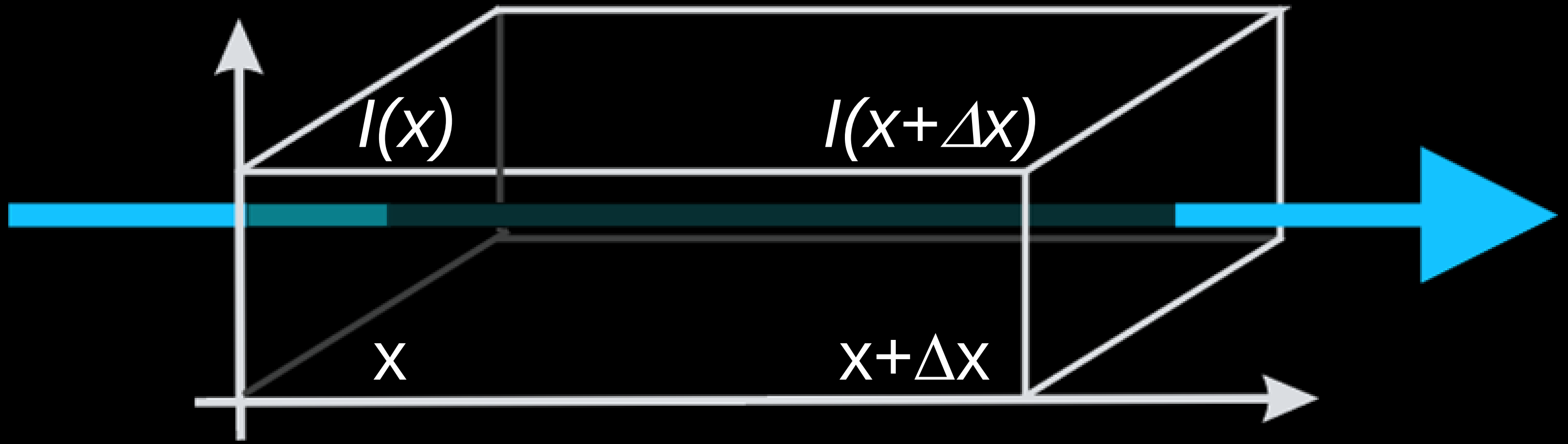


Stimulated emission

Due to the interaction of an excited atom and a photon, the atom returns to its ground state and emits an other photon with a probability B_{21}

$$B_{12}=B_{21}$$

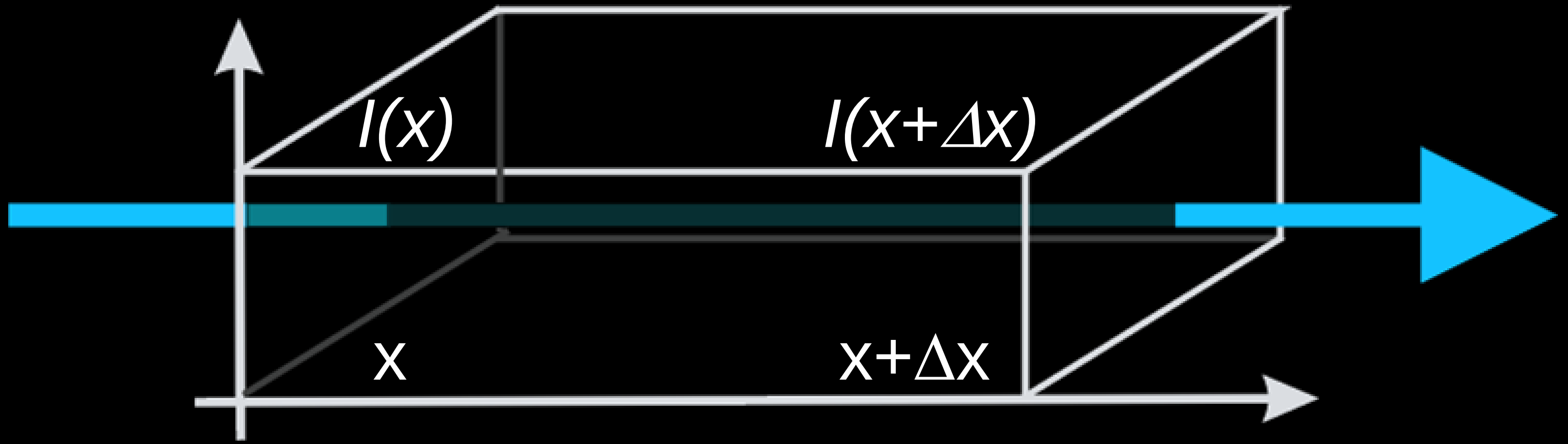
Einstein coefficients, absorption and emission phenomena



Let N_1 and N_2 the number of atoms in ground and excited state, respectively.

- absorption decreases the intensity, $\propto N_1 \cdot B_{12}$

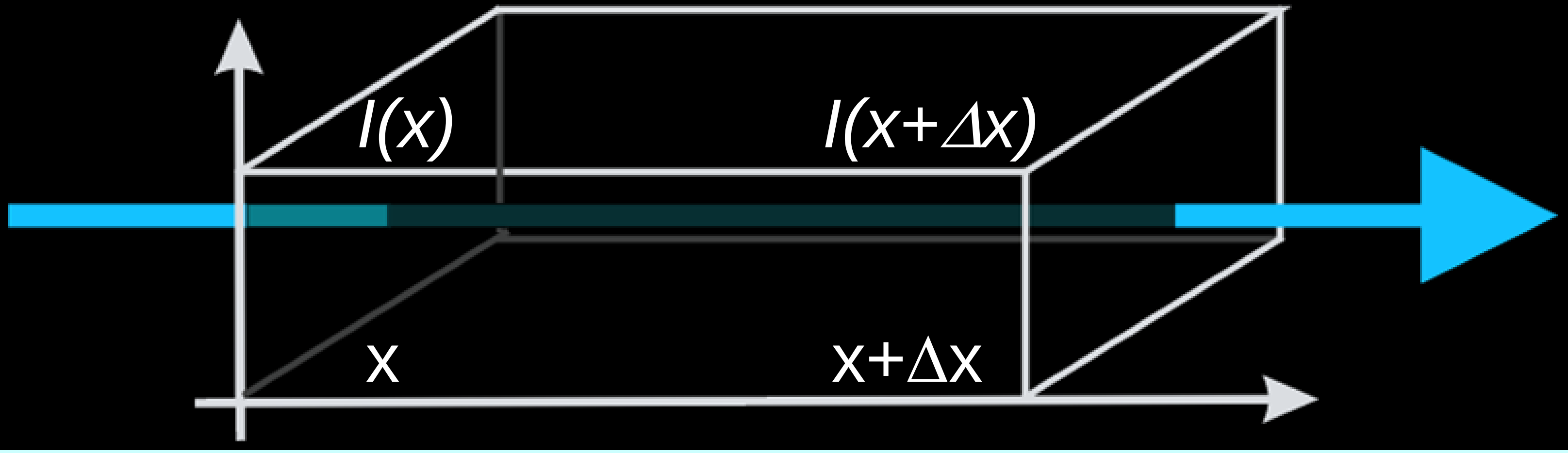
Einstein coefficients, absorption and emission phenomena



Let N_1 and N_2 the number of atoms in ground and excited state, respectively.

- stimulated emission increases the intensity $\propto N_2 \cdot B_{21}$

Einstein coefficients, absorption and emission phenomena

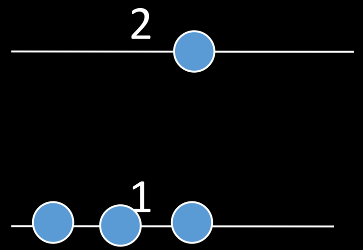


$$\Delta I \equiv I(x+\Delta x) - I(x) \propto \left(N_2 - N_1\right) \cdot B_{21} \cdot I \cdot \Delta x$$

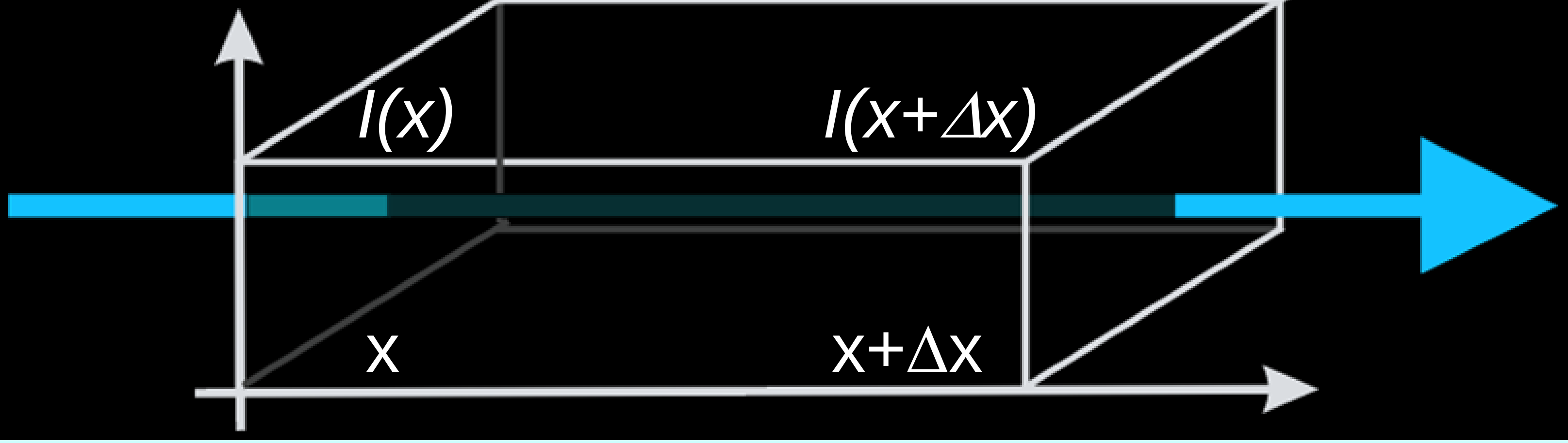
The solution of this equation: $$I(x) = I_0 \cdot e^{c\cdot(N_2 - N_1)\cdot B_{12}\cdot x}$$

c: constant

If $N_1 > N_2$ then the light wave weakens (as in case of Lambert law!)



Einstein coefficients, absorption and emission phenomena



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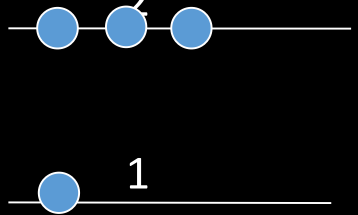
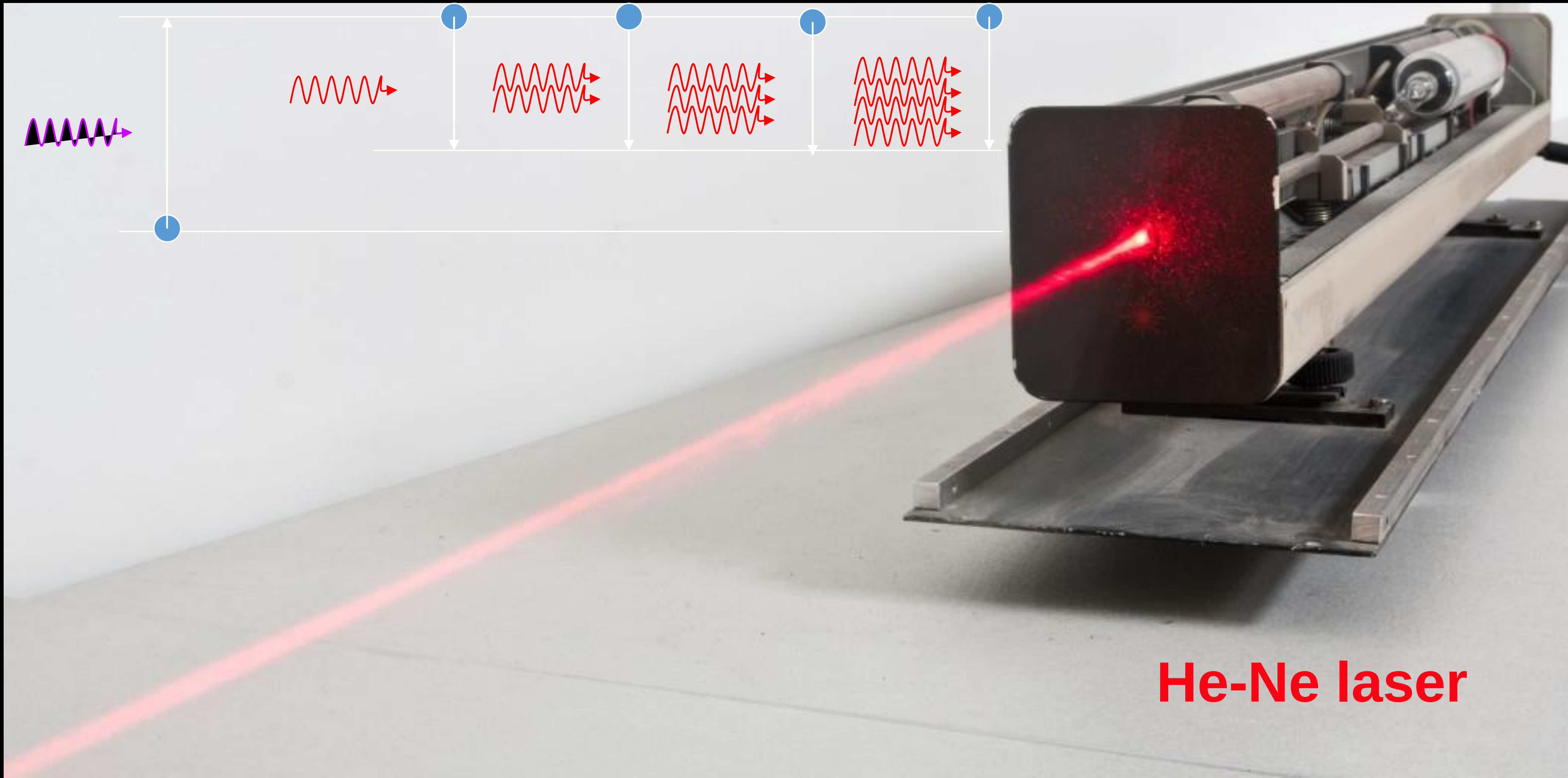


If $N_2 > N_1$ then the ***<u>light wave is amplified</u>***

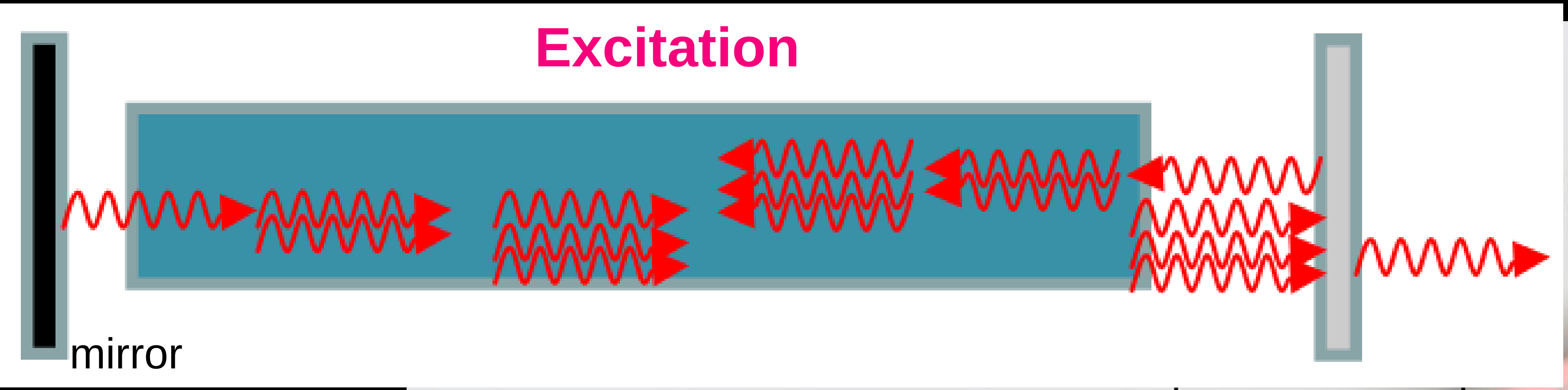
Operation of lasers

Stimulated emission + Population inversion = Amplification



Operation of lasers

Amplification +Feedback = LASER



Positive feedback is realised by the *resonator.*

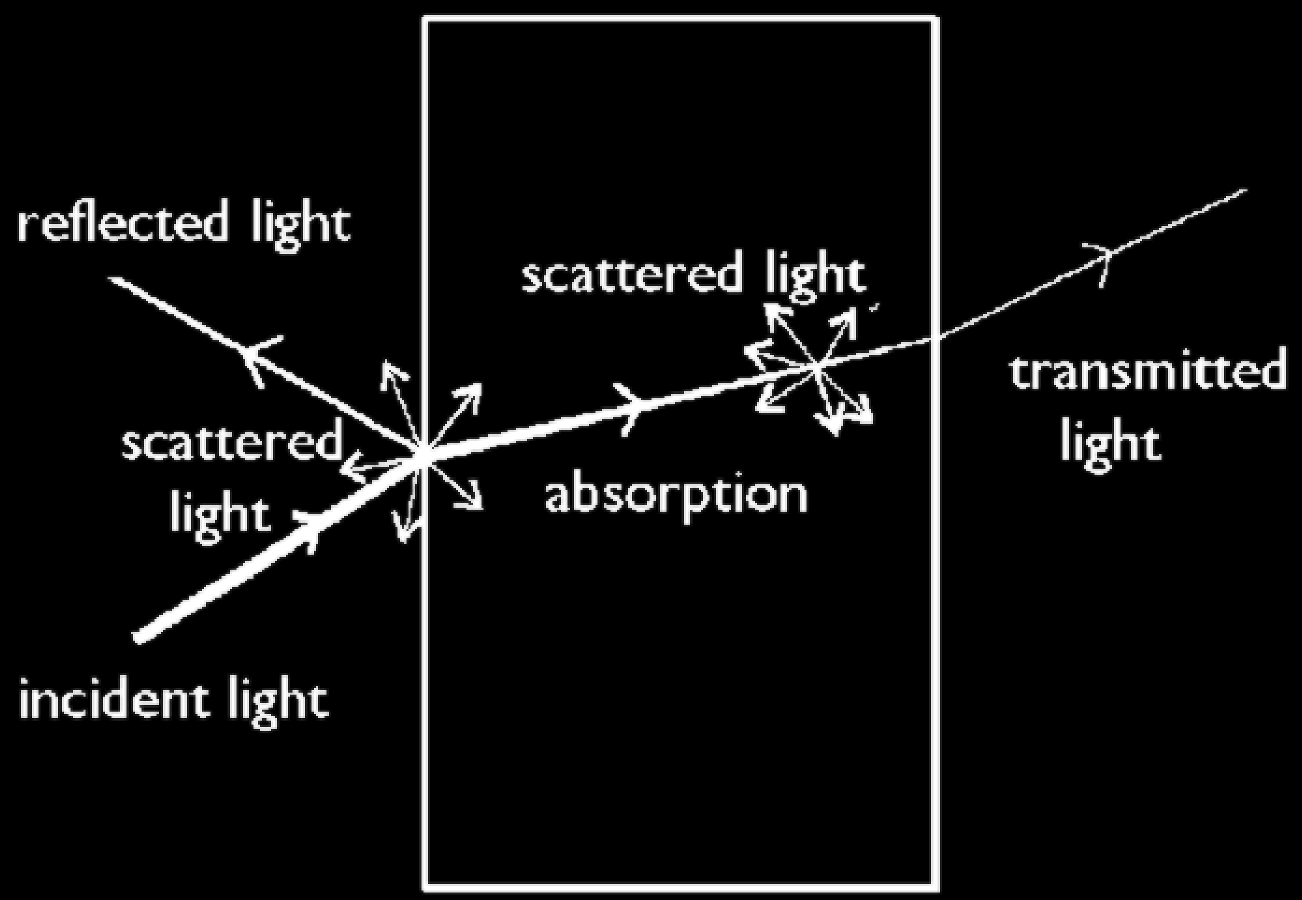
Properties of laser light

- **Wavelength:** it depends on the energy difference of the electronic transitions
- **Monochromaticity:** laser radiation consists of one single color or wavelength
- **Divergence:** the laser radiation is directional (collimated)
- **Coherence:** it characterizes the phase relation of the waves. Coherent light rays are able to produce interference
- **Energy and oputput power**: The output power is defined by several laser parameters (pumping, amplification, feedback, outcoupling)
- The laser radiation can be continuous (CW laser means Continuous Wave laser) in time or pulsed.

Lasers, power densities, pulse lengths

Laser type	Process time	Power density [W/cm^2]	wavelength
ion lasers (He-Ne, Ar+, Kr+)	ms-min	10^3-10^6	VIS
CO_2 lasers	ms-s	10^5-10^7	10,6 μm
Diode lasers	μs-s	10^3-10^6	UV-VIS-NIR
Q-switched solid state lasers	ns	10^6-10^{13}	UV-VIS-NIR
excimer lasers	ns	10^6-10^{11}	UV
Dye excimer laser	fs-ps	10^{10}-10^{14}	UV
CPA solid state lasers	fs	10^{10}-10^{17}	700-800 nm

Light – material interaction



Teeth…

The mouth is the primary portal of the alimentary system and a secondary portal for the respiratory system.

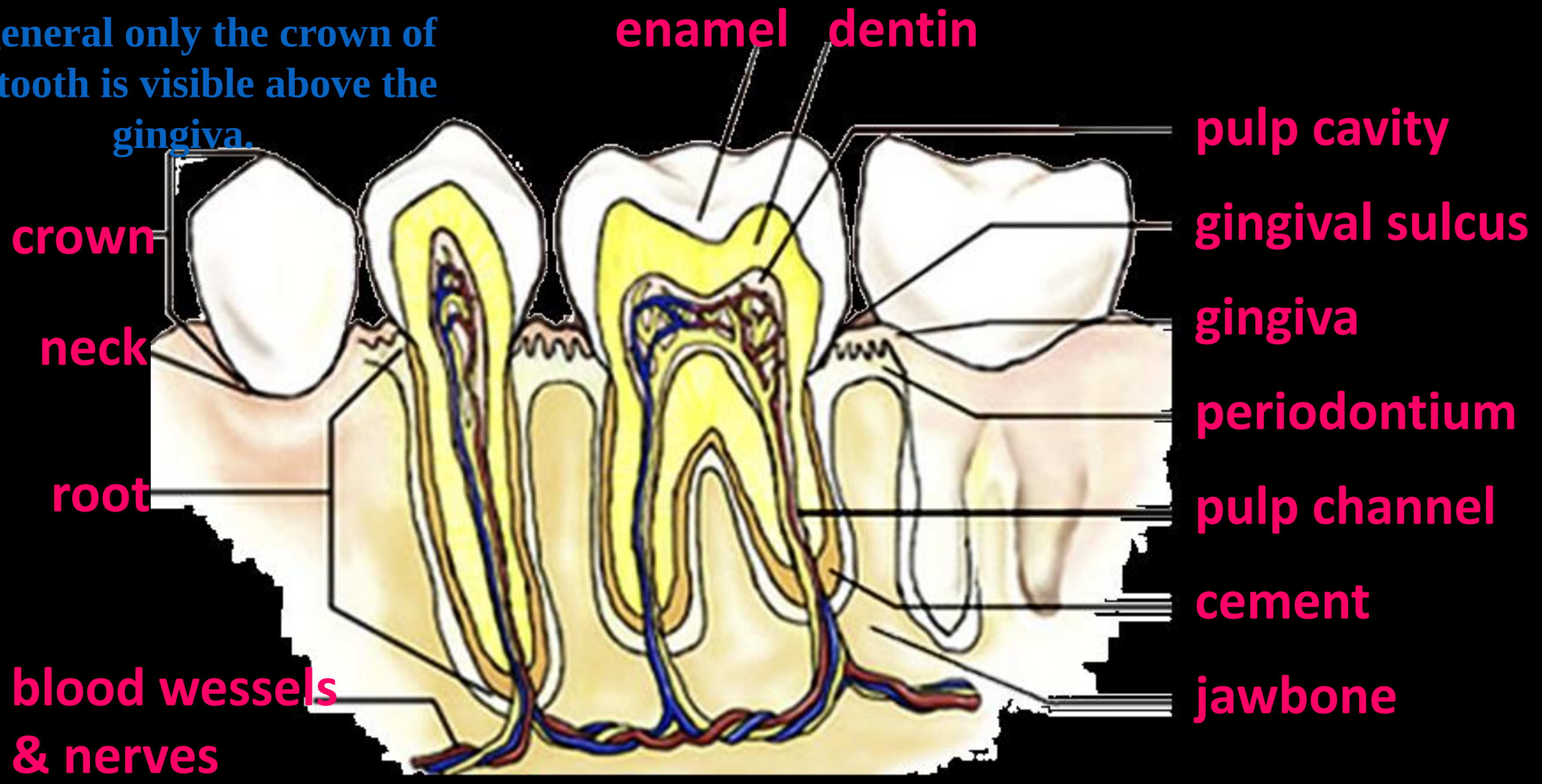
The roots of teeth are embedded in
- the maxilla (upper jaw) or
- the mandible (lower jaw)

and are covered by gums.

Benninghoff / Drenckhahn: Anatomie 1, 17.A. © Elsevier GmbH. www.studentconsult.de

Teeth and their structure

In general only the crown of the tooth is visible above the gingiva.



Each tooth has 3 mineralized portions:

Enamel / substantia Adamantina

98% inorganic components
(Calcium phosphate)
2% organic material
(soluble and insoluble proteins)
The enamel is made of enamel-prisms and is cell-free!

Dentin / substantia eburnea

70% inorganic components
(primarily calcium and phosphate
in the form of hydroxyapatite crystals).
20% organic matrix
90% of them - Type I collagen,
10% proteoglycans).

10% water

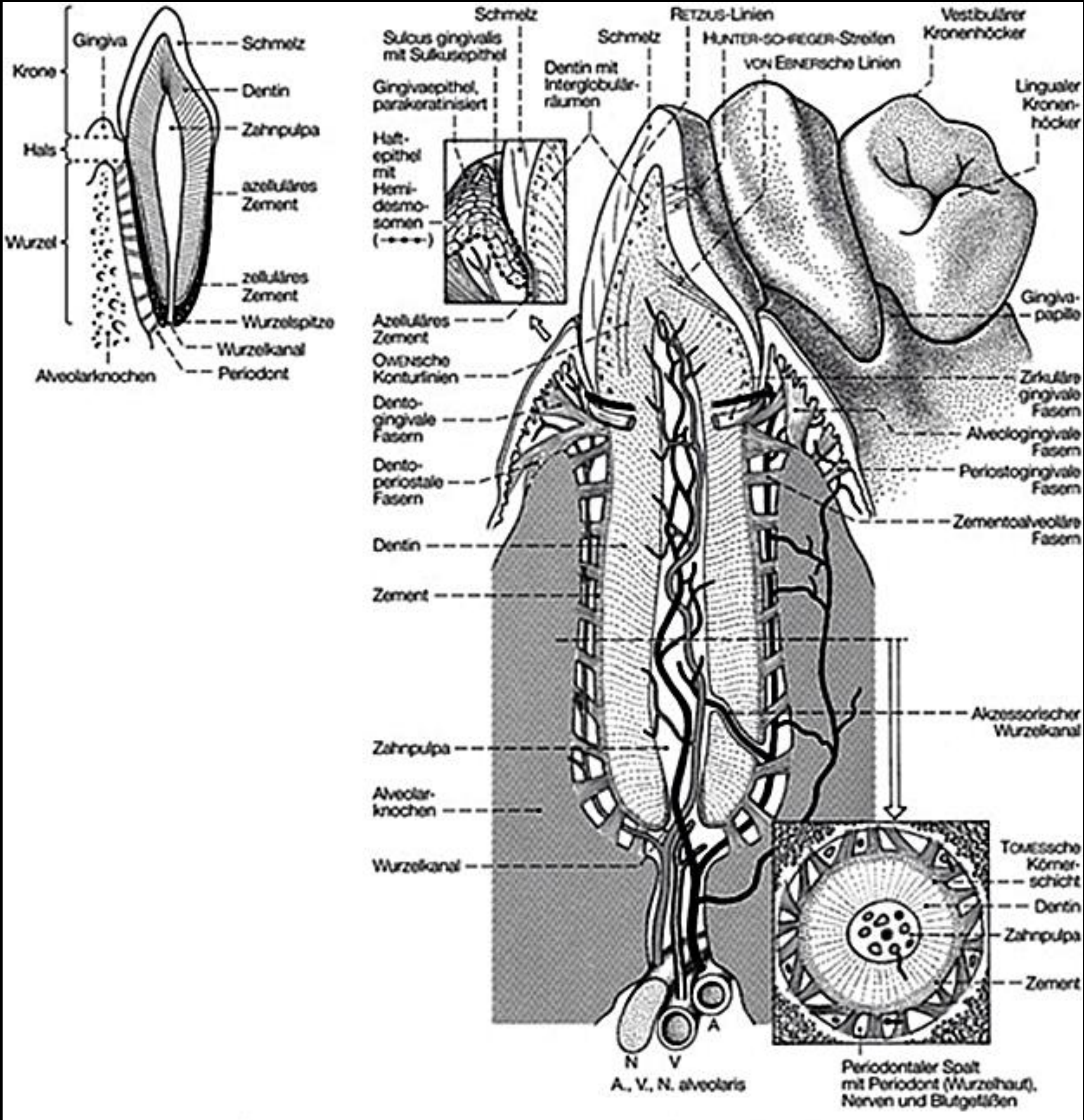
Cement / substantia ossea

Covers the dentin of the root;

Formed by the cementoblasts; they are already surrounded by the matrix - cementocytes;

50% inorganic material - amorphous calcium phosphate, hydroxyapatite crystals;

50% organic material: collagen fibers;



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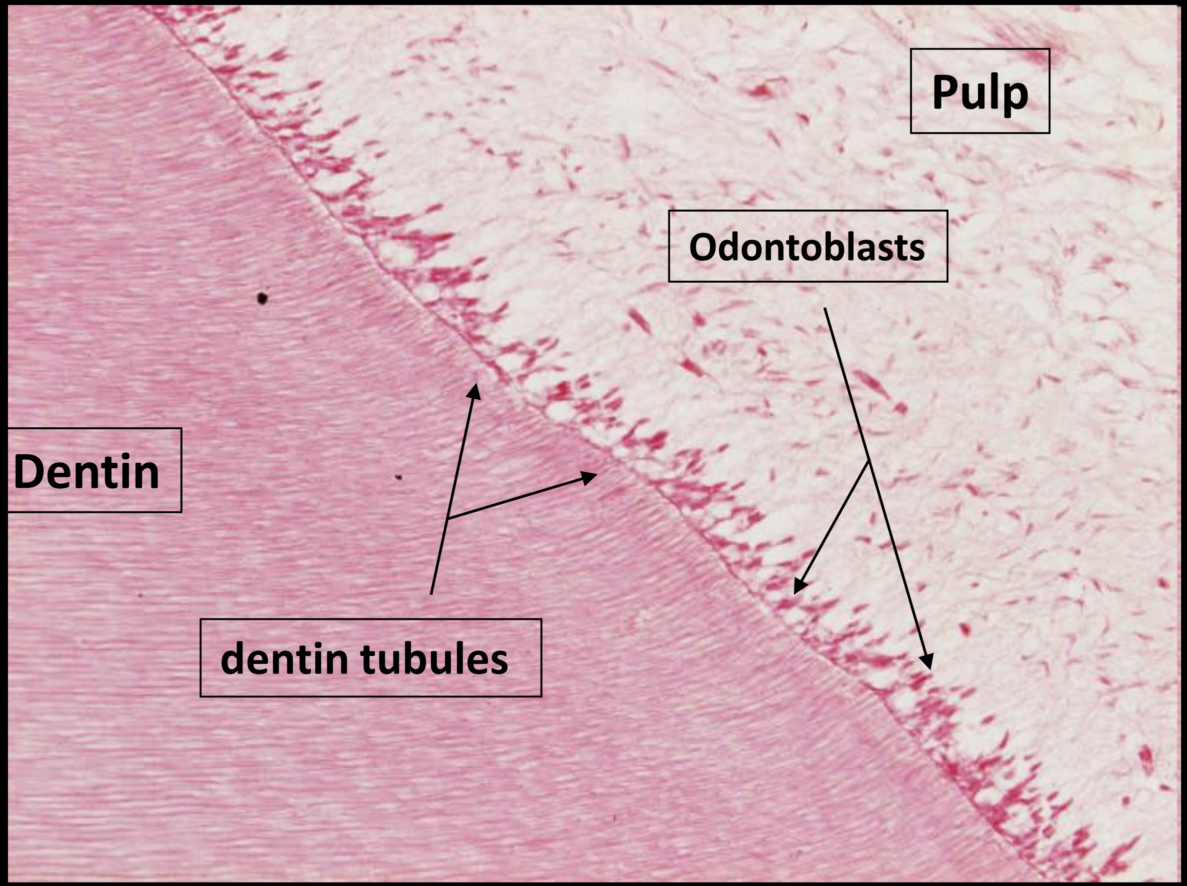
Dental pulp

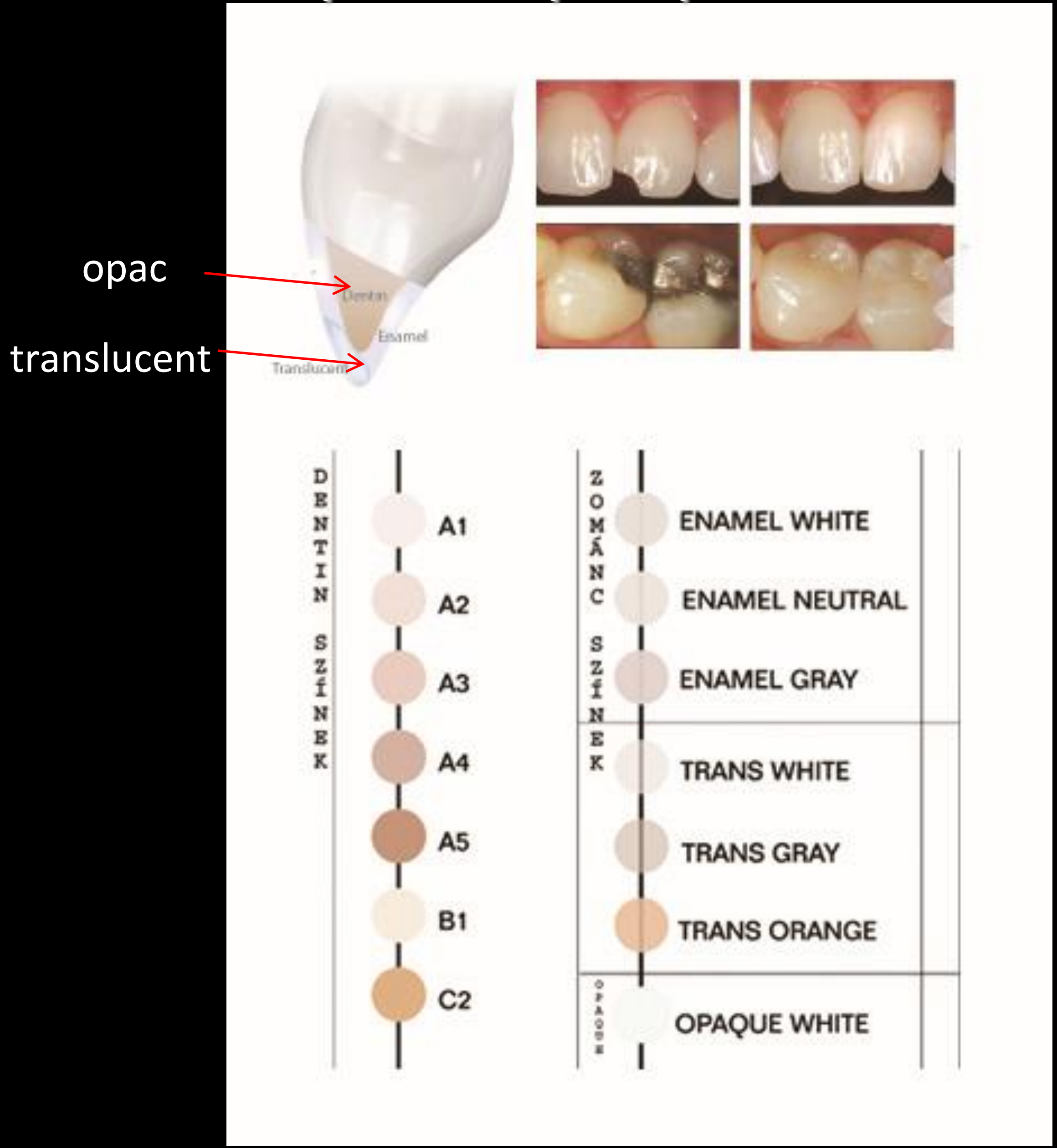
Loose connective tissue rich in blood vessels and nerves.

The dentin producing cells: odontoblasts

The Tomes fibers of the odontoblasts run into the dentinal tubules.

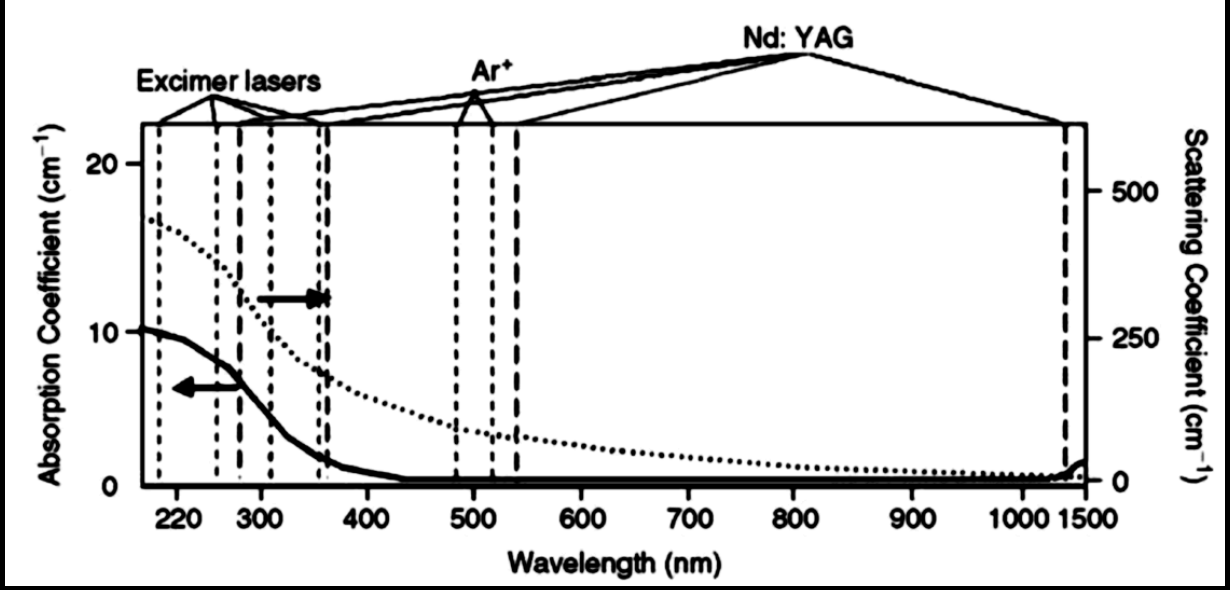


Optical properties: color of teeth



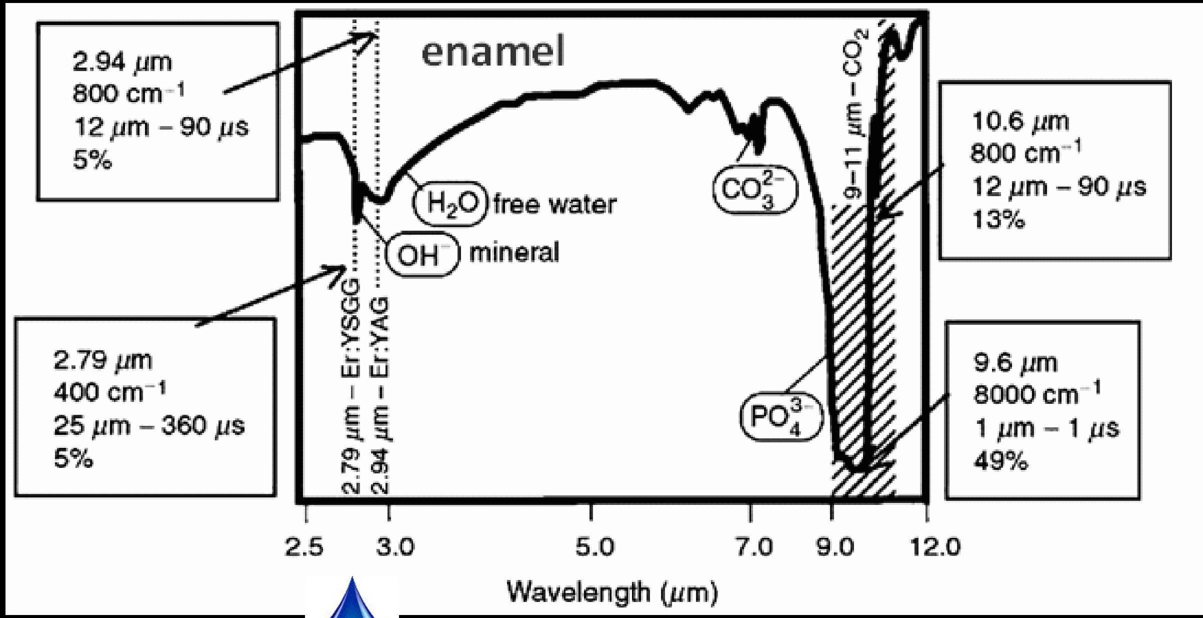
Optical properties: transmission, scattering, absorption

Enamel



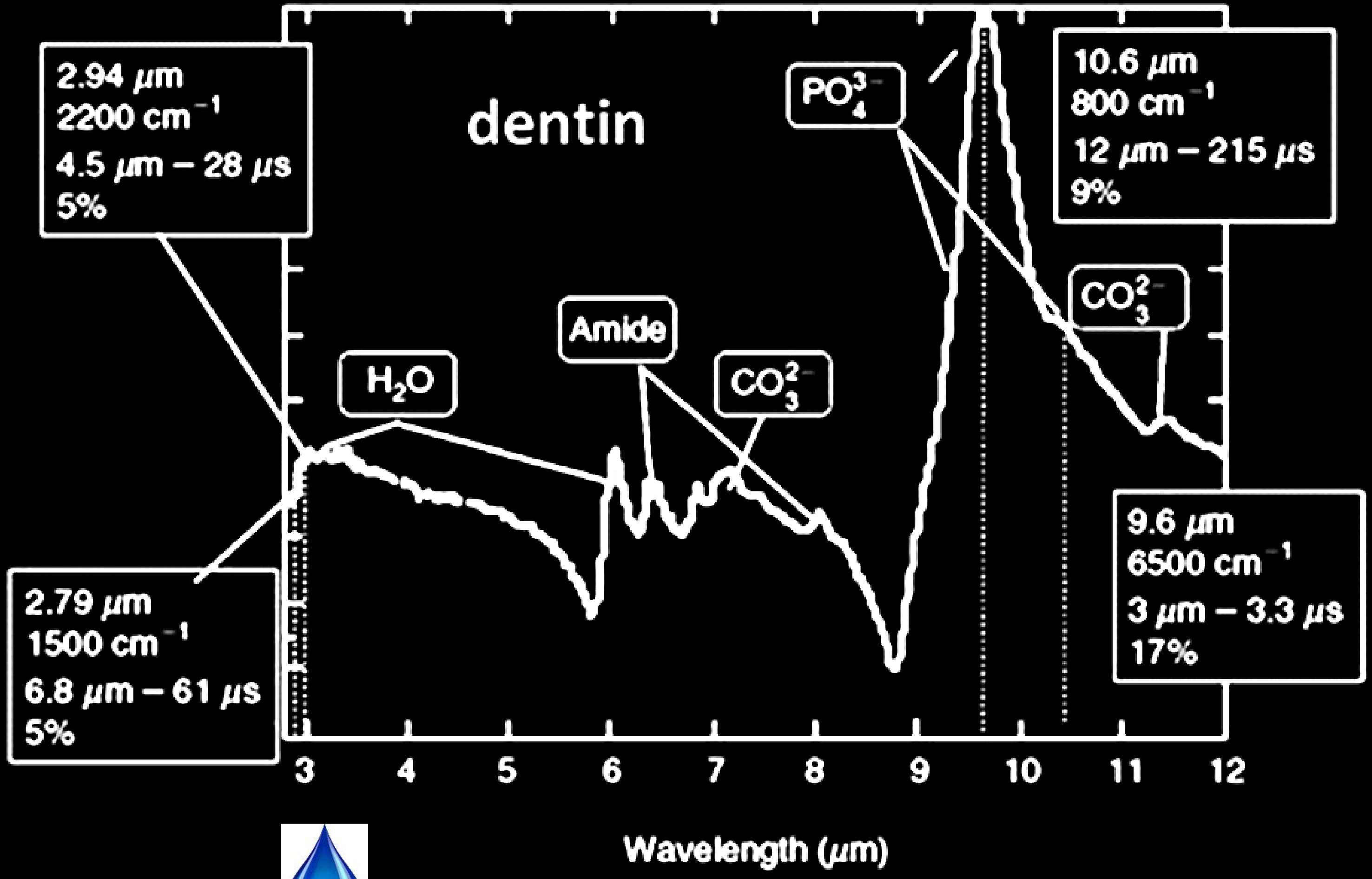
absorption spectrum of enamel in the VIS range

transmission spectra of enamel in the IR



Optical properties: transmission, scattering, absorption

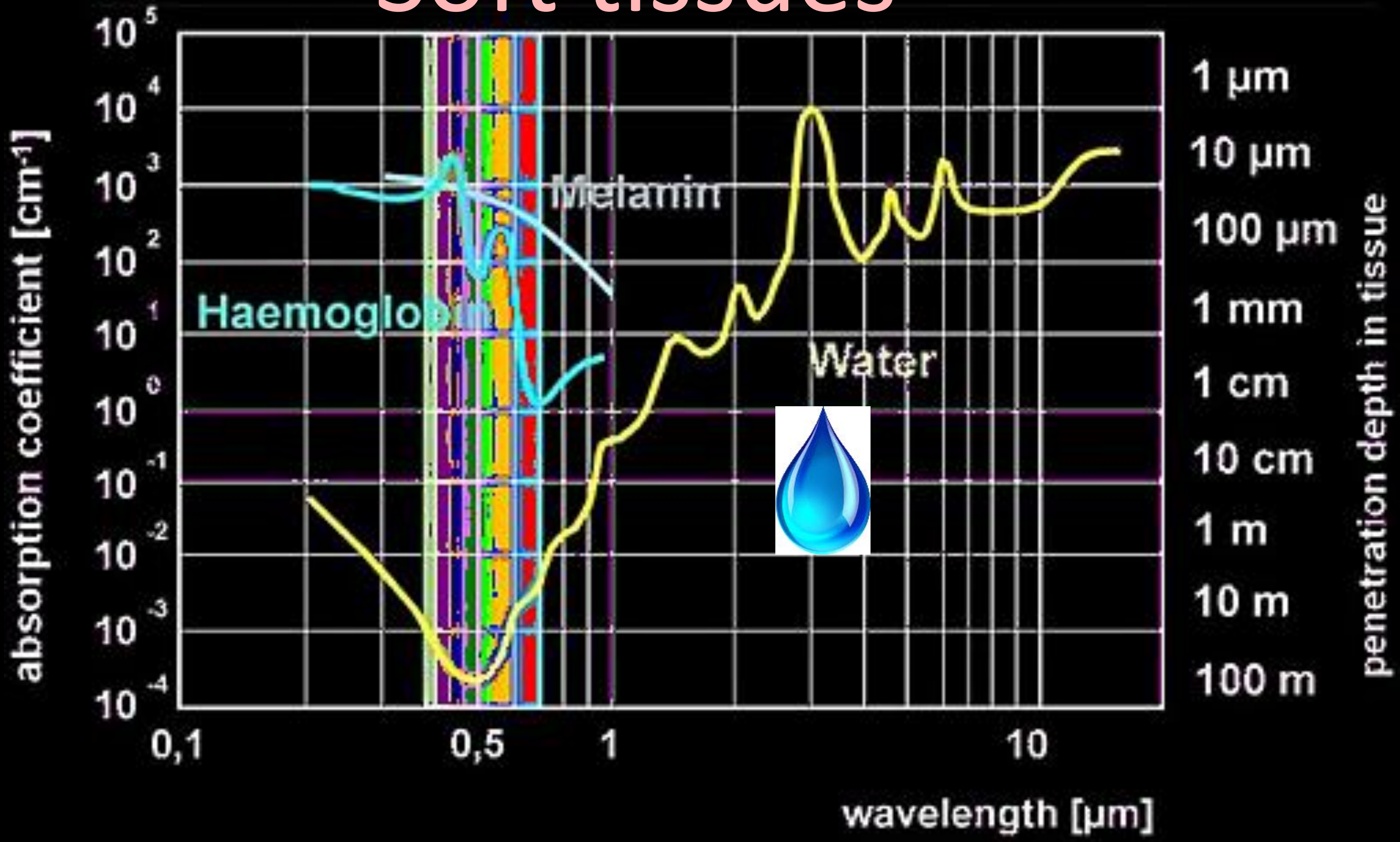
Dentin



Absorption spectrum of dentin in the IR

Optical properties: absorption spectra

Soft tissues



Laser processing of biological materials

- production of high energy particles,
  - hadron therapy
- drilling of teeth
- evaporation of hard tissues
- evaporation of soft tissues
  - laser surgery
- coagulation
- selective heat treatment
  - local heating of tumors

  treatment of skin deseases (e.g. psoriasis)

  treatment of allergic reactions of mucosa
- wound healing

Plasma formation
- generation of shock waves
- plasmachemical reactions

Evaporation
- drilling
- cutting

High temperature treatment

Heat treatment

- Stimulation without significant heating

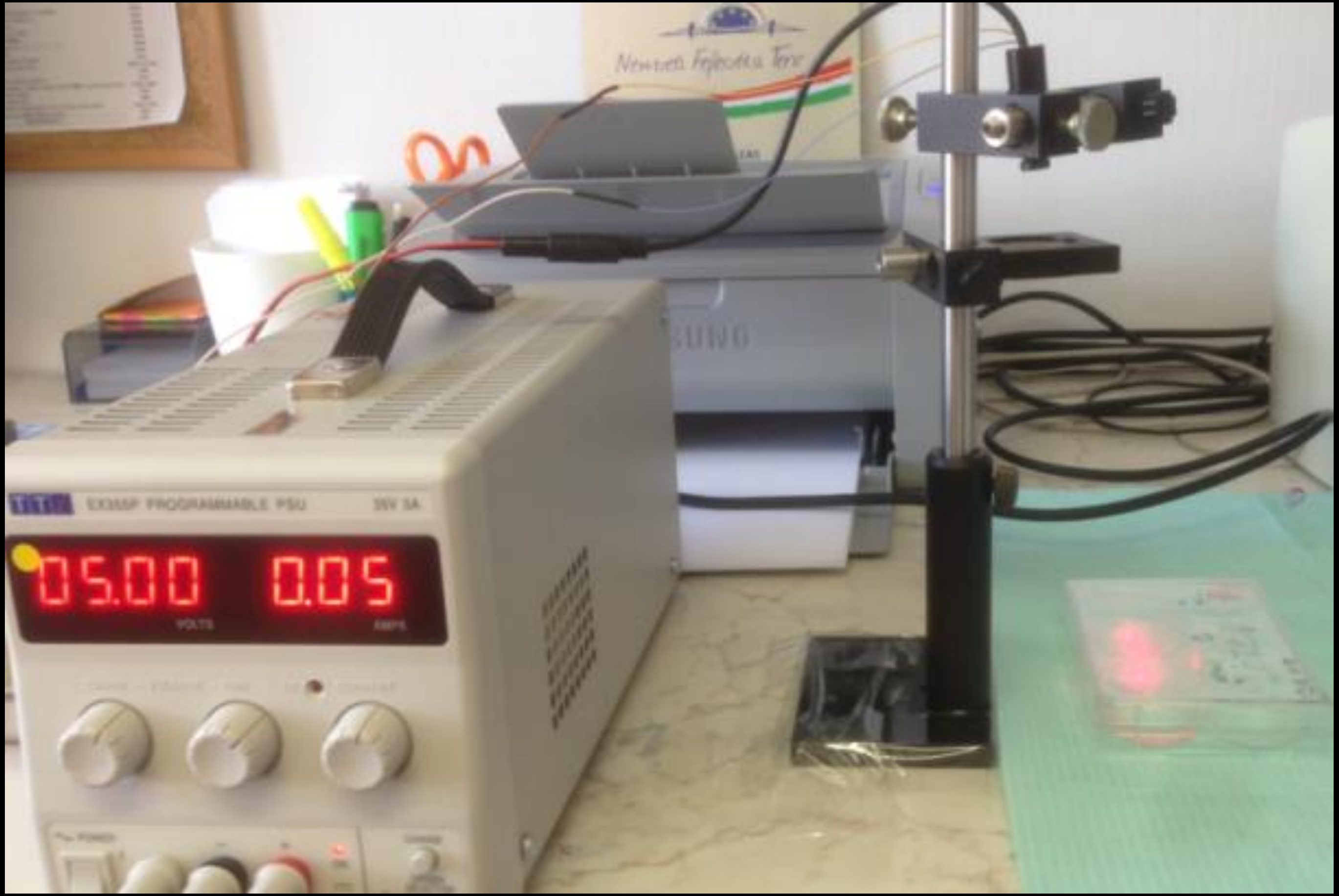
$$I = \frac{E}{A\ t}$$

Low-level laser therapy (LLLT): Ion lasers - Laser diodes red wavelengths

- Modestly effective, in relieving short-term pain
- The evidence for LLLT being useful in the treatment dentistry, and wound healing is unclear.
- Effects of LLLT appear to be limited to a specified set of wavelengths

Diode Laser on Healing of Tooth Extraction Socket:

Low-level laser therapy (LLLT):
Laser diode - cell culture experiment



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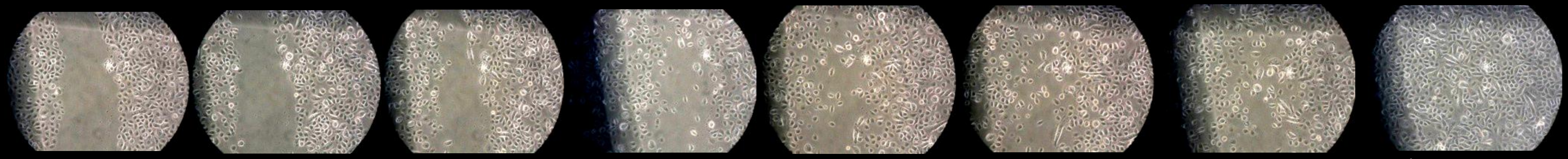
Low-level laser therapy (LLLT):

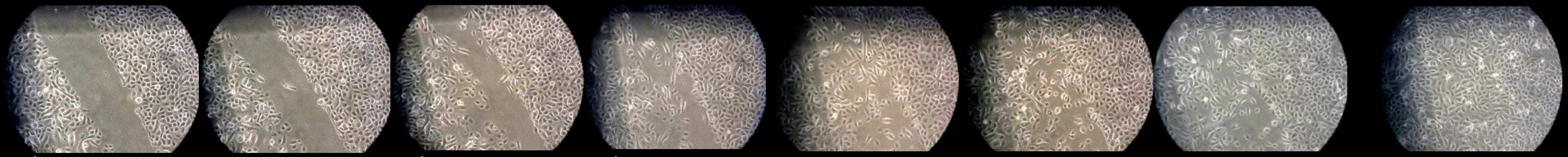
Laser diode - cell culture experiment

HUMAN EPITHEL CELLS



0.h. 1.h. 2.h. 3.h. 4.h. 5.h. 6.h. 24.h.

- Diode Laser: (λ=650 nm) Power: 20 mW 30 s illumination



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Tooth whitening CW ion / semiconductor lasers: Blue wavelengths

CO_2 Lasers

Active laser medium is CO_2 gas.
wavelength of 10,9 μm,

- Soft tissue applications

Frenectomy

Peri-Implantitis treatment

smile design

Little to no bleeding, swelling, post-operative pain
Less risk of infection: Quicker healing time

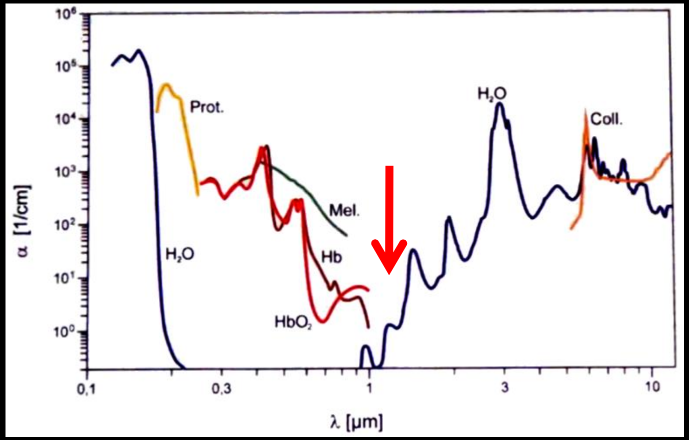
Solid State Lasers: Nd:YAG lasers Root canal treatment

Active laser medium is neodymium-doped yttrium aluminium garnet (Nd:Y3Al5O12).
wavelength of 1064 nm,

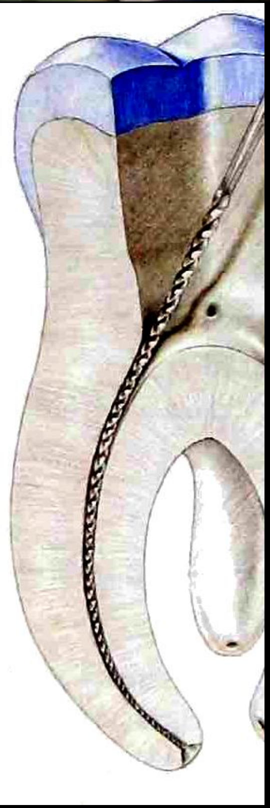
ENDODONTIC Treatments

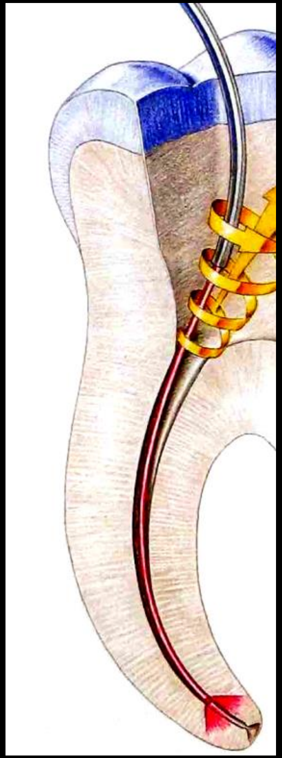
The laser disinfection complements conventional treatment.

- **The high energy laser light is capable to destroy bacteria in the root canal and in dentinal channels.**
- **Approx. 500 µm in depth of the dentin tubules is also effective in addition to the canal walls.**
- **Greater security can be the sterilized running inside the tooth root canal.**
- **Using the laser success, rate of endodontic treatments increases.**



Root canal treatment





Nd:YAG laser treated dentinal channels

Solid State Lasers: Er:YAG or Er,Cr:YSGG lasers

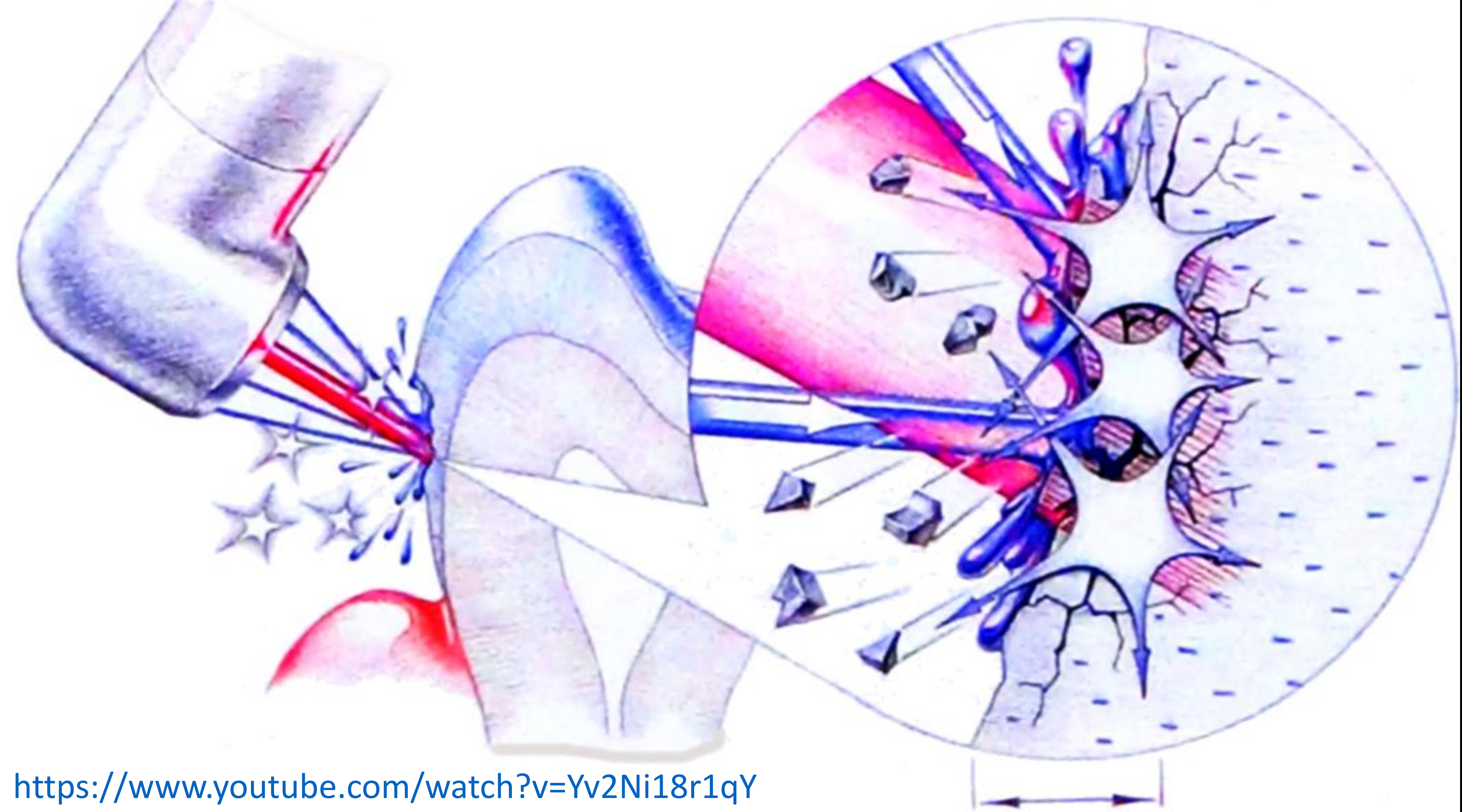
- Active laser medium is erbium-doped yttrium aluminium garnet (Er:Y3Al5O12).
- wavelength of 2940 nm,
- Soft tissue application
- like CO_2 lasers

- Periodontal pocket treatments

Solid State Lasers: Er:YAG or Er,Cr:YSGG lasers

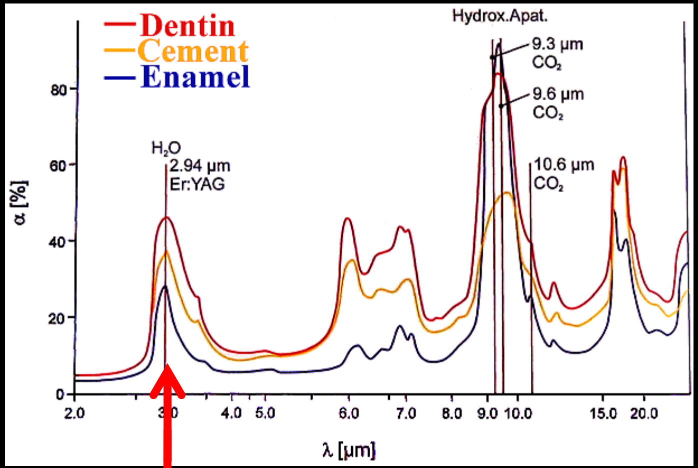
- Hard tissue application

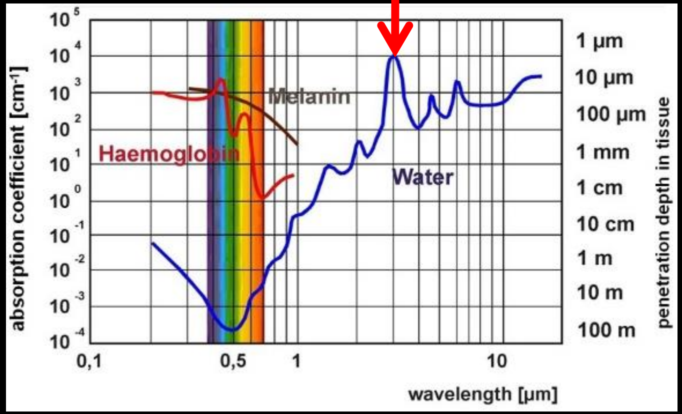
Er:YAG laser ablation of dental tissues

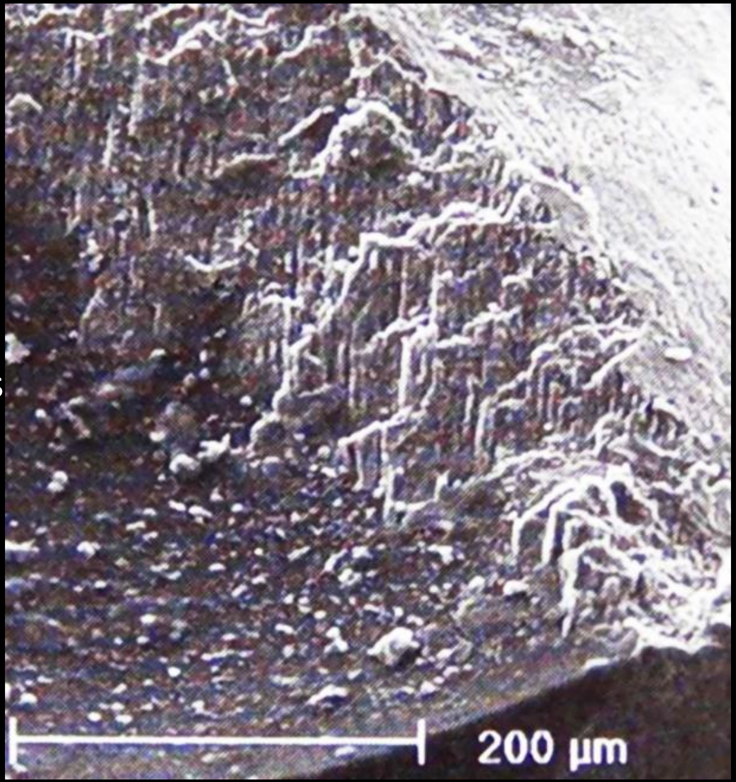


https://www.youtube.com/watch?v=Yv2Ni18r1qY

Extended fissure sealing





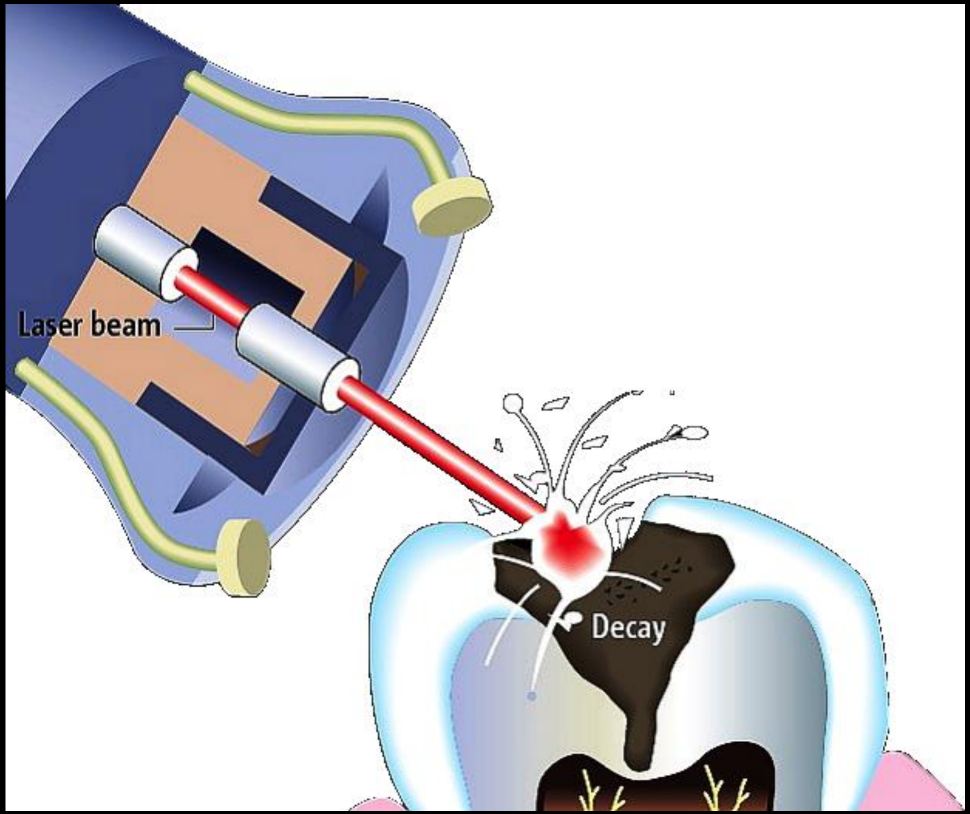


selective removal of water containing contanimations

- Roughening of enamel
  - it is applied to elicite acidic roughening.

Cavity preparation

- Dental Erbium YAG laser drills through photodistruption (crushing) effect.
- The short pulses absorbed by the water content of enamel and dentin.
- As water instantly boiled, its pressure mechanically break out of the hard tissue particles in the form of very small crystals.
- Minimal thermal effect on dentin.
- Selective removal of tooth decay.
- Removal of fillings.
  - It is not good for amalgam! Mercury gas forms.



Cavity preparation

- In most cases local anesthesia is not necessary because laser drilling is painless.

- There is no damage to the tooth by heat because the surrounding dental tissue do not have time to warm up because of short pulses.

- There is no vibration and vibration of the tooth in the skull, because the laser drill a tooth without touching.

- The formed cavities will be sterile, since the laser beam evaporates the bacteria from the cavity.

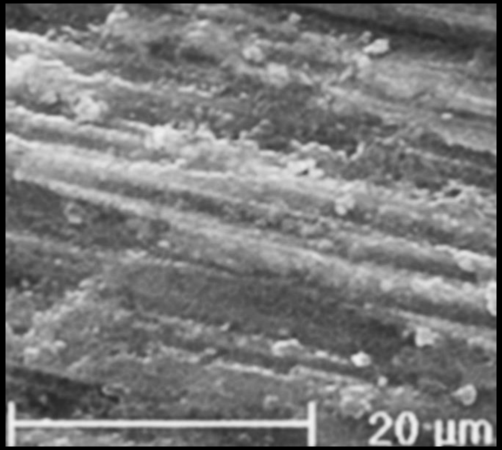
- The surface will be uneven, which provides better grip all adhesive filling methods, thus increasing traction is no longer necessary by etching with acid of the developed cavities.

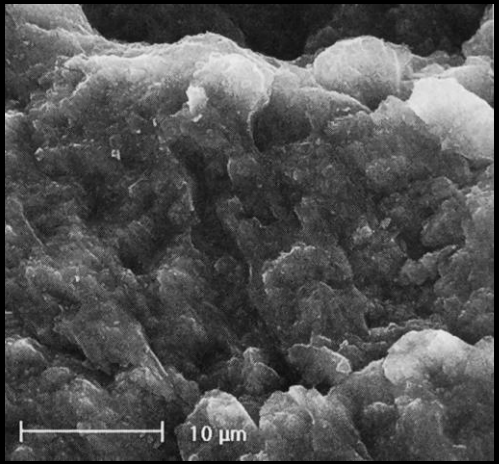
Cavity preparation

Mechanically drilled

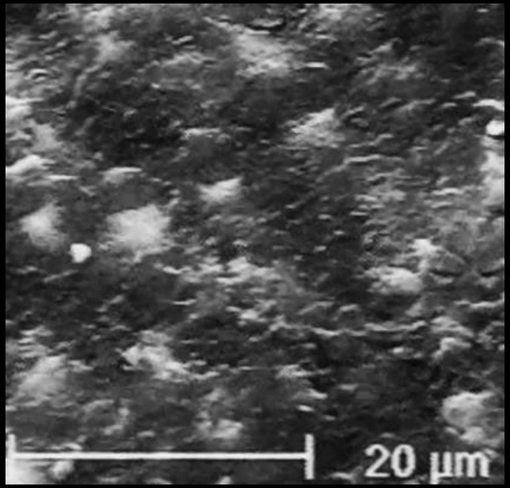
Laser ablated

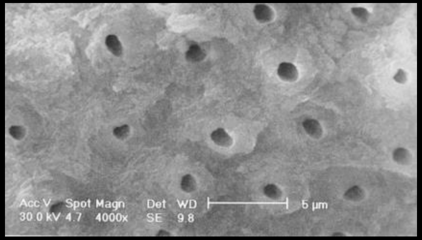
Enamel





Dentin



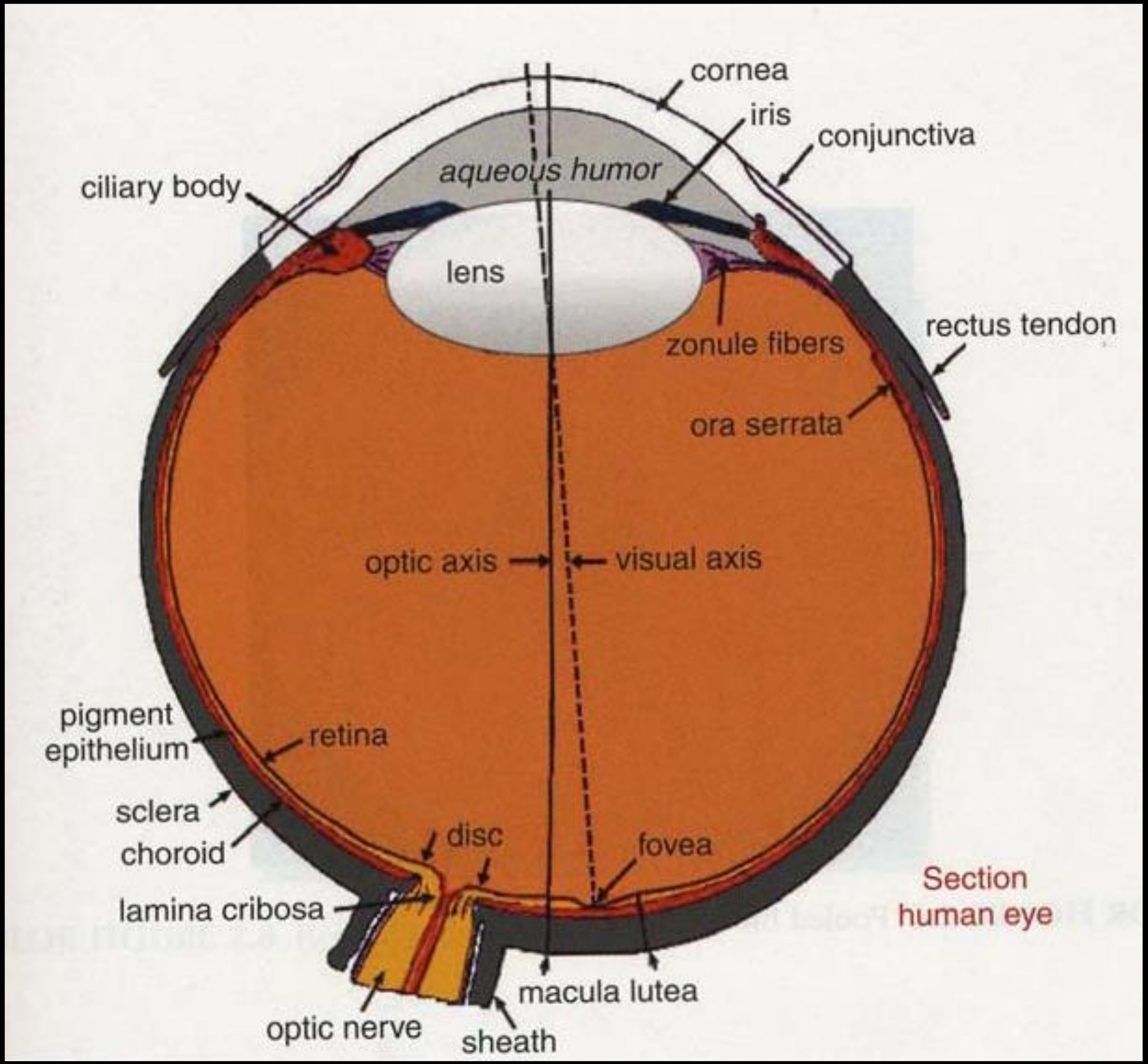


No smear layer!

Laser safety

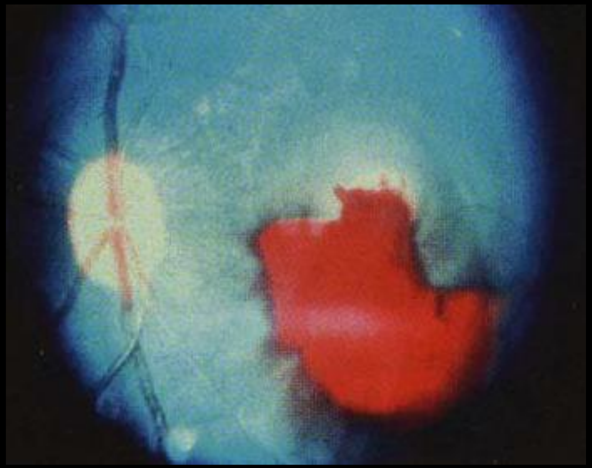
Laser safety

- Cornea, lens, and retina are susceptible to damage by laser light.
- Parallel laser light is focused by the lens onto the retina!
- The eye in essence intensifies light intensity, particularly the visible and the near-infrared wavelengths, in some cases as much as 100,000 times.

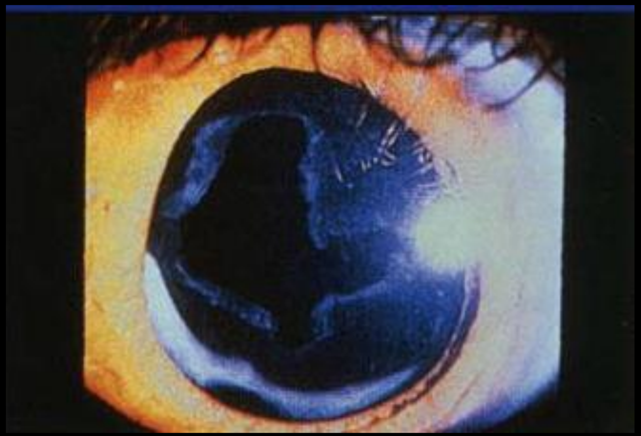


Eye injury by laser light

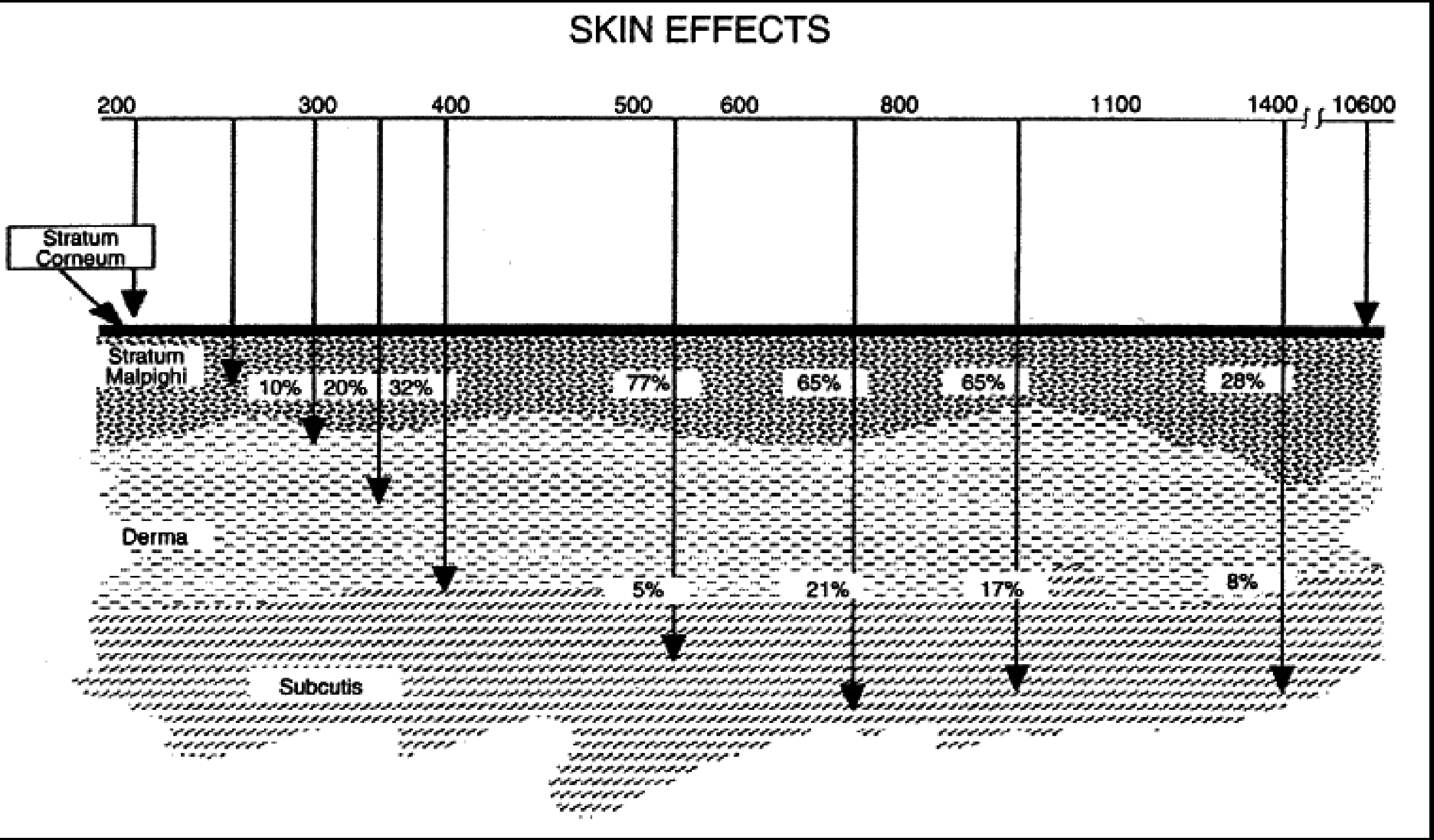
- **Symptoms of Exposure:** If the eye has been damaged by laser light the first symptoms can be a bright flash of light (if a visible wavelength) followed by watering of the eye, headache, and **floaters**.
- Floaters are actually dead cells that have detached from the retina and choroid.



- If the cornea has been damaged there will be a sensation of grittiness, as if sand were in the eye. In some cases there may be immediate pain at the site of exposure.



Skin transmission by wavelength

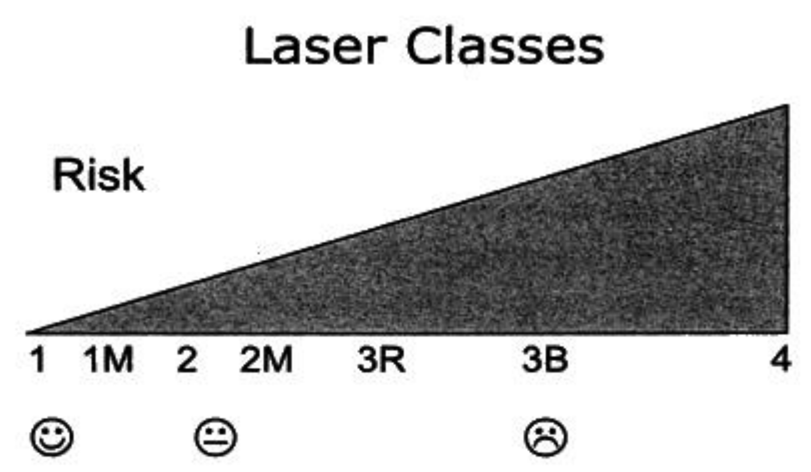


Hazards caused by various light wavelengths

Wavelength Range	Effect on Eye	Effect on Skin
Ultraviolet C 200–280 nm	Photokeratitis	Erthema (sunburn) Skin cancer Accelerated skin aging
Ultraviolet B 280–315 nm	Photokeratitis	Increased pigmentation
Ultraviolet A 315–400 nm	Photochemical cataract	Pigment darkening Skin burn
Visible 400–700 nm	Photochemical Thermal retinal injury	Pigment darkening Skin burn
Near-infrared 700–1,400 nm	Cataract and retinal burn	Skin burn
Mid-infrared 1,400–3,000 nm	Corneal burn Aqueous flare, cataract	Skin burn
Far-infrared 3,000–100,000 nm	Corneal burn	Skin burn

Laser hazard classification

Class	Basis for Classification
Class 1: Safe Visible and nonvisible	Lasers that are safe under reasonably foreseeable conditions of operation; generally a product that contains a higher-class laser system but access to the beam is controlled by engineering means.
Class 2: Low power Visible only	For CW lasers, protection of the eyes is normally provided by the natural aversion response, including the blink reflex, which takes approximately 0.25 sec. (These lasers are not *intrinsically* safe.) AEL = 1 mW for a CW laser.
Class 1M: Safe without viewing aids 302.5 to 4000 nm	Safe under reasonably foreseeable conditions of operation. Beams are either highly divergent or collimated but with a large diameter. May be hazardous if user employs optics within the beam.
Class 2M: Safe without viewing aids Visible only	Protection of the eyes is normally provided by the natural aversion response, including the blink reflex, which takes approximately 0.25 sec. Beams are either highly divergent or collimated but with a large diameter. May be hazardous if user employs optics within the beam.
Class 3R: Low and medium power 302.5 nm to 1 mm	Risk of injury is greater than for the lower classes but not as high as for class 3B. Up to 5 times the AEL for class 1 or class 2.
Class 3B: Medium and high power Visible and nonvisible	Direct intrabeam viewing of these devices is always hazardous. Viewing diffuse reflections is normally safe provided the eye is no closer than 13 cm from the diffusing surface and the exposure duration is less than 10 sec. AEL = 500 mW for a CW laser
Class 4: High power Visible and nonvisible	Direct intrabeam viewing is hazardous. Specular and diffuse reflections are hazardous. Eye, skin and fire hazard. Treat class 4 lasers with caution.



How to protect?

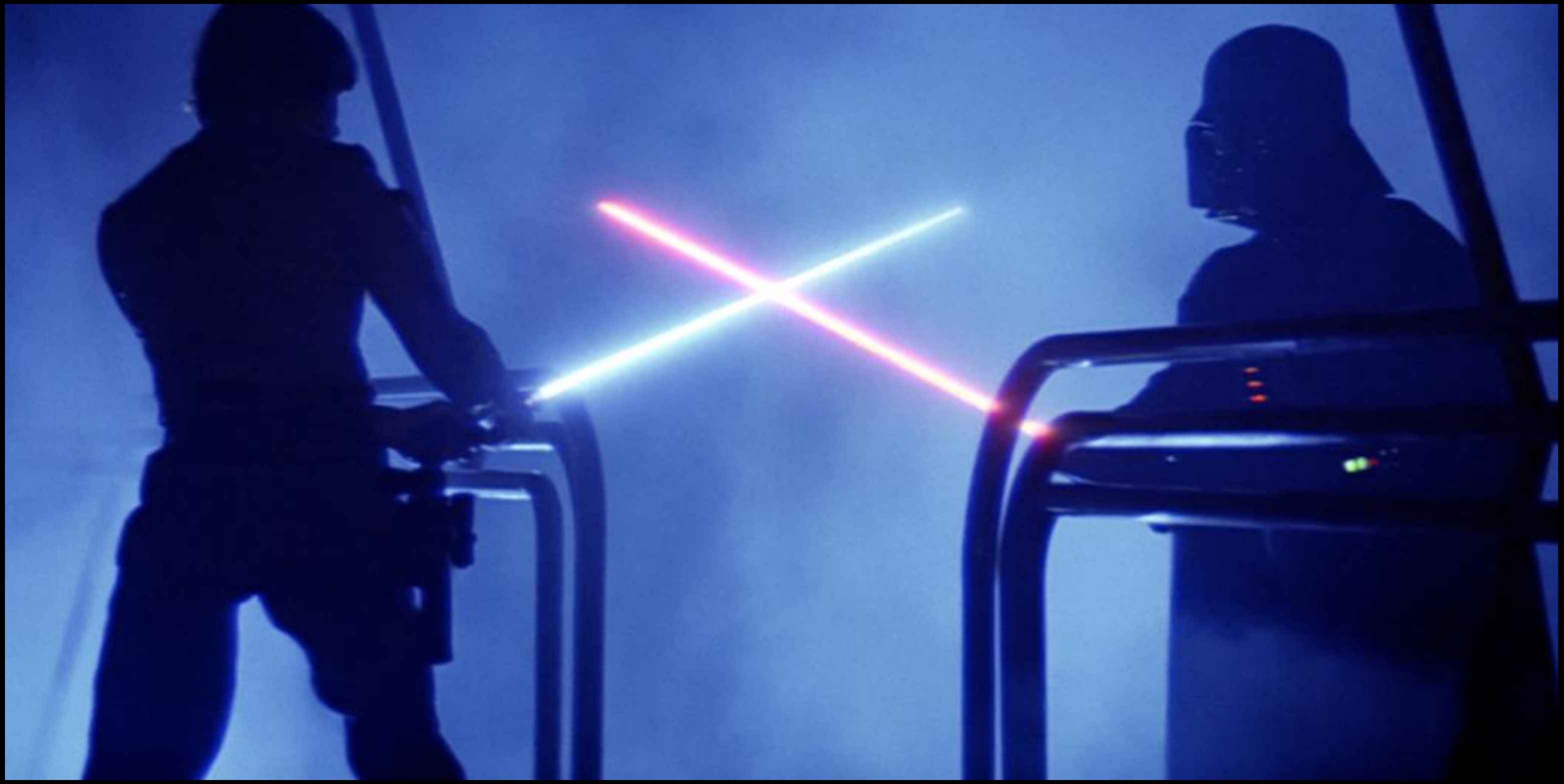
- Take seriously the labels:

How to protect?

- Do not look to laser light directly!
- Use the appropriate protecting glasses for your patient and YOURSELF!

How to protect?

- Cover the skin with clothes:



SUMMARY: examples for Laser applications in dentistry

prevention

- treatment of sensitivity by closing tubules
- supplementing fluoride treatment
- preventing tooth decay (UV light germicidal effect)

diagnosis

- caries detection by photoluminescence

science

- implant surfaces
- interferometry
- holography, etc

therapy

- teeth whitening by oxidative processes (promoting lower drug concentrations, shorter treatment time and higher sufficiency)
- tooth drilling
- root Canal Treatment
- fillings removal
- treatment of oral and periodontal diseases
- laser surgery
- photodynamic therapy
- soft laser therapy: stimulation of wound healing and periodontitis
- and many more...

Thank you for your attention!