SUMMARY OF THE COURSE

in master's programme Biomedical Engineering
Course 134.154 Laser in Physics, Chemistry, Biology and Medicine

Old exam questions

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Contents

1 Exam

1. **Which of the Einstein Coefficients of the Laser Medium shown above have been set different from zero in the simulation leading to the result?**
   Which ones have to be set to non-zero to obtain a real laser medium "ready to go" for amplification?

   a) B21, A21
   b) A23, A24; B34, A34; A41

2. **Suppose we have a light with the wavelength lambda = 548,42 nm. What is the frequency ot the corresponding electromagnetic field? (With units!) (Result: Value and units in the form: number+unit without blank)**

   $549,2025 \cdot 10^{12}\,Hz$

   $$f = \frac{c}{\lambda}$$
   $$f = \frac{2,99 \cdot 10^8}{548,42 \cdot 10^{-9}} = \underline{\underline{5,466 \cdot 10^{14}}} Hz$$

f	frequency	[Hz]
c	speed of light	[m/s]
λ	wavelength	[m]

3. **Explain why a resonator is needed for realizing a laser. How does the spatial electric field distribution in the laser resonator look like? Explain the intensity distribution in stable TEM-modes.**

   A resonator is needed to focus the radiation field energy of the system to only a few modes. It has to have positive feedback for a few modes and properties such that all the other modes will get attenuated/expelled after a few reflections. The best TEM mode is the TEM_{00} mode. This means that in the plane normal to the direction of propagation of the wave there are no nodes in the x-direction and no nodes in the y-direction This leads to a Gaussian intensity profile.

4. **In order to treat the interaction of light with "matter", in many cases the so-called semi-classical approach is used. Check the correct statements!**

   a) In this treatment the solution is always obtained via solving the time dependent Schrödinger equation.
   b) A two-level energy scheme can be sufficient to describe "matter" (in this context)
   c) A three-level energy scheme is usually sufficient to describe the general features of laser-"matter" interaction

5. **Light interacts with a medium, which at the beginning is found in its lower state (the electrons). The wavelength of the light is in resonance with an oscillating dipole due to levels i,k of the medium. Amplification/Absorption of the light can be described by the following equation.**
   $\alpha(v) = [n_i - n_k] \cdot \left(\frac{\hbar\omega_{ik}}{c} B_{ik}\right)$
   Consequently, the Intensity of a laser beam travelling in the medium in the z-direction is given by
   $I(z) = I_0 e^{-\alpha z}$
   i,k stands for lower (i) and upper (k) level of the medium. Which statements below are correct?

   a) Lets assume that for a specific medium the lower level i is identical with the ground state. In this case we can easily achieve amplification of the light.

   b) Absorption can go to zero. In this case the medium becomes transparent for light of this wavelength.

6. **Explain the formula (equations)** $\alpha(v) = [n_i - n_k] \cdot \left(\frac{\hbar\omega_{ik}}{c} B_{ik}\right)$ **and** $I(z) = I_0 e^{-\alpha z}$ **In the Question "Amplification" with a few sentences; particularly, explain the meaning of the symbols in the equation.**

$\alpha(v)$	Absorption/Amplification Coefficient
n_i, n_k	population numbers of the two states i and k between which the absorption can happen.
$\hbar = \frac{h}{2\pi}$	where h is the Planck'sches Wirkungsquantum
c	Speed of light
ω_{ik}	oscillation frequency of the theoretical dipole
B_{ik}	Einstein-coefficient for induced absorption (emission)
$I(z)$	Beer's law of absorption
I_0	Initial Intensity
z	the length of the matter
α	extinction coefficient

The absorption/amplification coefficient α depends on the frequency of the light wave. It also depends on the probability for absorption which is proportional to the Einstein-coefficient B_{ik}.
α can be positive of negative, depending on the medium. Negative α would give a positive exponent in the Beer's law and would thus lead to increase of the intensity.
The Beer's law describes the attenuation (or also amplification) in a medium. It depends on the initial intensity. I_0, on the position where the attenuation/amplification is determined and on the attenuation/amplification coefficient.

7. **What is a plane wave? Give a mathematical description (formula, equation) of a one-dimensional plane wave. Explain all used symbols.**

A wave or field constant over any plane that is perpendicular to a fixed direction in space.

$A(z,t) = A0 \cdot \cos(\omega t - kz)$

$A0$	Maximal amplitude	[]
ω	Frequency	[Hz]
t	Time	[s]
k	Wave number	[1/m]
z	Propagation in space	[m]

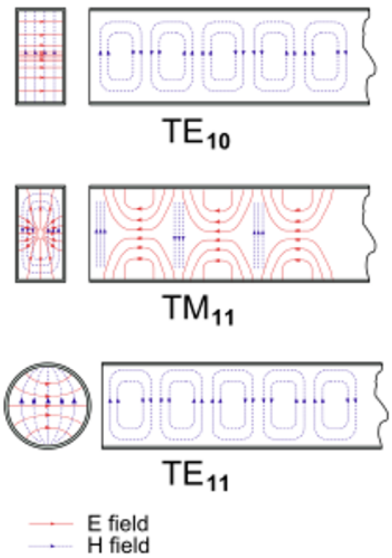
8. **Which of the following statements are correct a)-f)**
On a separate sheet of paper back of (Fragebogen, 1st page) explain what we understand under transversal and longitudinal modes of a laser.

a) Spontaneous emission is an essential step in the operation of any laser.

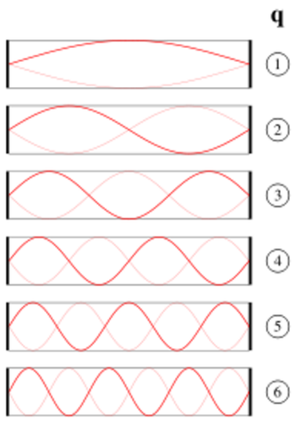
b) Amplification of light is based on stimulated emission between two energy levels of an atomistic system.

c) The process of stimulated emission produces emission of coherence light.

A transverse mode of electromagnetic radiation is a particular electromagnetic field pattern of radiation measured in a plane perpendicular (i.e., transverse) to the propagation direction of the beam



A longitudinal mode of a resonant cavity is a particular standing wave pattern formed by waves confined in the cavity. The longitudinal modes correspond to the wavelengths of the wave which are reinforced by constructive interference after many reflections from the cavity's reflecting surfaces. All other wavelengths are suppressed by destructive interference.



9. In the following a short excerpt from a laser text book. Which one is without errors? (only one answer possible!)

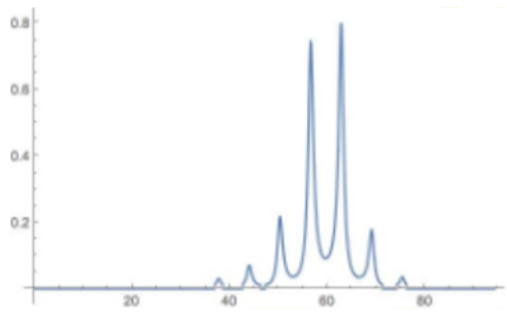
The constant factor B_{12} the Einstein coefficient of induced absorption, depends on the electronic structure of an atom, ii.e. on its electronic wave functions in two levels 1 and 2. Each absorbed photon of energy hv decreases the number of photons in one mode of the radiation field by one.
The radiation field can also induce molecules in the excited stat E_2 to make a transition to the lower state E_1 with simultaneous of a photon of energy hv. This process is called induced (or stimulated) emission. The induces photon of energy hv is emitted into the same mode (frequency and direction) that caused the emission.

10. One of the most important parameters of the light produced by a laser concerns its wavelength spectrum. In the following several statements are listed. Which ones are correct.
For at least for one of the figures fill in the physical quantity shown on the x- and y-axis (not only some symbol, but explain the physical value).
(the numbers shown for both the aces are arbitrary numbers!!)

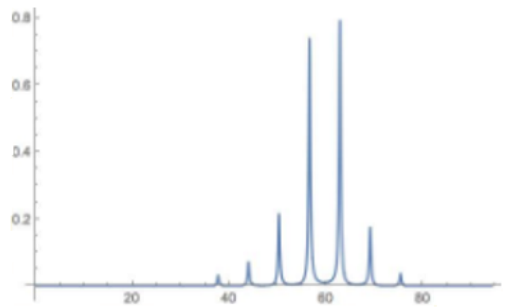
a) The wavelength spectrum of a laser depends on the frequency depend amplification of the amplitude of the amplifier medium and the resonator parameters.

b) A laser is never monochromatic in that sense, that the emitted light wave can be described ba a sine-wave with exactly one frequency.

c) Does the following figure display a correct frequency (wavelength) spectrum of a laser? What is the meaning of both axes (Since in should represent the frequency (wavelength) spectrum of the light leaving the laser it does not matter whether the form of the spectrums is correct for the meaning of the axes)



d) Does the following figure display a correct frequency (wavelength) spectrum of a laser? What is the meaning of both axes (Since in should represent the frequency (wavelength) spectrum of the light leaving the laser it does not matter whether the form of the spectrums is correct for the meaning of the axes)



11. In the following set of statements, which are correct?

a) produces an exponentially decaying light field with a typical half-width τ

b) The emission of many spontaneously emitted photons produces light statistically distributed in all directions.

c) is the origin of basically any light in nature

12. In the following statements concerning rate equations, check which are correct and if an equation is displayed, check which one describes an correct rate equation.

a) The rate equations yield the probability to find the system in a specific energy state as a function of time.

b) $$\frac{d}{dt}n_n(t) = \sum_{m\neq n} n_m(t)\cdot I\cdot B_{mn} - n_n(t)\sum_{m\neq n} I\cdot B_{mn} - n_n(t)\sum_{m[E_m<E_n]} A_{mn}$$

$$\frac{d}{dt}n_n(t) = -n_n(t)\sum_{m[E_m<E_n]} A_{mn}$$

13. The most fundamental description of light is:

The electric field

2 Exam

1. **Suppose that a laser dye allows amplification of light between 520 and 580 nm. How many laser modes can oscillate (in principle), if no mode competition takes place and the resonator has a length of 0.5 m. (velocity of light $c = 3 \cdot 10^8\, m/s$)**

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   $$N_m = \frac{n \cdot c}{2 \cdot l} \longrightarrow N_m = \frac{2 \cdot l}{\lambda_1} - \frac{2 \cdot l}{\lambda_2}$$
   $$N_m = \frac{2 \cdot 0,5}{520 \cdot 10^{-9}} - \frac{2 \cdot 0,5}{580 \cdot 10^{-9}} = \underline{\underline{198939}}$$

N_m	Number of modes	[]
n		[]
c	speed of light	[m/s]
l	resonator length	[m]
λ	wave length	[m]

2. **Contrary to radiations sources with broad emission continua used in conventional spectroscopy, tunable lasers offer radiation sources in the spectral range from the UV of IR with extremely narrow bandwidths and with spectral power densities that may exceed those of incoherent light sources by many orders of magnitude**
   Therefore, the advantages of absorption spectroscopy with tunable lasers may be summarized as follows (Which text (only one!) is correct)

   a) No monochromator is needed, since the absorption coefficient and its frequency dependence can be directly measured form the difference between the intensities of the reference (incoming) beam and the transmitted beam. The spectral resolution is higher than in conventional spectroscopy. With tunable single-mode lasers it is only limited by the line-widths of the absorbing molecular transitions. Using Doppler-free techniques, even sub-Doppler resolution can be achieved.

   b) Because of the high spectral density of many lasers, the detector noise is generally negligible. Intensity fluctations of laser, which limit the detection sensitivity, may essentially be suppressed by intensity stabilization. This furthermore increases the signal-to-noise ratio and therefore enhance the sensitivity.

3. **Excimer Laser**

   a) The excimer laser is a pulsed laser

   b) The excimer laser is a gas laser

4. **Check below the correct answers concerning Absorption Spectroscopy as compared to Laser induced Fluorescence Spectroscopy.**

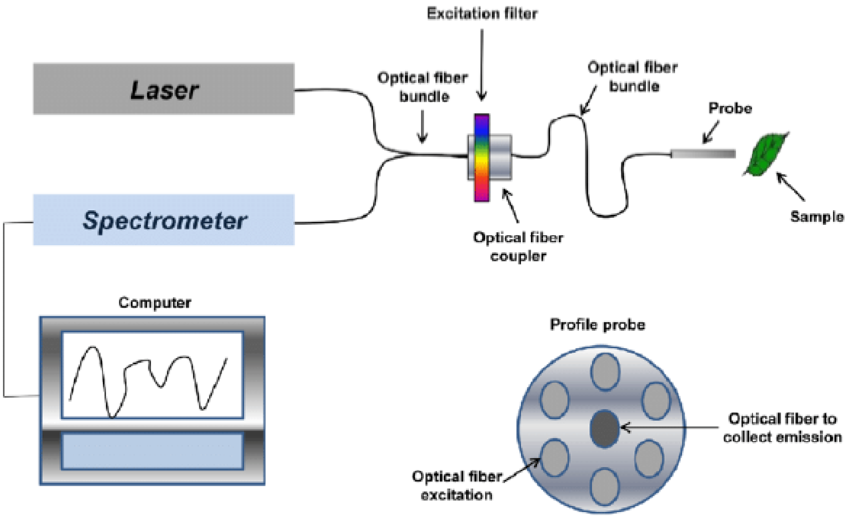
   a) LIF is more sensitive than AS

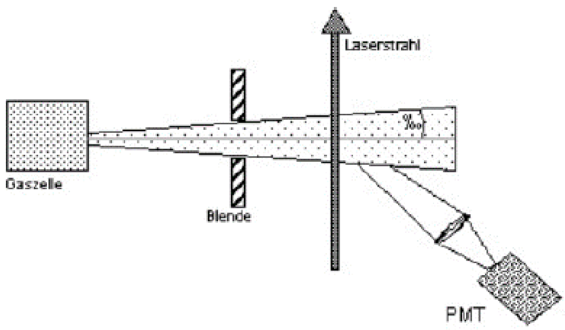
   b) AS and LIF can be performed with pulsed and C.W. lasers as well

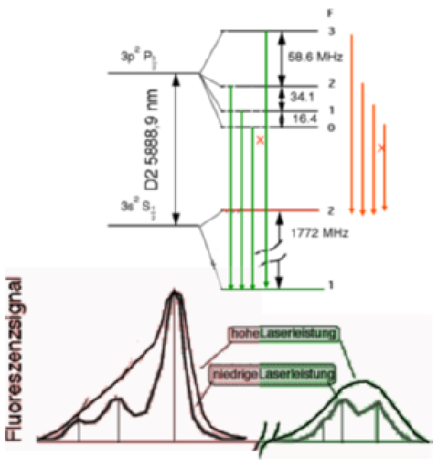
   c) in LIF, in general, the detected light is much broader (frequency spectrum) than the laser light

5. **Sketch the possible LIF experiment explaining all components to the sketch and explain the resulting measured data (also in a figure).**

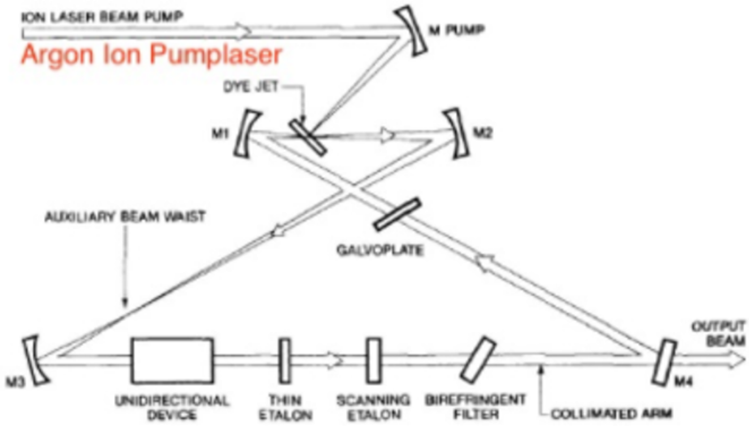
   Laser Induced Fluorescence is a spectroscopic method in which an atom or molecules is excited to higher energy level by the absorption of laser light followed by spontaneous emission of light.
   Selection of wavelength at which the selected intel of observation has its largest cross-section. It is 3 orders of magnitude better than the UV absorbance spectroscopy.

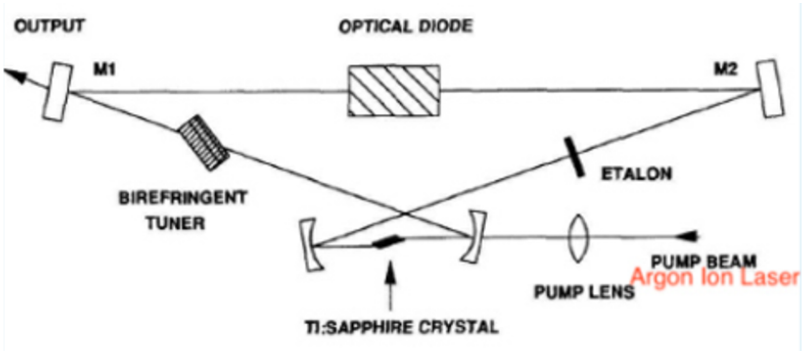






6. **In the following different tunable lasers schemes are shown. Which ones can operate in single mode operation.**

a) 

b) 

7. **How would you define Mode Competition?**

Modes with low losses use up all the potential for amplification and thus cause modes with higher losses to fall below the threshold for lasing.

8. **Ring lasers are often used instead of linear Laser resonators. Select the correct statements below:**

   a) In most cases ring lasers are used to realize single mode lasers
   b) The mode competition in a ring laser is more efficient than in a linear cavity.
   c) The mode spacing in a linear laser, as well in a ring laser is c/(2L)

3 Exam

1. **For warm-up check in the Antwortbogen, witch "items" are required for producing ultra-short-laser-radiation.**
   The (separately) describe the principle of an ultra-short-laser system and what you need for realising a ultra-short-laser system. (Sketch!)

   "Items":
   Short light pulse needs a high number of interfering modes and/or a wide laser gain profile.

   Active: shutter in resonator closes roughly in same frequency as mode spacing of resonator. Modulation frequency and its harmonics are phase-locked.

   Passive: non-linear absorber (e.g. dye) inserted into the resonator. Works as an absorber at low laser powers.

   Self phase modulation: in dispersive media the pulse is delayed, broadened and a frequency chirp is imprinted. Send pulse through two parallel gratings to compensate for the widening through different optical path-lengths for different wavelengths.

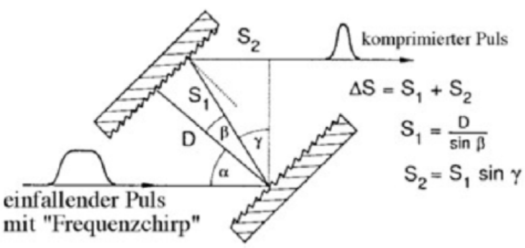
   Other way to compensate for Self phase modulation: Chirped mirrors Different spectral components are reflected in different depths of the mirror causing frequency dependent group-speed delay.

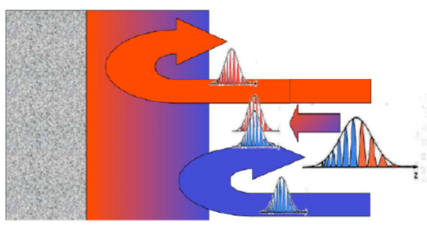
   Principle:

   a) Laser emission in the range of femtoseconds to ten picoseconds.
   b) The first step in generating ultrashort pulses is to exploit the mode structure of the laser. Due to the molecular nature of the active medium, the gain profile of most lasers will be inhomogeneously broadened. Accordingly, a large number of modes will generally oscillate

   Components:

   a) Pump laser of population inversion media
   b) Self-phase modulation
   c) Mode locking
   d) Laser resonator





2. **In particular, also comment on the formula shown, which gives the output electric field of an ultra-short laser oscillator (make a plot, pulse length etc.**

$$E_{aus} = E_0 e^{i2\pi v_0 t} \frac{\sin\left(\Delta v_{Mode} N t\right)/2}{\sin\left(\Delta v_{Mode} t\right)/2}$$

   a) pump laser for population inversion of media

   b) self phase modulation

   c) mode locking

   d) laser resonator

3. **Read the following 4 paragraphs form a "laser in medicine" book. On a separate sheet comment on the text, in particular give reasons for the undefined sentences.**

   Dermatology is one of the few medical disciplines where biostimulative effects of laser radiation have been reported. Positive simulation on wound healing is one of the current topics of controversy. A considerable number of papers has been published, but most of the results could not be reproduced, and initial claims could thus not be verified. Moreover, the principle mechanisms of biostimulation have not yet been understood. In general, one should be very careful when using laser radiation for such purposes, especially when applying so-called "soft-lasers" with extremely low output powers which most probably doe not evoke any effect at all other than additional expenses according ot Alora and Andersn (2000).

   Radiation from the Nd:YAG laser is significantly less scattered and absorbed in skin that radiation form the argon ion laser.The optical penetration depth of Nd:YAG laser radiation is thus much larger. According to Seipp et al. (1989), major indications for Nd:YAG laser treatments in dermatology are given by deeply located hemangiomas or semimalignant skin tumours. However, argon ion and C=$_2$ lasers should never be replaced by Nd:YAG lasers when treating skin surfaces.

   Treatment of port wine stains with argon ion lasers is usually performed in several sessions. First, a small test area of approximately 4 mm^2 is irradiated. During this test, a suitable laser power is determined by gradually increasing it until the skin visibly pales. According to Dixon and Gilbertson (1986) and Philipp et al. (1992), laser powers of 2-5 W are applied during an exposure time of 0.02-0.1 s. Immediately after laser exposure, inflammation of the skin frequently occurs. After four weeks, ...Laser radiation is usually applied by means of flexible handpiece. In the treatment of facial stains, the eyes of both patient and surgeon must be properly protected. One disadvantage of treating port wine stains with argon ion lasers is that it is rather painful to the patient. Depending on the location and spatial extent of the stain, treatment is performed during either local or complete anaesthetization.
   Less painful and probably even more efficient is the treatment of port wine stains with dye lasers. Although quite expensive, these machines have recently gained increasing significance in dermatology, especially in the treatment of port wine

stains and capillary hemangiomas. Detailed studies were reported by Morelli et al. (1986), and Tan et al. (1989). Frequently, Rhodamine dye lasers are used which emit radiation at wave-lengths in the range 570-590 nm. Typical pulse durations of 0.5 ms and energy densiseies of 4-10 J/cm^2 have been recommended.

Temperature control of the treated and untreated area can be influenced by the laser intensity, wavelength, pulse length and other boundary conditions.

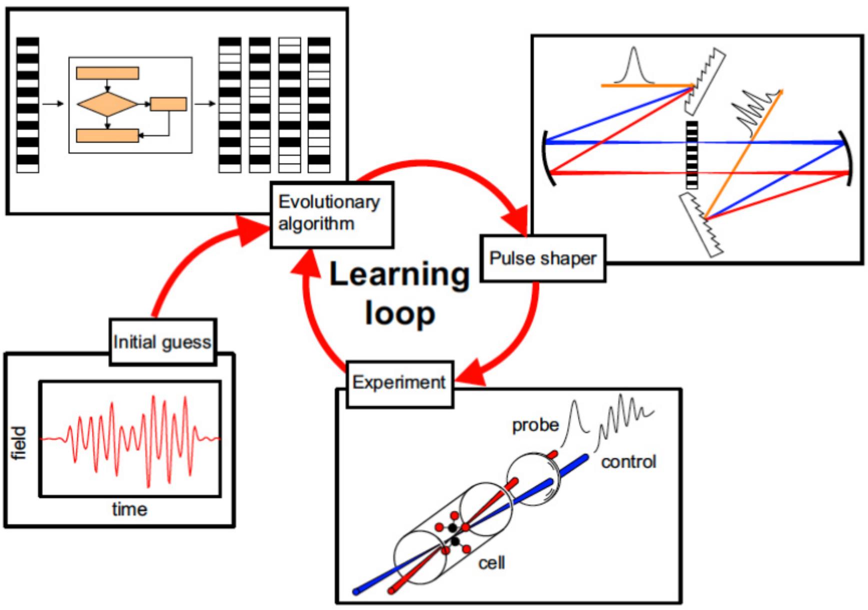
4. **Separately answer the following questions: Explain the principle of a self-learning genetic loop (algorithm). How does it work (don't forget a simple sketch) and discuss which lasers are needed and why.**

   a) Self learning genetic loops can be performed for all kind of different experimental situations (physical problems, set-ups).

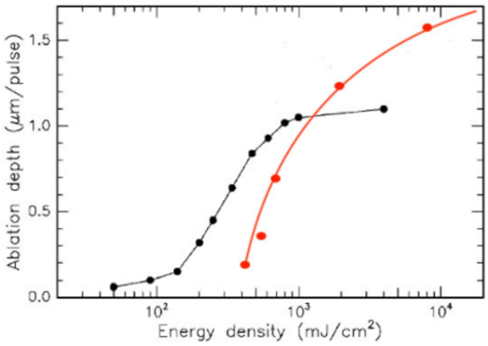
   b) Experimental Pulse shaping is performed in the frequency - Fourier - domain.

   c) If the phase function of the pulse is modified according to its Taylor-series $\varphi(\omega) = \varphi_0 + \varphi_1 \frac{\omega - \omega_0}{1!} + \varphi_2 \frac{(\omega - \omega_0)^2}{2!} + \varphi_3 \frac{(\omega - \omega_0)^3}{3!}$... around the central frequency ω_0 only with respect to $\varphi_2 = \frac{d^2\phi}{d\omega^2}|_{\omega=\omega_0}$, then the pulse will be broadened in time.

One approach is to determine the required laser field in a control loop that uses a signal obtained from the experiment as feedback. This optimisation loop is run until a pulse that meets the requirements is found. Previous experiments in this field were largely limited to the wavelength range of Ti:Sa lasers and their harmonics.



5. **The following figure shows the Ablation curve of rabbit cornea obtained with 2 different laser types. Which statement are correct?**



   a) Laser Black will allow more precise modification of the tissue (cornea).
   b) The ablation dependence of laser intensity for laser black shows a very low threshold.
   c) The best working conditions for laser black is around 10^2 mJ/cm^2

6. **The 3-D object shown in the figure has been produced with Two-Photon Polymerization (TPP). Two photons as well as other multiphoton-photon-polymerization processes can, i principle, take place in materials.**

   a) Traditional One photon polymerization can be realized with more types of lasers or even powerful lamps.
   b) Two photon polymerization represents as special case of non-linear effects happening when lasers interacts with materials.
   c) Realistically ultra short lasers are required for Two Photon Polymerization.

7. **Which items are required for producing ultra-short laser radiation?**

   a) Pump laser of population inversion media
   b) Self-phase modulation
   c) Mode locking
   d) Laser resonator

8. **For surgical applications what kind of "burning" can be realised with a LASER? Explain the underlying processes and by which lasers they might be "effectively" performed. Also explain how the different processes might be identified experimentally in a laboratory setup. [Discussion].**
   Choose one or more answers:

   a) A pulsed laser is required for surgical applications in basically all realistic cases
   b) Excitation (by the laser) of electrons into antibonding electronic states of the molecular substances of a tissue helps to avoid thermal heating.

Kinds:

a) Explosive
b) Thermal
c) Photoablation

Interaction ("Burning")	Power Density (W/cm2)	Exposure time	Pulse duration	Physical effect	Application
Photochemical: absorption (in the UV region) of light with wavelengths in the order of electron wavelengths of π-orbitals of organic molecules.	0.01-50 (~ 1)	> 1 s	1-CW	Excitation	PDT
	Examples: Photosynthesis, vitamin D synthesis, skin cancer, photochemotherapy, photodynamic therapy.				
Photothermal: light absorption by vibrational- and rotational- bands. **Extension of burn zone (duration of healing time) is dependent on penetration depth of radiation.	~ 1 to 10^6	~ 10^- 6 to 1 min	1µs-1min	Excitation +internal conversion	Coagulation, Vaporisation, Decomposition
	Examples: Coagulation, Vaporisation, Carbonization, Melting, Pyrolysis.				
Photo Spallation: hydrodynamic process that enables ablation of tissue even below vaporisation. **Thin surface layer heated rapidly such that no "normal" thermal expansion is possible**	10-10^6	< 1 µs	<1µs	fast expansion	Refractive surgery
	Example: Ablating corneal tissue				
Photo ablation: UV-light induced explosive removal of tissue	10^7-10^10	< 1 µs	10-100ns	Excitation + dissociation	Refractive surgery
	Example: Application: Refractive corneal surgery (excimer laser (e.g. ArF) with pulse durations of 10 – 100ns)				
Plasma induced ablation: local electric field (plasma ionisation) strength of the light exceeds 10^7 V/cm	10^11-10^13	~ps	100 fs-500 ps	Ionisation	Refractive surgery caries therapy
	Examples: refractive corneal surgery, caries therapy				
Photo disruption: optical breakdown within soft tissue or fluids that generates cavitation and shock waves.	10^11-10^16	~ns	100 fs-100 ns	Ionisation Creation of cavities Shockwaves	Minimal invasive surgery
	Application: Non-invasive surgery				

4 Open questions

1. **Excimer Laser – Explain the principle and the important parameters, types and specification of an excimer laser. Discuss important applications (what and why)**

   Principle of the Excimer Laser:

   a) The gas molecules are used as a laser pump

   b) Electron discharge and fall from the negative electrode and they will interact with the medium and pump molecules

   c) The amplifier medium needs short intense discharge pulses that require sophisticated electronics and electrode arrangements.

   d) Produced and initial photons travel in the same direction inside the LASER cavity.

   e) These photons pass through a series of mirrors and eventually pass through a convex lens to sharpen the beam into a point

   f) This point source hits the target and creates plasma

   Important parameters of the Excimer Laser:

   a) Operational in the UV spectrum wavelengths

   b) Because of its large beam cross-sections, the electric field distribution typically consists of many transversal modes and the intensity distribution is inhomogeneous.

   c) An excimer is a molecule that can only exist in an excited state.

   d) The amplifier medium requires short, intense discharge pulses, which require sophisticated electronics and electrode arrangement

   e) The electronic ground state is anti-bonding.

   f) When the molecule partners are excited, they can form an excited dimer-molecule which, in the case of suitable molecules, can disintegrate into the ground state through dipole light emission, where it dissociates immediately. This scheme represents an ideal four level laser, because the basic state is initially not occupied and is immediately "emptied" again.

   Types and Specifications (Possible laser media):

   a) ArF (193 nm)

   b) KrCl (248 nm)

   c) XeCl (308 nm)

   Most Important Applications:

   a) Medical Appliances e.g. Refractive corneal surgery:

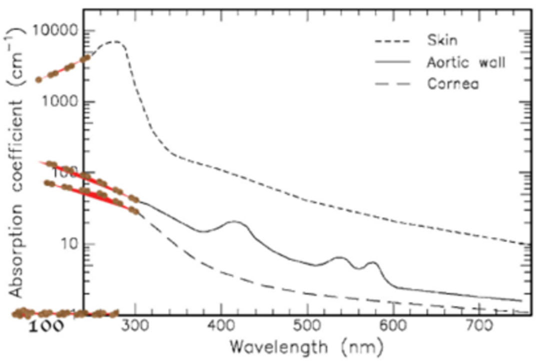
b) Semiconductor appliances e.g. Micromachines

c) used as a pump laser for dye lasers

2. How would you defined Mode Competition?

Mode with low losses use up all the potential for amplification and thus cause modes with higher losses to fall below the threshold for lasing.

3. In the following figure the absorption dependencies on wavelength for some human "materials" are shown. Fill into the figure below useful laser at the appropriate wavelengths. (Type of lasers and its wavelength must be given), which can be used for treatment of least one of the three issue types shown. You must also indicate, for which tissue the laser can be used.

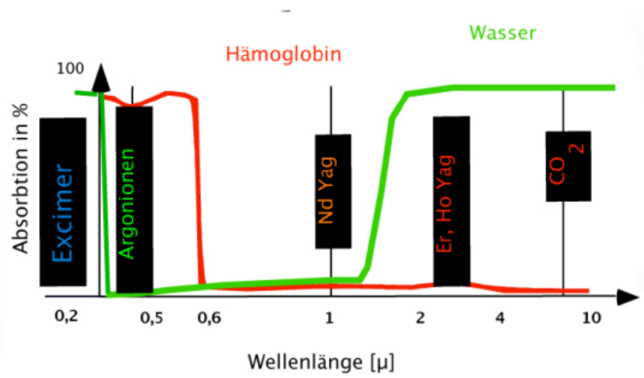


Skin (a lot of water): CO2 laser (10,600 nm), Er (erbium) Yag laser (2940 nm) + Excimer Laser (UV-light)

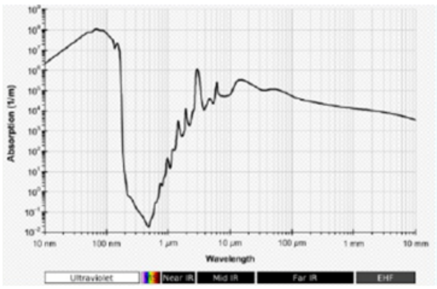
Aortic Wall: Argon-Ion, blood vessels closed through burning

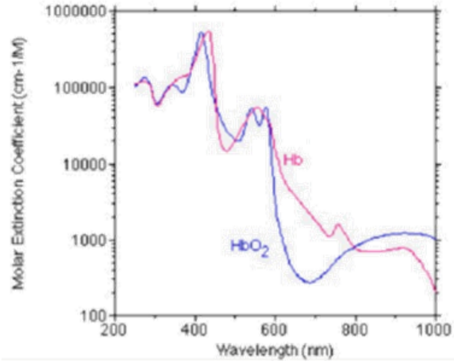
Oxygenated haemoglobin: max absorption around 400 nm (Argon-ion laser)

Cornea (a lot of water): Excimer Laser, photochemical ablation, 193/248/308 nm (UV)



4. **Based on the absorption dependencies on wavelength for some human “materials” as shown in the following figures (Haemoglobin, water). Which statements are correct?**





   a) In order to treat tissue, mainly consisting of haemoglobin as absorber, an excimer laser is well suited.

   b) Recently a research group reported efficient laser curing using an Er:YAG on a material with high water content.

5. **Explain shortly what is needed to scan a basically “monochromatic” single mode operating laser. What defines the maximal scan width? Explain shortly the basic physics of the elements needed.**

A laser can be “tuned” to operate in single-mode and yield a monochromatic output. Monochromaticity refers to the “colour purity” in the case of a laser, the spectral bandwidth of the laser < 1 MHz (sometimes referred to as the laser linewidth). Any number of longitudinal modes can lase provided they lie within the window where the gain exceeds the loss. The number of these lasing modes (N) is given by the gain bandwidth divided by the resonator frequency spacing: $N = \frac{B}{\Delta v}$ This is done by “shifting” the active, oscillating laser mode on the frequency axis (changing the length of the resonator).

Remark: shifting the laser mode alone is not enough, since it would move out of the maximum of the transmission curve of the frequency-determining etalon and thereby promote a mode jump. This is why it is necessary to readjust these elements with single-mode lasers.

The etalon mode is made to overlap with one of the laser cavity modes and only a single longitudinal mode lases. The spectral width of this mode is controlled by the reflectivity and stability of the cavity which is quantified in the cavity’s quality factor Q

How can this be achieved?

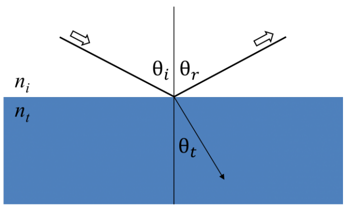
   a) Mounting one of the resonator mirrors on a piezo element Physics of the element required (piezo element) $\rightarrow$ voltage leads change in resonator length
   OR

b) Inserting a small rotatable glass (quartz) plate approximately at the Brewster angle in the resonator. Here the effective resonator length is changed by changing the path of the light in the material. Physics of the element required (rotable quartz) $\longrightarrow$ It must be installed at the Brewster's angle to minimise reflection losses.

6. Light-material interactions

Maxwell's equations must remain satisfied when light interacts with a material, which leads to boundary conditions at the interface. Incident light will reflect and refract at the interface. The angle between the incident ray and sample normal (θ_i) will be equal to the reflected angle, (θ_r). Light entering the material is refracted at an angle θ_t. The same occurs at each interface where a portion of light reflects and the remainder transmits at the refracted angle. The boundary conditions provide different solutions for electric fields parallel and perpendicular to the sample surface.

$$n_i \cdot \sin\theta_i = n_t \cdot \sin\theta_t$$

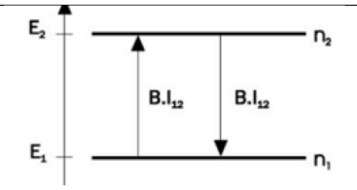
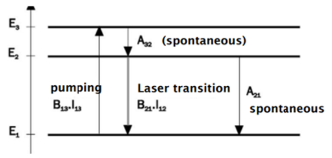
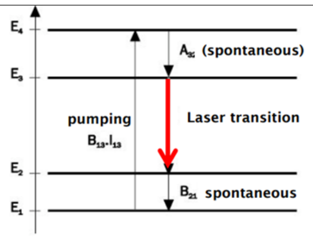


7. How does a laser start to emit light (Spontaneous and Stimulated emission, and how light gets amplified)?

A dipole moment + population inversion + energy transitions must occur, so a laser can emit light.

Phenomena	External E-field required?	Level of interaction	Einstein coefficients	Amplification
Stimulated/ Induces Emission (coherent)	Yes	E2 $\longrightarrow$ E1 down	B_{21}	Optically amplification in the gain medium
Spontaneous Emission (incoherent)	No	E2 $\longrightarrow$ E1 down	A_{21}	

8. **Energy levels (Niveau) and how they are distance between each other affects the emission of photons.**

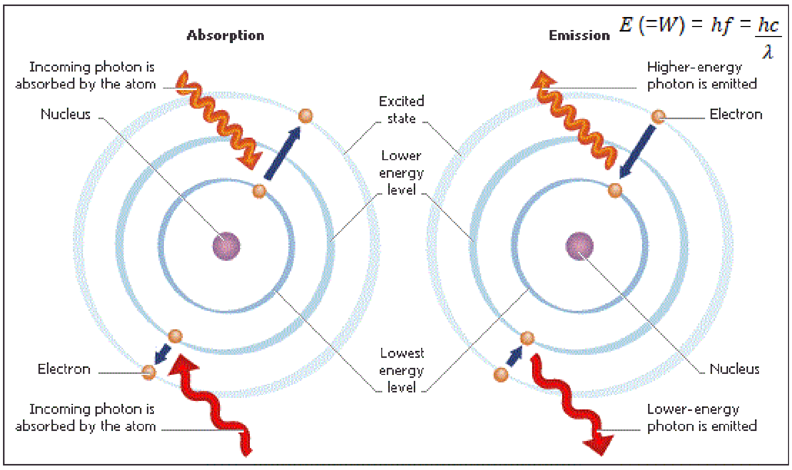
Levels	Image	Einstein Coefficients	Pumping
2		$B_{12} = B_{21}$	Intensive illumination. Same in the levels n_2=n_1
3		$B_{13}\rho(v) =$ Pumping $A_{32} =$ Spontaneous $B_{21}\rho(v) =$ Laser Transition $A_{21} =$ Spontaneous	Population inversion! Perormed at a wavelength other than the lasing wavelength.
4		$B_{13}\rho(v) =$ Pumping $A_{32} =$ Spontaneous $B_{21} =$ Spontaneous	Decoupling the lower laser level from the ground state. Most lasers are of this type.

9. **How it happens inside the atom (electrons losing energy then emits a photon).**

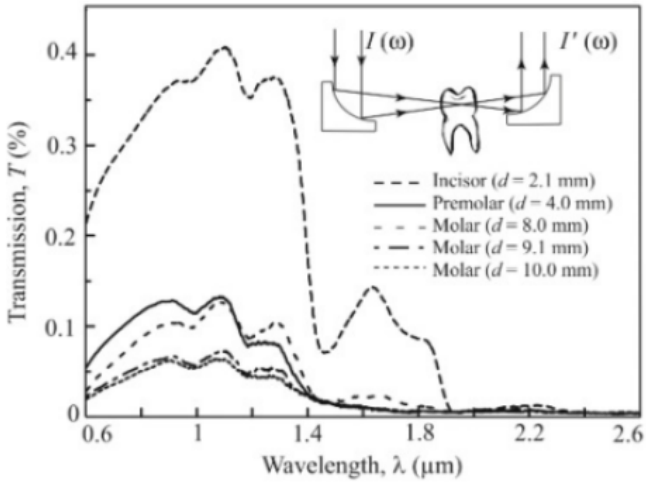
a) Emission is the process of elements releasing different photons of colour as their atoms return to their lower energy levels

b) Atoms emit light when they are heated or excited at high levels

c) Absorption occurs when electrons absorb photons which causes them to gain energy and jump to higher energy levels



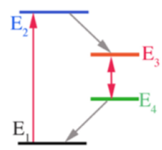
10. **A dentist wants to use a laser for drilling dentin. He obtained the following transmission spectra for high though dentin (different concentrations) from a research lab. He buys a laser system and after his first applications he reports the results of his colleagues. Which ones make sense?**



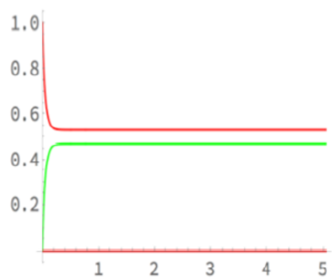
a) I first tried drilling a hole into dental material with a Ti; Sapphire laser at very low intensities and had no success. But at high laser intensities I observed substantial material removal

b) Using a CO2 laser with high intensities I could achieve drilling, but observed substantial burning, actually I found carbon deposits on the treated tooth.

11. **A typical energy level schema of a laser medium is show below:**



Befor the energy pump (light source with frequency corresponding to the transition E1 to E2) is turned on all electrons are found in level E1. The following solution of the rate equation yields a time dependence of n1 (red) and n2 (green) curve:



12. Setting the parameter(s) to nonzero reflects which kind of physics?

It describes the discrete energy changes via the eigenstates/values of the atom $\longrightarrow$ Quantum physics.