Exam

Only a calculator is allowed as help. At the end of this exam sheet you can find many helpful constants and formulas. You can obtain a maximum of 38 points. Good luck!

Problem 1 (3 points)

a) What does the acronym LASER stand for? (1 point)

b) Why is stimulated emission used to generate LASER radiation? (1 point)

c) Explain why most solid-state LASERs can generate pulses that are much shorter than the average lifetime of the excited state. (1 point)

Problem 2 (5 points)

a) Define homogeneous broadening and name 2 effects causing it. (2 points)

b) If you have an active medium, how would you experimentally check whether it is predominantly homogeneously or inhomogenously broadened? (1 point)

c) What is the dominant broadening mechanism in gaseous active media at low pressure? Assuming that all other parameters stay constant, how does the absorption/emission linewidth of these active media change for higher temperatures? Why? (2 points)

Problem 3 (7 points)

a) Consider two spherical mirrors with the same radius of curvature $R = 1\ m$ and assume that they cannot be placed closer than 50 cm to each other. What are the maximum and minimum resonator lengths that can be used to build a stable resonator? Show the trajectory described by the resonator on the stability diagram as its length is changed. (2 points)

b) What are the main differences between stable and unstable resonators? (1 point)

c) What are the longitudinal modes of a resonator? (1 point)

d) What are the transverse modes of a resonator? (1 point)

e) How are the transverse modes of a resonator related to the focusability of the laser beam emitted from it? (1 point)

f) You happen to have a collimated, very powerful mode-locked green laser operating at 515 nm with 1 mJ pulse energy, a pulse duration of 200 fs at 1 kW of average power, and with a beam diameter of 50 mm. What is the spot diameter you can achieve when sending the beam to the Moon at 384000 km distance? (1 point)

Problem 4 (7 points)

In a 2-level system the rate of change of the population density of the excited state (N_2) is:

$$\frac{dN_2}{dt} = W_{12}\left(N_1 - N_2\right) - S_{21} N_2$$

where W_{12} is the transition probability between the laser levels, S_{21} is the spontaneous decay rate and N_1 is the population density in the lower laser level. Consider that this active medium has been doped with a total density N of laser active particles, where $N = N_1 + N_2$.

a) Identify the different terms in the equation above and say which light-matter interaction is described by each one. (1.5 point)

b) Calculate the rate of spontaneous emission of photons in steady-state when $S_{21} = W_{12}$ and when $S_{21} = 2W_{12}$. If the spontaneous decay rate of the system is doubled, does it automatically mean that the rate of spontaneous emission of photons will also be doubled? Why? (2.5 points)

c) The equation that describes the evolution of the photon flux at frequency ν (ϕ_ν) along a 2-level medium is:

$$\frac{d\phi_\nu}{dx} = (N_2 - N_1)\,\sigma_\nu \phi_\nu$$

where σ_ν is the cross-section at frequency ν and N_2 and N_1 are the population densities at the upper and lower energy levels, respectively. Consider that the populations densities N_2 and N_1 are independent of the position along the active medium and that there is a thermal population of the energy levels for $t < 0$. Assuming that photons are coupled in the medium at the frequency at which the maximum cross-section can be found, draw qualitatively the temporal evolution of the photon flux at the output of the 2-level medium. Additionally consider that the photon flux at the input of the medium is $\phi_{\nu o}$ for $t \geq 0$. Explain this behavior. (2 points)

d) If now the frequency of the photons coupled in the active medium is detuned from the maximum of the cross-section (but the new frequency still falls within the linewidth of the transition), draw qualitatively the new temporal evolution of the photon flux at the output of the 2-level medium and compare it with that from c). Explain the differences. (1 point)

Problem 5 (6 points)

a) Why are relaxation oscillations typically observed in solid-state lasers and not in gas lasers? (1 point)

b) Explain the operating principle of Q-switching using a diagram that depicts the temporal evolution of the pump power, the cavity losses, the inversion and the photon density. Additionally draw the temporal evolution of the threshold inversion of the system. (2 points)

c) Imagine that you have two active media with identical characteristics (i.e. operation wavelength, gain bandwidth, cross-sections at the signal wavelength, ion concentration, etc) but one of them is a 3-level system and the other one an inverse 3-level system. If you want to build a Q-switched laser using the same resonator, with which one of the active media can you extract more energy? Why? (2 points)

d) With which one of the active media of c) would you potentially get shorter Q-switched pulses? Why? (1 point)

Problem 6 (3 points)

a) Briefly explain the operating principle of mode-locking. (1 point)

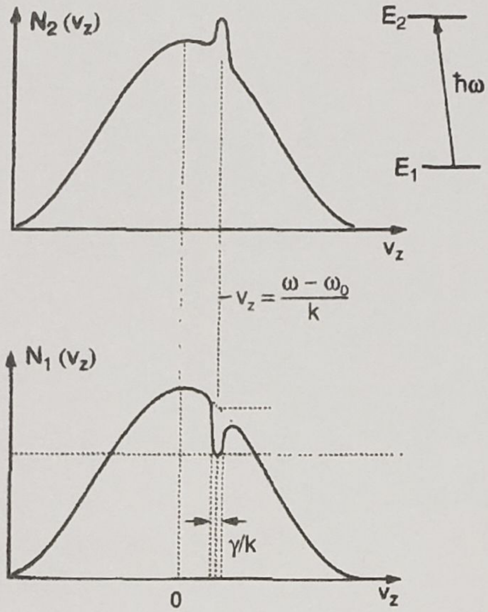
b) You have a laser amplifier system that emits gaussian pulses at 1030 nm with a duration equal to 1-cycle of the electrical field. Which is the full-width-at-half-maximum (FWHM) wavelength bandwidth of the pulses? To which wavelength range does this FWHM wavelength bandwidth correspond? (2 points)

Problem 7 (4 points)

a) Draw a qualitative energy level diagram for spontaneous Raman scattering. Indicate between which levels the Raman scattered light is observed! Is Raman scattering an elastic or an inelastic process, why? (2 points)

b) Which conditions have to be fulfilled so that a molecular oscillation is Raman active or infrared active? (2 points)

Problem 8 (3 points)
An intensive pump laser at a fixed wavelength generates the following population distribution in a Doppler broadened medium:



Describe an experimental setup with which the "hole burning" in this population distribution N_1 can be proven! Sketch the absorption profile which is measured by this setup! (3 points)

Physical constants and units:

$h = 6.626 \cdot 10^{-34}$ Js

$c = 2.998 \cdot 10^{8}$ m/s

$e = 1.602 \cdot 10^{-19}$ C

$\epsilon_0 = 8.854 \cdot 10^{-12}$ F/m

$m_e = 9.1093 \cdot 10^{-31}$ kg

Helpful formulas:

time-bandwidth product for Gaussian pulses:
$\Delta\upsilon\Delta t = \frac{2\ln 2}{\pi}$

Gauss : $A \cdot e^{-4\ln 2\left(\frac{x-x_0}{\Delta x}\right)^2}$

$\int_0^\infty e^{-2\frac{r^2}{w^2}} r dr = \frac{w^2}{4}$