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 40 points. Good luck!

Problem 1 (7 points)

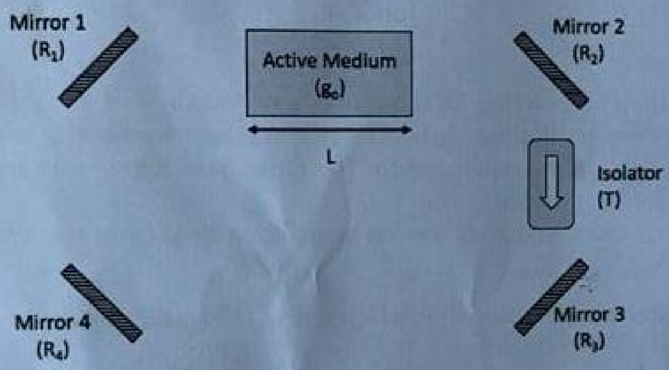
a) What is a LASER? (1 point)

b) Why is it possible to get very high peak intensities with laser radiation? (1 point)

c) Write and explain the Beer-Lambert's law for amplification. (1 point)

d) Which amplification regime is described by the Beer-Lambert's law? Why? (1 point)

e) If you have the following ring cavity:



where the active medium has a gain coefficient g_o and a length L. The isolator has a transmissivity of T, and the mirrors a reflectivity of R_1,R_2,R_3 and R_4, respectively. Calculate the threshold condition of laser operation. (1 point)

f) Imagine that you send a secondary high-power beam at the laser wavelength in the active medium of the cavity from problem e). If this second beam crosses the path of the beam in the cavity perpendicularly, how would this affect the laser threshold? Why? (1 point)

g) Why isn't a laser a system in thermal equilibrium? (1 point)

Problem 2 (4 points)

a) Explain the differences between homogeneously and inhomogeneously broadened active media. (1 point)

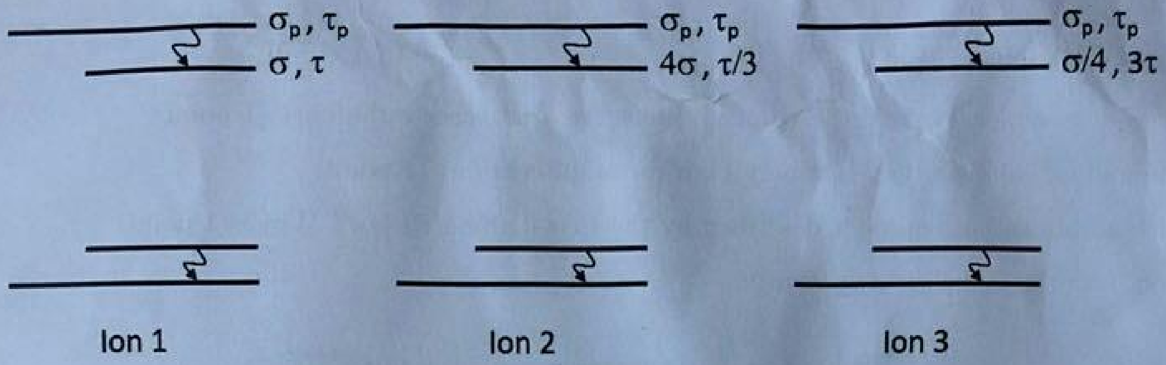
b) If you amplify a weak ultrashort pulsed beam in two active media with exactly the same shape and gain characteristics, when would you get a shorter output pulse: using an homogeneously or an inhomogeneously broadened medium? Why? (2 points)

c) What do you need to do to obtain a laser emitting at several wavelengths simultaneously if its active medium is homogeneously broadened? (1 point)

Problem 3 (6 points)

a) Explain what the emission and absorption cross-sections are. (1 point)

b) Imagine that you have 3 different active media with the same dimensions and total ion concentration N_{tot}. Their corresponding spectroscopic characteristics are schematically represented in the following diagram:



where σ_p represents the cross-section at the pump wavelength, σ is the cross-section of Ion 1 at the laser wavelength, τ_p is the average lifetime of the ions in the pump level and τ is the average lifetime of Ion 1 in the upper laser level. Obtain an expression for the pump rate required to reach the lasing threshold in the active medium using Ion 1. (1 point)
Hint: Assume that $\tau_p << \tau$ and that the ion population density in the upper laser level needed to reach the lasing threshold $N_{2_{th}} << N_{tot}$.

c) When placed in the same optical resonator, which one of the active media above would have the lowest pump power lasing threshold? Why? (2 points)

d) Which one of the active media above would allow you to minimize the pump power required to produce Q-switched pulses with a certain energy (disregard the repetition rate in the discussion)? Why? (2 points)

Problem 4 (5 points)

$P_{out} =$

a) Explain the physical origin of relaxation oscillations. (1 point)

b) If you have two identical active media, but one of them has a cross-section at the laser wavelength of σ and the other one of 2σ, in which one will the relaxation oscillations be faster? Why? (2 points)

c) What output parameter other than the average power changes in an active Q-switched laser when the pump power is varied? Why? (1 point)

d) What output parameter other than the average power changes in an passive Q-switched laser when the pump power is varied? Why? (1 point)

Problem 5 (6 points)

a) Draw the stability diagram of optical resonators indicating the position of stable resonators. (2 points)

b) Explain the meaning of the beam quality factor M^2. (1 point)

c) Which laser can potentially have a better beam quality factor: one built with a stable resonator or one built with an unstable resonator? Why? (1 point)

d) What is a thermal lens? (1 point)

e) Imagine that a cylindric active medium develops a radially-symmetric, longitudinally homogeneous thermal lens when operating at high power. If you place such a medium in a concentric resonator, sketch the evolution of the position of the resonator in the stability diagram with increasing power. Why does it show this behavior? (1 point)

Please turn over!

Problem 6 (4 points)

a) Why is it that if you want to get single-longitudinal mode operation in a laser you need to ensure single-transverse mode operation first? (1 point)

b) What are the main characteristics of the output radiation emitted by a single-longitudinal mode laser? Why? (1 point)

c) Imagine that you have 10 single-longitudinal mode lasers emitting the same power at wavelengths that are evenly spaced in the frequency domain. If you synchronize these 10 lasers perfectly and you combine their emissions into a single beam, what are the main characteristics of the output radiation? Why? (1 point)

d) If now you play with the power emitted by the different lasers in c) (i.e. you make that they do not emit the same power anymore), which parameters of the output radiation will change? why? (1 point)

Problem 7 (4 points)
Sketch the detected signal of a Doppler-free, two-photon experiment! Explain the origin of the main features of the signal!

Problem 8 (4 points)
Depending on the incident intensity, different regimes in materials processing occur. Specify these processes, and explain briefly the underlying mechanism.

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:

$g = \sigma n$

$dn/dt = -\sigma c p n - \Gamma n + W_p \cdot (N_{tot} - n)$ for a 4-level system