Exam

Only a calculator is allowed as a 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 (5 points)

a) Name three characteristics of laser radiation and explain why are they important for applications. (1.5 points)

b) Draw the schematic of a laser indicating its main components and briefly explain their function. (1.5 points)

c) If the reflectivities of the cavity mirrors in a laser are R_1 and R_2 and the length of the active medium (which completely fills the cavity) is L, calculate the gain coefficient required to obtain 1W of average output power. (1 point)

d) Which gain coefficient would you need in the laser of c) to obtain 100 W of average output power? Why? (1 point)

$G = R_1 R_2 e^{gL}$

Problem 2 (6 points)

a) Why do you need an active medium with at least 3 energy levels to build an optically pumped laser? (1 point)

b) Define what gain saturation is and explain the physical origin of this effect. (2 points)

c) Explain why the saturation intensity in 3-level systems is usually lower than in 4-level systems. (1 point)

d) What is ideally the maximum power that can be extracted from an optical amplifier at the signal wavelength λ_s when it is pumped with a power P_p at the pump wavelength λ_p? (1 point)

e) Plot the qualitative evolution of the output power in an amplifier at the signal wavelength λ_s as a function of the signal input power P_{in} for a constant pump power P_p. (1 point)

Problem 3 (6 points)

$P_{av} = E_g$

$P = P_0 \frac{g_0}{1+I}$

a) What is spectral hole-burning? (1 point)

b) What is spatial hole-burning? (1 point)

c) Why is it more difficult to observe spatial hole-burning in gas lasers than in solid-state lasers? (1 point)

d) Imagine that you want to simultaneously amplify two CW signals with different wavelengths with the same active medium. One of the signals is amplitude modulated and the other is not. Which are the main differences that will be observed in the output signals after amplification when using homogeneously or inhomogeneously broadened active media? (1 point)

e) In some real solid-state CW lasers it is possible to observe mode hopping (i.e. a random temporal switching of the laser emission between different longitudinal modes). Explain the origin of this effect. (1 point)

f) Would you expect to see this effect in gas lasers? Why? (1 point)

Problem 4 (4 points)

We have a pulsed seed signal with a spectral full-width at half maximum (FWHM) bandwidth of 15 nm centered at 1030 nm. After amplification in an active medium the power of this signal increases to 250 W and the pulse energy grows to 1 mJ. The spectral gain of the amplifier has a Gaussian shape with a FWHM bandwidth of 25 nm centered at the signal wavelength.

a) Calculate the seed pulse duration assuming a Gaussian temporal pulse shape. (1 point)

b) How short can the pulse be after amplification? (1 point)

c) What is the pulse repetition rate of the seed laser? (1 point)

d) What is the pulse peak power after amplification? (1 point)

$E_p = \frac{P_{av}}{freq}$

T

$D \quad 0.94 \quad E_p$

Problem 5 (3 points)

a) Draw the stability diagram of passive resonators indicating the position of stable symmetric resonators and the regions of stability. (2 points)

b) The resonances of a passive stable resonator form a frequency comb that usually does not start at 0 Hz. Explain why this happens. (1 point)

Problem 6 (5 points)

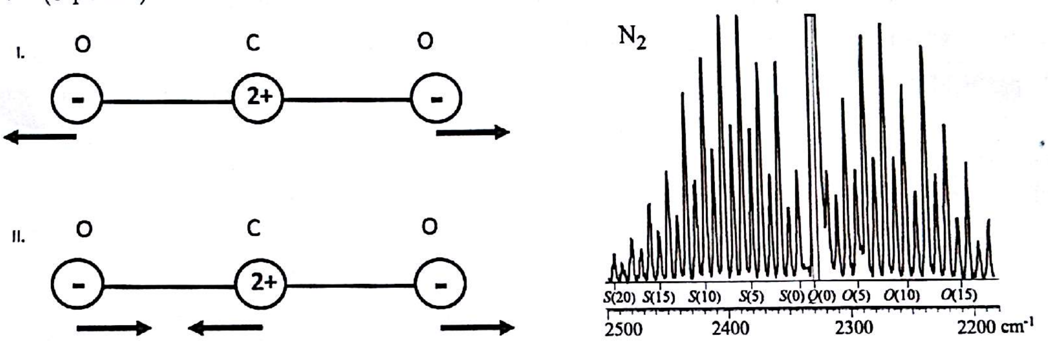
a) Describe the operation principle of Q-switching using a diagram that shows the temporal evolution of the loss, the inversion and the signal photon density in the cavity. Indicate the threshold inversion levels for the high-Q and low-Q states of the optical cavity. (2 points)

b) Explain the operation principle of mode-locking. (1 point)

c) The fact that the temporal separation between two consecutive pulses in a pulse train emitted by a laser is not constant is known as "timing jitter". Explain why the "timing jitter" is particularly strong in passively Q-switched lasers. (1 point)

d) What can cause "timing jitter" in a mode-locked laser? Justify your answer. (1 point)

Problem 7 (6 points)



(a) (b)

Figure 1: Raman scattering

a) Which of the following vibrations of the CO_2-molecule shown in Figure 1(a) is Raman active and/or infrared active? Explain, why. (2 points)

b) Raman scattering is a powerful technique in molecular spectroscopy. With the help of the Raman shift spectrum in Figure 1(b), explain qualitatively, how:

1) the vibrational and rotational constants can be determined. Give estimates (in cm^{-1}), neglecting possible prefactors;

2) the temperature can be measured.

(4 points)

Problem 8 (3 points)

An intensive pump laser at a fixed wavelength generates in a Doppler broadened medium the population distribution shown in Figure 2.

a) Describe an experimental setup with which the "hole burning" in this population distribution N_1 can be proven. (2 points)

b) Sketch the absorption profile, which is measured by this setup. (1 point)

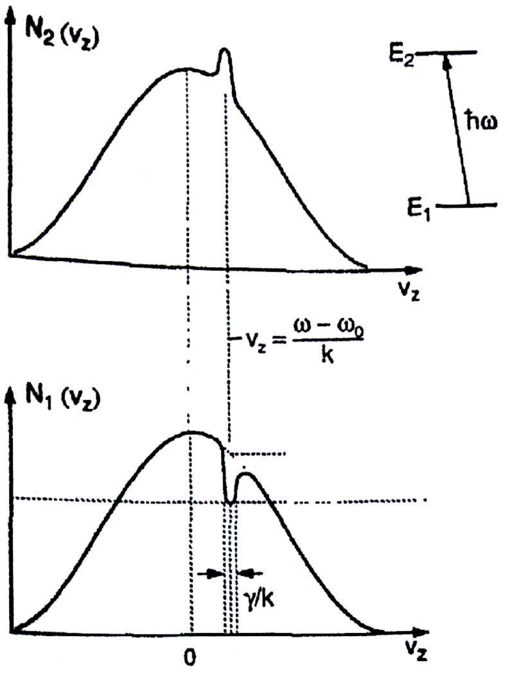


Figure 2: Population distribution

Physical constants and units:

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

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

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

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

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

Helpful formulas:

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

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

$\int\limits_0^\infty e^{-2\frac{r^2}{w^2}} r dr = \frac{w^2}{4}$