Exam

No help other than a calculator is allowed in the exam. All the constants and formulae required to solve the exam can be found on the last page. A maximum of 40 points can be achieved. Good luck!!

Problem 1 (8 points)

A Q-switched laser emits pulses with $\tau = 150\,\text{ns}$ FWHM duration and a peak power of $P_{\text{peak}} = 6\,\text{kW}$ at a repetition rate of $f_{\text{rep}} = 50\,\text{kHz}$.

a) Calculate the pulse energy E_p and average power P_av assuming rectangular pulses. (2 points)

b) Repeat a) assuming Gaussian pulses. (2 points)

c) Draw a diagram that qualitatively describes the evolution of inversion, intensity and cavity losses for the Q-switching process. (2 points)

d) Explain briefly the difference between active Q-switching and active mode-locking. (2 points)

Problem 2 (7 points)

A linear resonator consists of two concave mirrors with radius of curvature $R_1 = 500\,\text{mm}$ and $R_2 = 800\,\text{mm}$, respectively. The distance L between the mirrors can be adapted.

a) Plot the stability diagram using the g_1 and g_2 parameters and label the stability regions. (2 points)

b) Explain the difference between a stable and an unstable resonator using the physical picture of ray optics. (1 point)

c) Explain the difference between a stable and an unstable resonator using the physical picture of wave optics. (1 point)

d) The distance L between the mirrors is continuously tuned starting from $L = 100\,\text{mm}$ to $L = 2000\,\text{mm}$. Draw the path travelled in the stability diagram. How can L be chosen in order to achieve a stable resonator? (3 points)

Problem 3 (4 points)

The general rate equation for the evolution of the population of the upper level N_2 in an active medium is:

$$\frac{dN_2}{dt} = -\frac{N_2}{\tau} + \frac{I_\text{p}}{h\nu_\text{p}}(\sigma_{\text{ap}}N_1 - \sigma_{\text{ep}}N_2) + \frac{I_\text{s}}{h\nu_\text{s}}(\sigma_{\text{as}}N_1 - \sigma_{\text{es}}N_2)$$

with the lifetime of the excited state τ, the pump/signal intensities $I_{\text{p/s}}$, the pump/signal frequencies $\nu_{\text{p/s}}$, the absorption cross-sections for pump/signal $\sigma_{\text{ap/as}}$ and the emission cross sections for pump/signal $\sigma_{\text{ep/es}}$. The population of the lower and upper level are related to each other through the total number of active ions $N_{\text{tot}} = N_1 + N_2$.

a) Calculate the maximum relative population of the upper level $N_{2\text{max}}/N_{\text{tot}}$ that can be achieved in the medium in steady state. Explain, which conditions for I_p and I_s have to be satisfied to achieve this. (2 points)

b) Calculate the minimum relative population of the upper level $N_{2\text{min}}/N_{\text{tot}}$ that can be present in the medium in steady state for I_s larger than the saturation intensity. Explain, which conditions for I_p and I_s have to be satisfied to achieve this. (2 points)

Problem 4 (4 points)

Is it possible to amplify the signal emitted from a mode-locked laser in ...

a) ... a purely homogenously broadened medium? If possible, what would happen with the pulse duration? (1 point)

b) ... a purely inhomogenously broadened medium? If possible, what would happen with the pulse duration? (2 points)

c) If someone tells you that they want to build an ultrashort-pulse laser with a solid-state active medium which gain profile is Doppler-broadened to a linewidth of 1 GHz, what would you recommend them? (1 point)

Problem 5 (7 points)

Imagine an active medium with effective cross-sections according to Fig. 1 (where the positions of the transitions have been indicated):

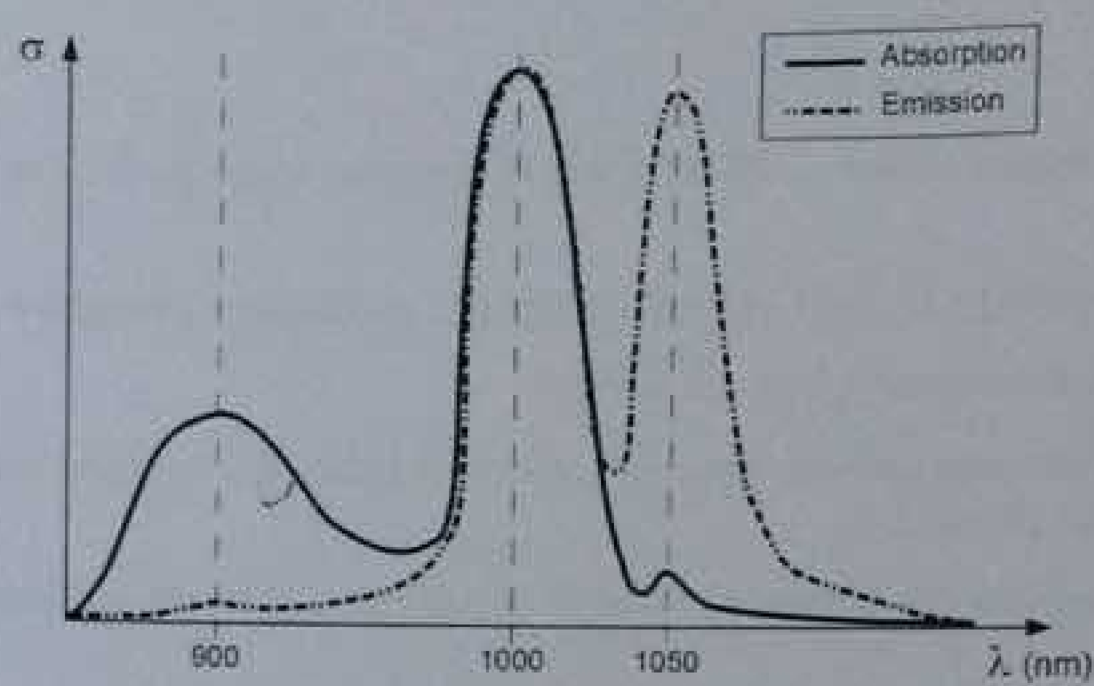

Figure 1: Effective emission and absorption cross-sections of the active medium.

a) Draw the energy-level diagram of the active ion indicating the energy of each level (in cm^{-1}) assuming that the ground level has an energy of $0\,\mathrm{cm}^{-1}$. (2 points)

b) With the ion above it is possible to realize a 4-level system, a 3-level system and an inverse 3-level system. Give the combination of pump and signal wavelength for each possibility. (3 points)

c) Which of the systems above (4-level, 3-level, inverse 3-level) would you use if you wanted to amplify a small signal with low pump power? Why? (1 point)

d) Which of the systems above would you use if you wanted to build a high-average-power system? Why? (1 point)

Problem 6 (8 points)

a) Sketch the setup for an intracavity absorption measurement! Show at least one configuration for signal detection! (2 points)

b) What are the advantages of this technique compared to conventional absorption spectroscopy? (2 points)

c) At which pump power should the laser be operated for highest sensitivity? Explain! (2 points)

d) A similar technique is cavity ring-down spectroscopy. Compare the physical quantities, which have to be measured for both techniques! (2 points)

Problem 7 (2 points)

An intensive pump laser at a fixed frequency ω generates a population distribution in a Doppler broadened medium according to Fig. 2. 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! (2 points)

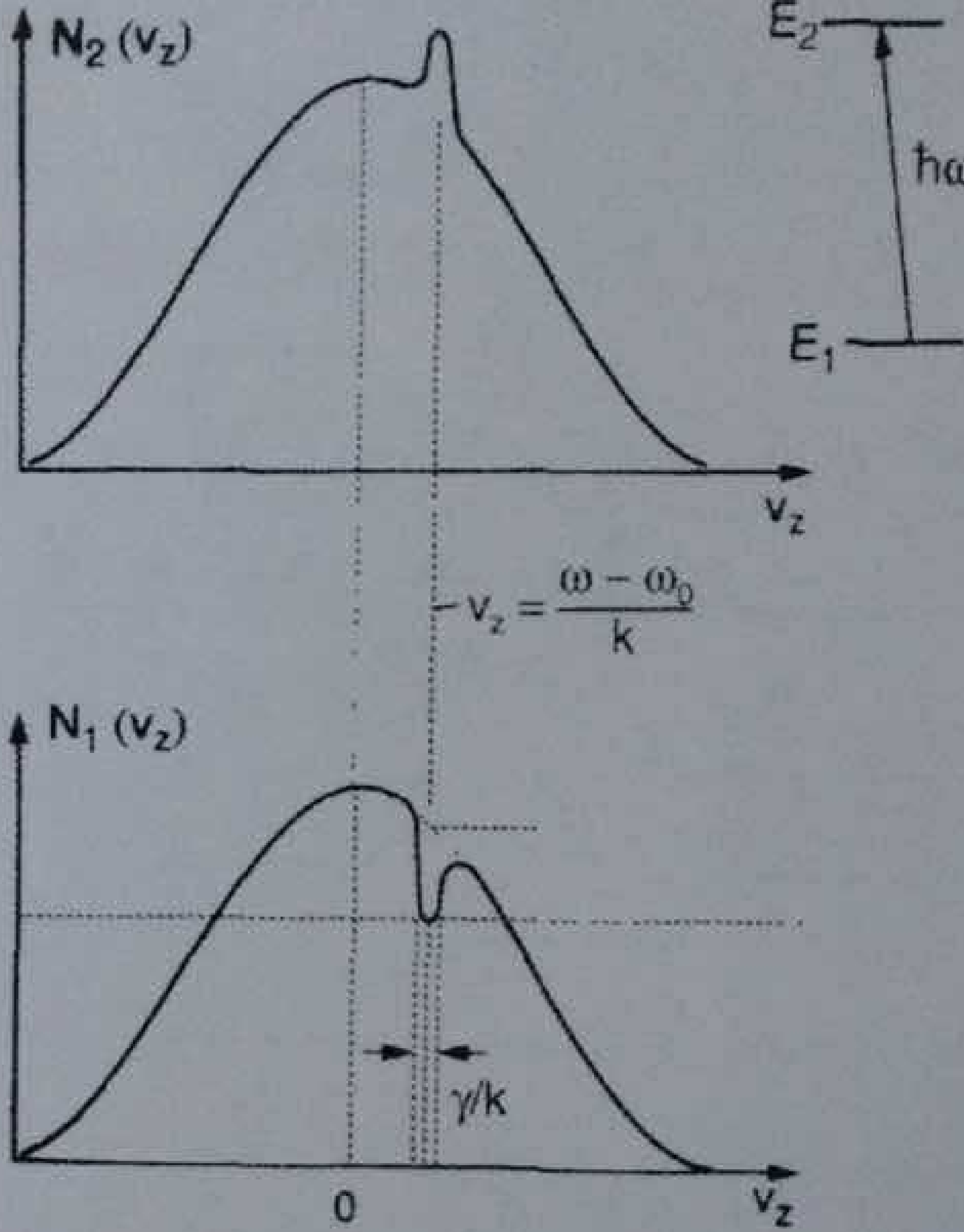

Figure 2: Population distribution for the upper (N_2) and lower level (N_1).