

EXERCISE 14.1-1

Attenuation and Gain in a Ruby Laser Amplifier.

- (a) Consider a ruby crystal with two energy levels separated by an energy difference corresponding to a free-space wavelength $\lambda_0 = 694.3$ nm, with a Lorentzian lineshape of width $\Delta\nu = 330$ GHz. The spontaneous lifetime is $t_{sp} = 3$ ms and the refractive index of ruby is $n = 1.76$. If $N_1 + N_2 = N_a = 10^{22}$ cm⁻³, determine the population difference $N = N_2 - N_1$ and the attenuation coefficient at the line center $\alpha(\nu_0)$ under conditions of thermal equilibrium at $T = 300^\circ$ K (so that the Boltzmann distribution discussed in Sec. 13.2 is obeyed).
- (b) What value should the population difference N assume to achieve a gain coefficient $\gamma(\nu_0) = 0.5$ cm⁻¹ at the central frequency?
- (c) How long should the crystal be to provide an overall gain of 4 at the central frequency when $\gamma(\nu_0) = 0.5$ cm⁻¹?

- 14.1-2 **Amplifier Gain and Rod Length.** A commercially available ruby laser amplifier using a 15-cm-long rod has a small-signal gain of 12. What is the small-signal gain of a 20-cm-long rod? Neglect gain saturation effects.
- 14.1-3 **Laser Amplifier Gain and Population Difference.** A 15-cm-long rod of Nd³⁺:glass used as a laser amplifier has a total small-signal gain of 10 at $\lambda_0 = 1.06$ μ m. Use the data in Table 14.3-1 to determine the population difference N (Nd³⁺ ions per cm³) required to achieve this gain.

EXERCISE 14.2-1

Optical Pumping.

Assume that $R_1 = 0$ and that R_2 is realized by exciting atoms from the ground state $E = 0$ to level 2 using photons of frequency E_2/h absorbed with a transition probability W . Assume that

$\tau_2 \approx t_{sp}$ and $\tau_1 \ll t_{sp}$ so that in steady state $N_1 \approx 0$ and $N_0 \approx R_2 t_{sp}$. If N_a is the total population of levels 0, 1, and 2, show that $R_2 \approx (N_a - 2N_0)W$, so that the population difference is $N_0 \approx N_a t_{sp} W / (1 + 2t_{sp} W)$.

- 14.2-4 **The Two-Level Pumping System.** Write the rate equations for a two-level system, showing that a steady-state population inversion cannot be achieved by using direct optical pumping between levels 1 and 2.