3.11. The CO_2 molecule has strong absorption lines in the neighborhood of $\lambda = 10\ \mu m$. Assuming that the cross sections of CO_2 molecules with N_2 and O_2 molecules are $\sigma(CO_2,\ N_2) = 1.20\ \mathrm{nm}^2$ and $\sigma(CO_2,\ O_2) = 0.95\ \mathrm{nm}^2$, estimate the collision-broadened linewidth for CO_2 in the atmosphere. (Note: Since the concentration of CO_2 is very small compared to N_2 and O_2 in air, you may assume that only N_2–CO_2 and O_2–CO_2 collisions contribute to the linewidth.) Compare this to the Doppler width.

3.15. Consider the absorption coefficient $a(\nu_0)$ of a pure gas precisely at resonance. Show that $a(\nu_0)$ is proportional to the number density of atoms when the absorption line is Doppler broadened, but is independent of the number density when the pressure is sufficiently large that collision broadening is dominant.

3.19. **(a)** What is the spontaneous emission rate for the helium $1S_0$–$2P_1$ transition at 58.4 nm?

(b) A cell is filled with helium at a temperature of 300K, and the density is sufficiently low that collision broadening is negligible. Calculate the absorption coefficient for the 58.4-nm transition.

4.1. Show how (3.12.5) and (4.3.4a) are modified if the light propagates toward $-z$ rather than $+z$, and derive (4.3.4b).

4.2. **(a)** Solve (4.5.7) as a function of time for the (unusual) case that the equation's loss parameters satisfy $\Gamma_{21} + A_{21} = (c/2L)(1 - r_1 r_2)$. Give the steady-state value of $n_2 + q_\nu$.

(b) Find the steady-state solution for q_ν in terms of p and n_2 for arbitrary loss parameters.

4.3. **(a)** Write the full set of equations for a three-level laser by modifying (4.7.4) and including the following equation for the third level (as shown in Fig. 4.6): $dN_3/dt = PN_1 - \Gamma_{32}N_3$, and show that the full set of equations satisfies $N_1 + N_2 + N_3 = \text{constant} = N_T$.

(b) Determine the steady-state values of the three level populations.

(c) Find the condition under which it is satisfactory to neglect level 3 [$N_3 \approx 0$] and to use Eqs. (4.7.2) and (4.7.4) as written in the text.