6-3. The rotational inertia is

\[ I = 2 m_H r^2 = 2(1.57 \times 10^{-27})(0.074 \times 10^{-9}/2)^2 \text{kg} \cdot \text{m}^2 = 4.6 \times 10^{-48} \text{kg} \cdot \text{m}^2 \]

(b) \( \Delta E = E_{01}^\text{rot} - E_{00}^\text{rot} = h^2/I = (6.626 \times 10^{-34}/2 \pi^2)/(4.6 \times 10^{-48}) \text{ J} = 2.4 \times 10^{-21} \text{ J} = 0.015 \text{ eV} \)

(c) \( P_1/P_0 = e^{-(\Delta E)/k_B T} = e^{-0.015/(6.62 \times 10^{-23})} = 0.55 \)

6-4. (a) \( \Delta E = E_{1}^\text{ vib} - E_{0}^\text{ vib} = h f = (6.626 \times 10^{-34}) (1.3 \times 10^{14}) = 8.6 \times 10^{-20} \text{ J} = 0.54 \text{ eV} \)

(b) \( P_1/P_0 = P_1/P_0 = e^{-(\Delta E)/k_B T} = e^{-0.54/(6.62 \times 10^{-23})} = e^{-21.4} \approx 5 \times 10^{-10} \)

6-5. The first few states of the energy level diagram in the electronic ground state are shown below. The energy labels are of the form \( E_{k,l} \). Associated with each vibrational state there is a number of rotational sublevels. An expanded view of each vibrational state with associated sublevels is shown at the right.

6-11. The original temperature is determined from the Wien displacement law

\[ \lambda_{\text{max}} T_1 = 2898 \mu \text{m} \cdot \text{K} \Rightarrow T_1 = \frac{2898 \mu \text{m} \cdot \text{K}}{\lambda_{\text{max}}} = \frac{2898 \mu \text{m} \cdot \text{K}}{0.55 \mu \text{m}} = 5269 \text{ K} \]

For the total radiant emittance to double,

\[ M_2 = 2 M_1 \Rightarrow \sigma (T_2)^4 = 2 \sigma (T_1)^4 \Rightarrow T_2 = 2^{1/4} T_1 = 6266 \text{ K} \]

The new maximum wavelength is

\[ \lambda_{\text{max}} = \frac{2898 \mu \text{m} \cdot \text{K}}{T_2} = \frac{2898 \mu \text{m} \cdot \text{K}}{6266 \text{ K}} = 0.462 \mu \text{m} = 462 \text{ nm} \]

6-14. Equation (6-12) indicates that \( A_{21}/B_{21} \) is inversely proportional to the cube of the wavelength. This ratio gain while spontaneous emission (essentially) does not. Thus, all else being equal, the gain on a transition resonant with short wavelength radiation is less than that of a transition resonant with long wavelength radiation.

6-18. (a) The half-angle beam spread is

\[ \theta = \frac{\lambda}{\pi w_0} = \frac{6.33 \cdot 10^{-7}}{\pi \cdot 5 \cdot 10^{-4}} \text{ m} = 4.0 \times 10^{-4} \text{ rad} = 0.023^\circ \]

(b) The diameter is about

\[ D = 2 d \theta = 2(1000 \text{ m})(4.0 \times 10^{-4}) = 0.8 \text{ m} = 80 \text{ cm} \]

6-22. The diode laser beam is generated in a very small region. The radius \( w_0 \) of the beam waist of the diode laser beam must therefore be very small (compared to other types of lasers). As indicated by Equation (6-16), the divergence angle is inversely proportional to \( w_0 \) and so will be larger for diode lasers than for other types of lasers.

6-23. As the irradiance in the laser cavity increases, the population inversion decreases. Given that there is a positive population inversion, the population densities of the upper and lower lasing levels satisfy the inequality \( N_{\text{upper}} > N_{\text{lower}} \). The magnitude of the net rate of depletion of the population inversion due to stimulated processes is proportional to \( I (N_{\text{upper}} - N_{\text{lower}}) \). Thus, increased irradiance causes a larger rate of depletion of the population inversion, leading to a lessened inversion.