Blackbody radiation

$$dU_{bbr} = \frac{8p}{l^3}\frac{\hbar dw}{e^{(\hbar w/kT_{rad})} - 1}$$

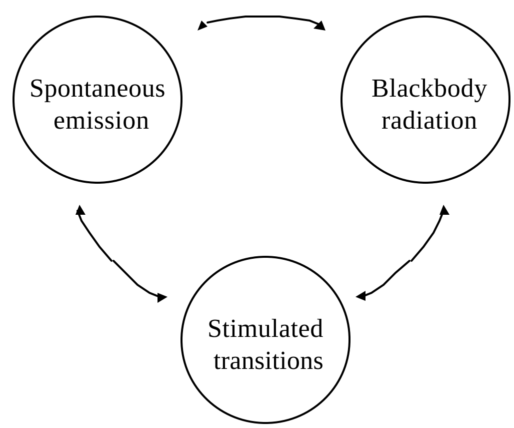
$$d|E_{bbr}|^2 = \frac{2}{e} dU_{bbr} = \frac{16p}{e l^3}\frac{\hbar dw}{e^{(\hbar w/kT_{rad})} - 1}$$

$$W_{12,bbr} \equiv W_{21,bbr} = \int dW_{12,bbr} \approx \frac{1}{16p}\frac{g_{rad}\, ed|E_{bbr}|^2\, l^3}{\hbar}$$

$$W_{ji,bbr} \equiv \frac{g_i}{g_j} W_{ij,bbr} = \frac{g_{rad,ji}}{e^{(\hbar w/kT_{rad})} - 1}$$

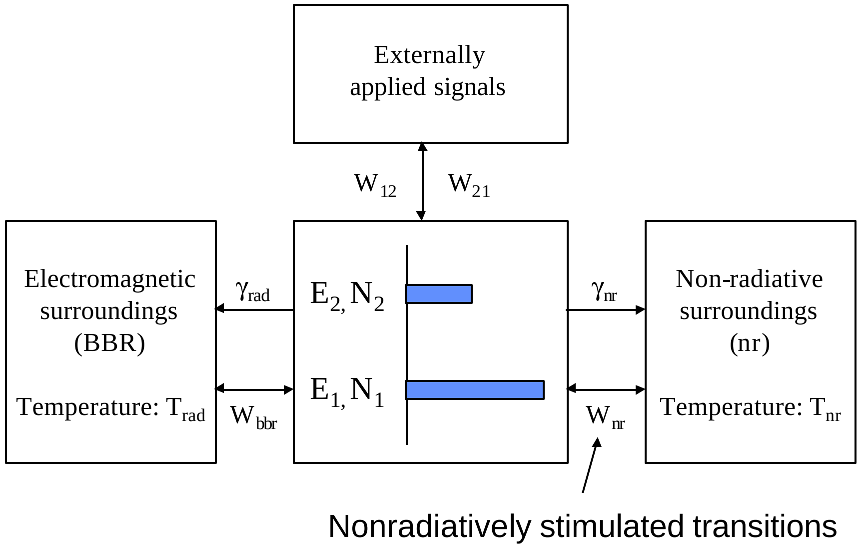
$$\frac{\text{energy flow out}}{\text{energy flow in}} = e^{\frac{\hbar w_a}{kT_{rad}} - \frac{\hbar w_a}{kT_a}}$$

Blackbody radiation <-> balance



Detailed balance => Exactly same line shape for spontaneous emission and stimulated absorption

Non-radiative relaxation and transitions



Non-radiative Stimulated Transitions

- Acoustic interactions
  - acoustic blackbodies
  - acoustic lasers or masers
- Inelastic gas collisions
- General rule: If exited atoms can lose energy to their surroundings through some mechanism, then these surroundings will be able to stimulate transitions (same probability for up and down transitions) through the same mechanism

Non-radiative relaxation

$$W_{ji,bbr} \equiv \frac{g_i}{g_j} W_{ij,bbr} = \frac{g_{rad,ji}}{e^{(\hbar w/kT_{rad})} - 1}$$

$$W_{ji,nr} \equiv \frac{g_i}{g_j} W_{ij,nr} = \frac{g_{nr,ji}}{e^{(\hbar w/kT_{nr})} - 1}$$

Valid for ANY ratiative or non-radiative surroundings

$$\left|\frac{dN_2}{dt}\right|_{down} = \left(W_{21,bbr} + g_{rad} + W_{21,nr} + g_{nr}\right) N_2 \equiv w_{21} N_2$$

$$\left|\frac{dN_1}{dt}\right|_{up} = \left(W_{12,bbr} + W_{12,nr}\right) N_1 \equiv w_{12} N_1$$

$$w_{21} = W_{21,bbr} + g_{rad} + W_{21,nr} + g_{nr} \qquad w_{12} = W_{12,bbr} + W_{12,nr}$$

Thermally stimulated relaxation transition probability

Two-level rate equations

$$\frac{dN_2}{dt} = -\frac{dN_1}{dt} = [W_{12} + w_{12}] N_1 - [W_{21} + w_{21}] N_2$$

$$W_{12} = W_{21}$$

$$\frac{w_{12}}{w_{21}} = e^{-\frac{\hbar w_a}{2kT}} \quad \text{with degeneracy}: \frac{w_{ij}}{w_{ji}} = \frac{g_j}{g_i} e^{-\frac{\hbar w_a}{2kT}}$$

Optical frequency approximation:

$$e^{-\frac{\hbar w_a}{2kT}} \approx 10^{-36} \Rightarrow w_{ij}(\uparrow) \approx 0 \;\&\; w_{ji}(\downarrow) \approx g_{ji}$$

- Accurately describes a large number of laser transitions

Two-level rate equations

$$\frac{dN_2}{dt} = -\frac{dN_1}{dt} = [W_{12} + w_{12}]N_1 - [W_{21} + w_{21}]N_2$$

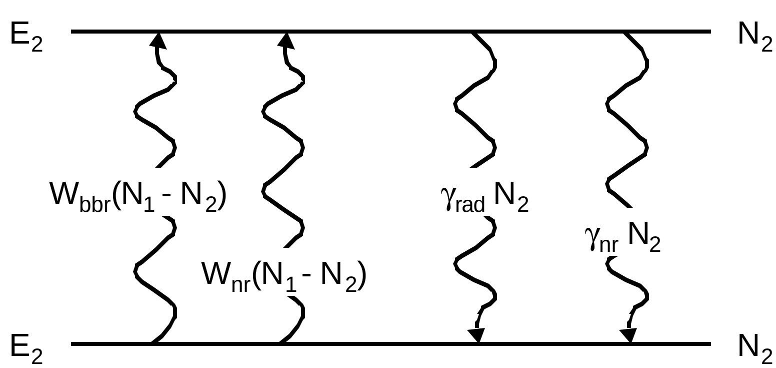
$$N = N_1 + N_2 \qquad \Delta N = N_1 - N_2$$

$$\frac{N_{20}}{N_{10}} = \frac{w_{12}}{w_{21}} = e^{-\frac{\hbar w_a}{kT}} \Rightarrow$$

$$\Delta N_0 = N_{10} - N_{20} = \frac{w_{21} - w_{12}}{w_{21} + w_{12}} N = N \tanh\left(\frac{\hbar w_a}{2kT}\right)$$

- Combine the two equations into a single rate equation

Relaxation on Atomic Transitions



Summary

- Black body radiation - Black body stimulated transitions - Thermal equilibrium
- Detailed balance => Exactly same line shape for spontaneous emission and stimulated absorption
- Non-radiative Relaxation and Stimulated Transitions
- Two-level rate equations
- Relaxation on Atomic Transitions
- HW 3 (due Friday Oct. 22nd): 3.7.2 (p. 174), 3.7.4 (p.175), 4.3.1 (p.194)