Lasers

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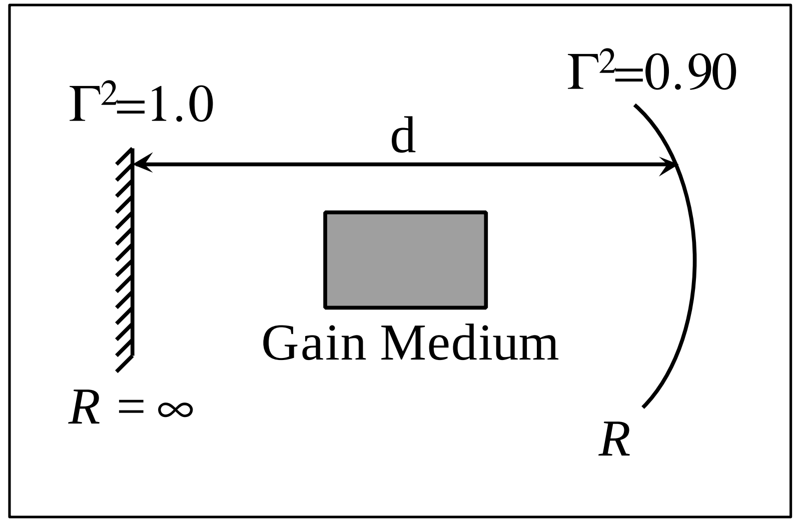
Laser Principles

- Gain Medium
  - Crystal, gas, semiconductor, glass
  - Gain $\geq$ loss $\Rightarrow$ lasing
- Resonator
  - Cavity (minimum of two mirrors)
  - Stability
    - ABCD matrix
    - Transmission matrix
- Loss Mechanisms
  - Mirror reflectivity
  - Gain medium interface (Brewster's angle)
  - Dirt, dust, water vapour



R - curvature of mirrors

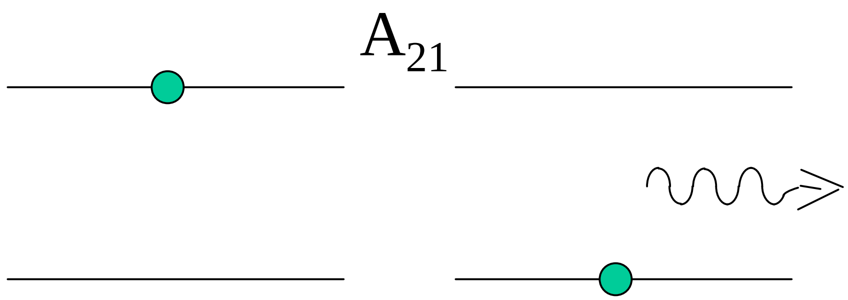
Γ^2 - Reflectivity

Laser Basics

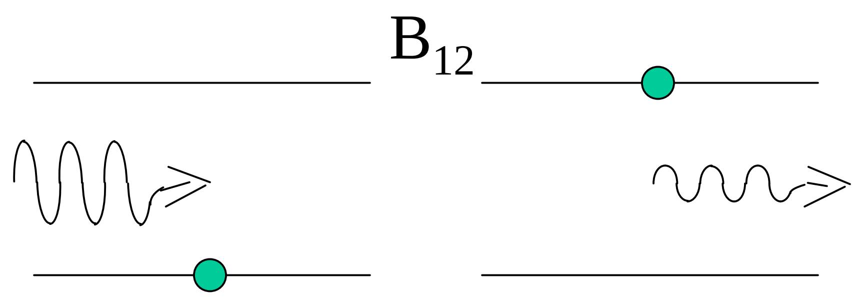
- Output Mechanism
  - Output coupler (a low reflectivity mirror)
  - Cavity dumper (acousto-optic cell)
- Pump Source (Electrical or Optical)
  - Supplies energy
  - Typically most expensive and cumbersome
- Most efficient Lasers: Semiconductor Lasers

  (> 60% of electrical pump energy converted to light)
- Typical Efficiency of Lasers < 10 %

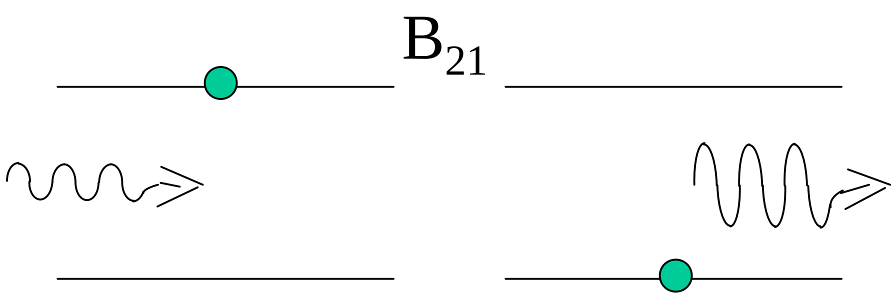
Gain Medium: Einstein's A & B Coefficients



Spontaneous Emission



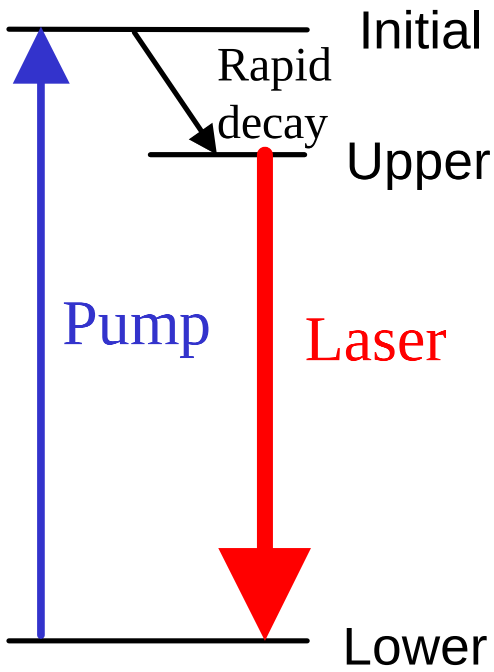
Absorption



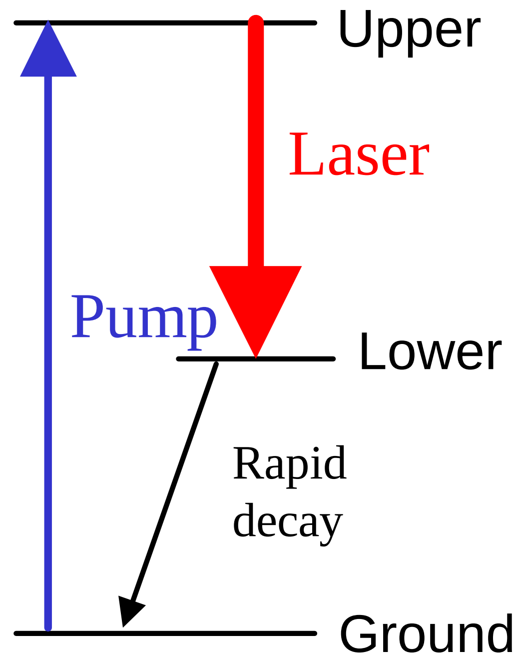
Stimulated Emission

$$I_n(z) = I_n(0) \cdot \underbrace{e^{g_0(n)\cdot z}}_{G_0(n)}$$

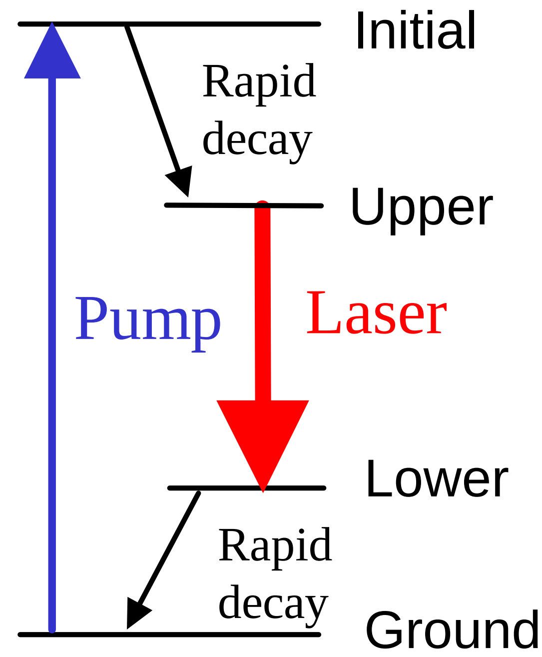
Typical Energy-level Arrangements



Traditional solid-state lasers

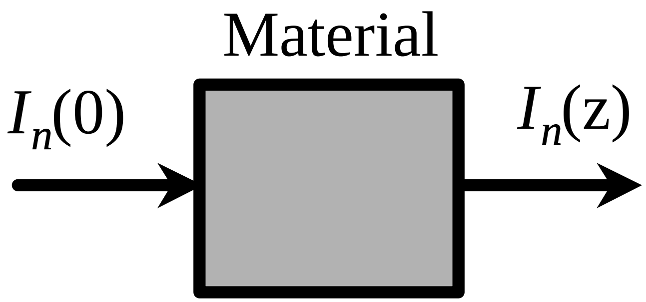


Gas Lasers



Solid-state and Dye Lasers

Gain Medium: Einstein's A & B Coefficients



After much calculation we realize for gain we need:

$$N_2 > \frac{g_2}{g_1} \cdot N_1$$

$$I_n(z) = I_n(0) \cdot \underbrace{e^{g_0(n) \cdot z}}_{G_0(n)}$$

$$g_0(n) = s(n) \cdot \left[N_2 - \frac{g_2}{g_1} \cdot N_1 \right]$$

$$s(n) = A_{21} \cdot \frac{l^2}{8pn^2} \cdot g(n)$$

$s(n)$: Stimulated Emission cross section

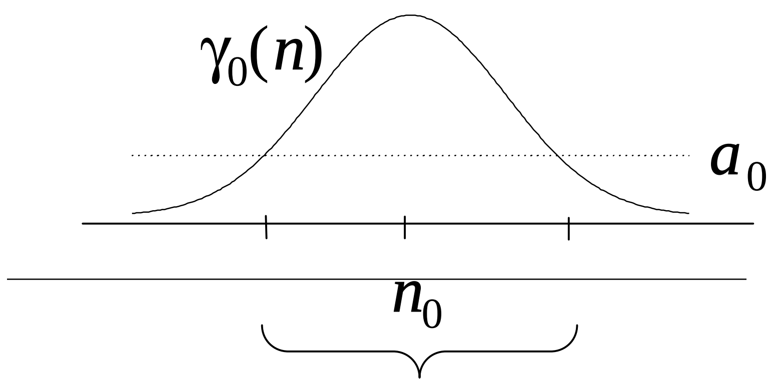
$g(n)$: Lineshape Function (width of transm. Spectrum)

Laser Oscillation

$$Loss = R_1 \cdot R_2 \qquad Gain = G_0^2(n) = (e^{\gamma_0(n)\cdot l})^2 = e^{2\gamma_0(n)\cdot l}$$

Here $\Rightarrow$

$$\underbrace{\gamma_0(n)}_{\text{Gain/Length}} \geq \underbrace{\frac{1}{2l} \cdot \ln\left[\frac{1}{R_1 R_2}\right]}_{\text{Loss/Length}} = \alpha_0$$



Possible Oscillation

Lasing takes place at longitudinal mode with highest gain to loss rate.

$\Rightarrow$ CW Operation

Laser Oscillation

$$g_0(n) = A_{21} \cdot \frac{l^2}{8pn^2} \cdot g(n) \cdot \left[N_2 - \frac{g_2}{g_1} \cdot N_1 \right] \qquad I_n(z) = I_n(0) \cdot e^{g_0(n) \cdot z}$$

For amplification we need to have Gain.

$$N_2 > \frac{g_2}{g_1} \cdot N_1$$

Population Inversion!

Longitudinal Modes

- Enhancements occur at each half-wavelength:

$$d = n\left(\frac{l}{2}\right)$$

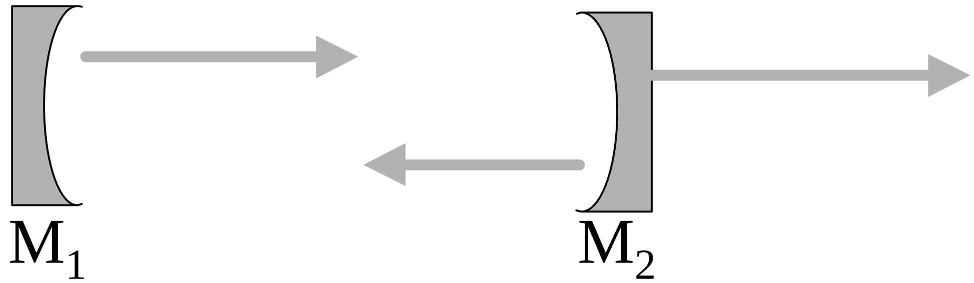
- In Frequency, each mode occurs at:

$$n = m\left(\frac{c}{2nd}\right)$$

- Distances between modes:

$$\Delta n = \left(\frac{c}{2nd}\right)$$

Longitudinal Laser Modes



Transmitted intensity:

$$\frac{I_t}{I_o} = \frac{1}{1 + F\sin^2\left(\frac{f}{2}\right)} \quad where \quad F = \frac{4R}{(1-R)^2}$$