Helium–Neon Laser

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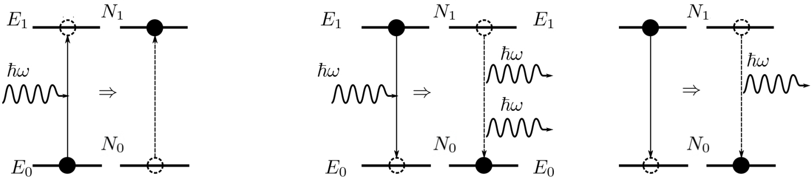
Abstract

TODO

Elementary processes



a) Absorption　　b) Stimulated Emission　　c) Spontaneous Emission

$$\left(\frac{dN_0}{dt}\right)_{\text{abs}} = -B_{01}N_0\rho(\omega)$$

Einstein coefficients are the same $B_{01} = B_{10} = B$

$$\left(\frac{dN_0}{dt}\right)_{\text{stim}} = B_{10}N_1\rho(\omega)$$

phase, direction and frequency of emitted and external photons are identical.

$$\left(\frac{dN_0}{dt}\right)_{\text{spon}} = -A_{10}N_1$$

photons radiate independently in all directions. $\frac{dN_0}{dt}$ **does not** depend on $\rho(\omega)$.

Where $\rho(\omega)$ – spectral energy density of the isotropic radiation field at the frequency of the transition.

Gain

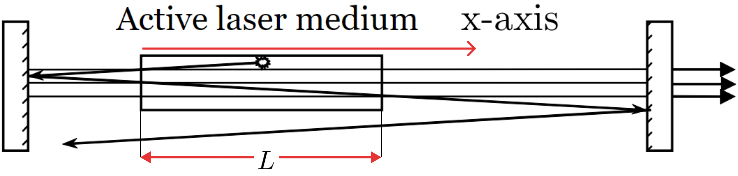


Figure: General laser scheme

Beer–Lambert–Bouguer law states that intensity of light $I(x)$ changes:

$$I(x) = I_0 \exp(\gamma x),$$

where γ – medium gain coefficient. With length L gain per period is called **laser gain**:

$$G = \exp\left(2\gamma L\right).$$

Population inversion

The fact that the number of spontaneously emitted photons does not depend on $\rho(\omega)$ gives us a reason to neglect $\left(\frac{dN_0}{dt}\right)_{\text{spon}}$ term. Number of photons emitted at a time dt:

$$\frac{dN}{dt} = \left(\frac{dN_0}{dt}\right)_{\text{abs}} + \left(\frac{dN_0}{dt}\right)_{\text{stim}} = B(N_1 - N_0)\rho(\omega) \tag{1}$$

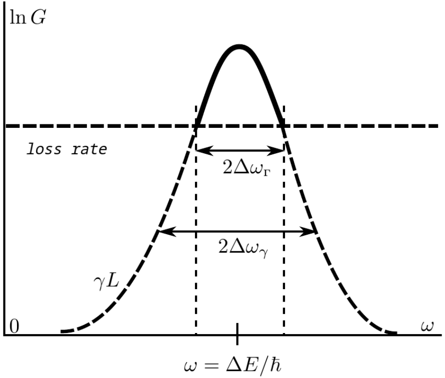
Therefore:

$$\gamma = \frac{dI}{I} = \frac{dN \cdot \hbar\omega}{\rho(\omega)} = B\frac{\hbar\omega}{v}(N_1 - N_0), \tag{2}$$

where $v = \frac{c}{n}$ – speed of light inside medium.

γ is positive if $N_1 > N_0$. This laser principle is called **population inversion**

Generation spectrum



Generation spectrum of He-Ne laser is defined by three factors: natural broadening, Doppler broadening and loss rate.

$\omega_n \approx 2\pi/\tau_n \Rightarrow \nu_n \approx 10^8$ Hz,

$\tau_n \approx 10^{-8}$ s – lifetime of 630 nm Ne transition.

$$\omega_D \approx \omega \frac{v_T}{c}, \approx 1.5 \cdot 10^9 \text{ Hz}$$

v_T – thermal motion velocity (assuming $T = 400$ K).
And loss rate reduces spectrum even further:

$$2\gamma L > -\ln K - \ln r_1 r_2,$$

r_1, r_2 – mirrors reflectance, K – part of remaining intensity.

Longitudinal Modes

Mode – stationary wave pattern in resonator with particular frequency and spatial distribution.

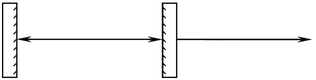


Figure: Longitudinal modes

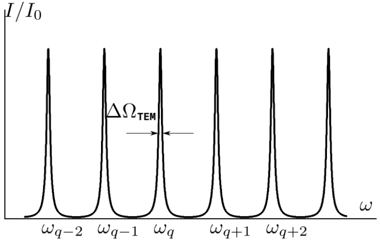
Most of the energy in resonator cavity is concentrated in standing waves. Therefore, condition on TEM_{00q} modes goes as follows:

$$L = q\frac{\lambda}{2} \ \Rightarrow \ \omega_q = q\frac{\pi c}{L} \approx 2\pi \cdot 100 \text{ MHz}, \ q \in \mathcal{N},$$

$L \approx 1.5$ m.

Modes spectrum

Every TEM_{00q} gives narrow spectrum $\omega_q \pm \Delta\Omega_{TEM}$.



Taking into account that

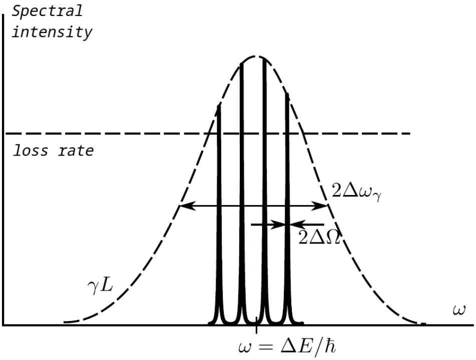
$$\Delta\Omega_{TEM} \approx \frac{\omega_q}{Q},$$

Q – Q-factor, and using common parameters of He-Ne laser we get:

$$\Omega_{TEM} \approx 2\pi \cdot 10^6 \text{ Hz}.$$

Singlemode and multimode

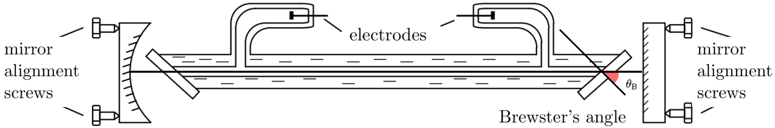
Applying modes spectrum to generation spectrum we get:

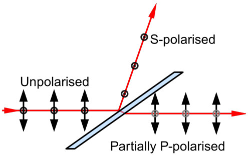


In generation spectrum, created by medium, resonator spectrum cuts off a few frequencies.
Estimating maximal number of modes:

$$N_m = \omega_D/\omega_n = 15.$$

Polarization of Laser Emission





To remove reflections from laser's windows the Brewster's angle properties can be used:

$$r_p = \frac{E_r}{E_i} = \left.\frac{n_2 \cos\theta_i - n_1 \cos\theta_t}{n_2 \cos\theta_i + n_1 \cos\theta_t}\right|_{\theta_i = \theta_B} = 0$$

Malus' law

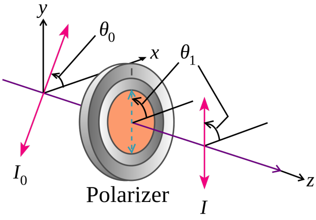


Figure: Malus' law (here $\theta_i = \theta_1 - \theta_0$)

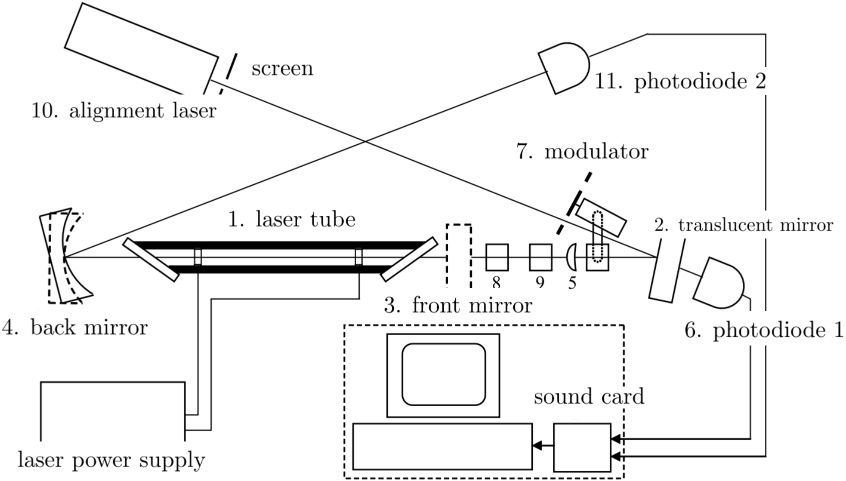
To study the laser's polarization, polaroid and Malus' law is used:

$$I(\theta_i) = I_0 \cos^2 \theta_i,$$

where I_0 is the initial intensity and θ_i is the angle between the light's initial polarization direction and the axis of the polarizer.

Measurements and Results

Experimental setup



Experimental Setup

Figure: Photo of laboratory setup

Laser Gain

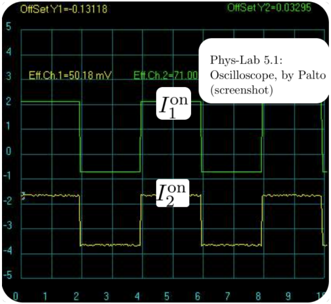


Figure: Phys-Lab 5.1: Oscilloscope, by Palto (screenshot)

Photodiodes are connected to the sound card with the ADC. This gives us a direct way to measure intensity.

$$G = \left(\frac{I_1^{\text{on}}}{I_1^{\text{off}}}\right) / \left(\frac{I_2^{\text{on}}}{I_2^{\text{off}}}\right),$$

where I_i^j – r.m.s. light intensity. Series of measurments gives the following result:

$$G = 1.029 \pm 0.006$$

Laser Polarization

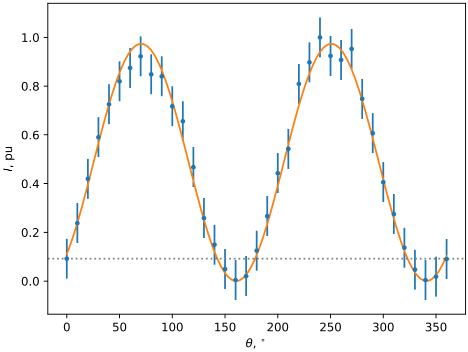


Figure: Intensity for different polaroid angles

Interpolating data series in the following form:

$$I(\theta) = A\cos^2(\Omega\theta + \theta_0),$$

We obtain the following parameters' values:

$$\Omega = 0.998 \pm 0.005$$

$$\theta_0 = (-70 \pm 1)^\circ$$

This demonstrates that Malus's law holds with a great precision.

Gain

The fact that the number of spontaneously emitted photons does not depend on $\rho(\omega)$ gives us a reason to neglect $\left(\frac{dN_0}{dt}\right)_{\text{spon}}$ term. Number of

1. laser tube

laser power supply

4. back mirror

3. front mirror

sound card

2. translucent mirror

6. photodiode 1

11. photodiode 2

7. modulator

screen

10. alignment laser Brewster's angle