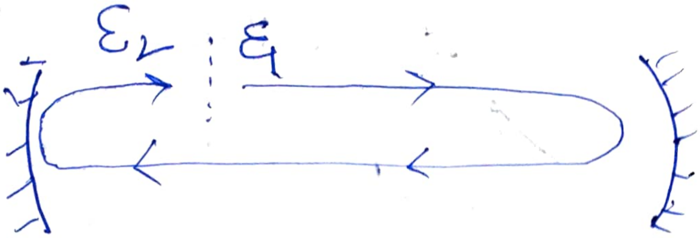
Laser Oscillation and Laser cavity modes



Round trip amplification in a laser cavity..

Condition for build-up of Laser Oscillation

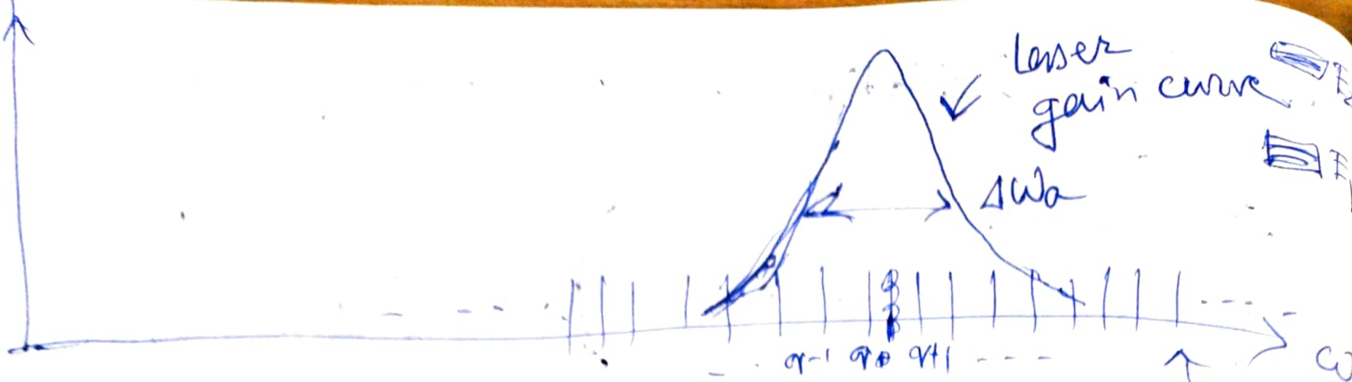
Small amount of spontaneous emission at laser transition frequency starts out along the axis of this device, being amplified as it goes.

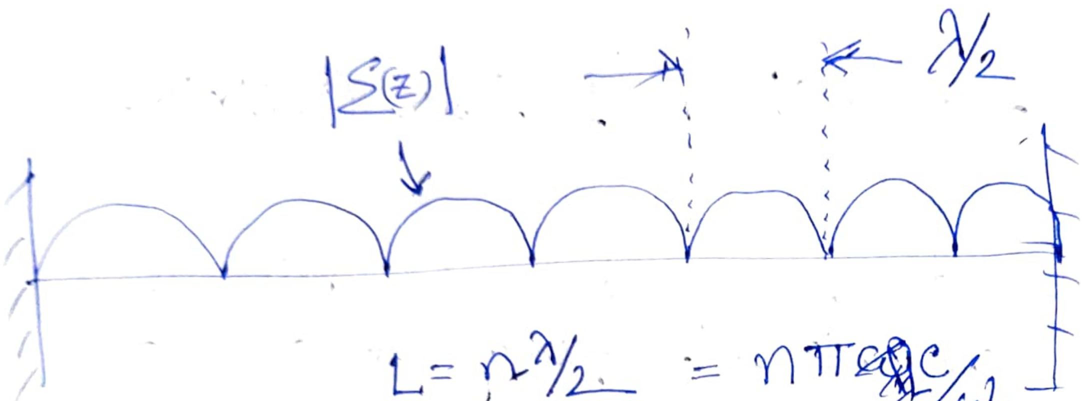
There are losses also. (Mirror are not 100% Reflective)

* Infact to get laser out one mirror is intentionally made partially transmittive.

* Total round-trip gain, including laser gain and mirror losses, is greater than unity

Noise-like spontaneous emission $\xrightarrow{\text{grow}}$ Coherent self sustained Oscillation in laser cavity.





$$L = n\lambda/2 = n\pi c/\omega_n$$

axial-mode resonance condition in a standing wave laser cavity..

$$\omega_n = \frac{n\pi c}{L}$$ $\cancel{\omega_n = \frac{L}{n\pi c}}$

allowed cavity modes

Separation of two consecutive axial modes

$$\Delta\omega_{ax} \equiv \omega_{q+1} - \omega_q = \frac{(q+1)\pi c}{L} - \frac{q\pi c}{L}$$

$$= 2\pi\frac{c}{2L}$$

$$q = \frac{\omega_q L}{\pi c} = \frac{2L}{\lambda_q}$$

Assume 2L is integer number of full wave length $2L = p$

$$= \frac{p}{\lambda_q} \approx 10^5 - 10^6$$

usually very large

$$\therefore \quad \Delta\omega_{ax} = 2\pi \frac{c}{p}$$

$\boxed{\text{H.W. for } L = 50 \text{ cm what is the separation of axial modes (mode spacing)?}}$

For ~~p~~practical Lasers mode spacing is smaller than the atomic linewidth $\Delta\omega_a$.

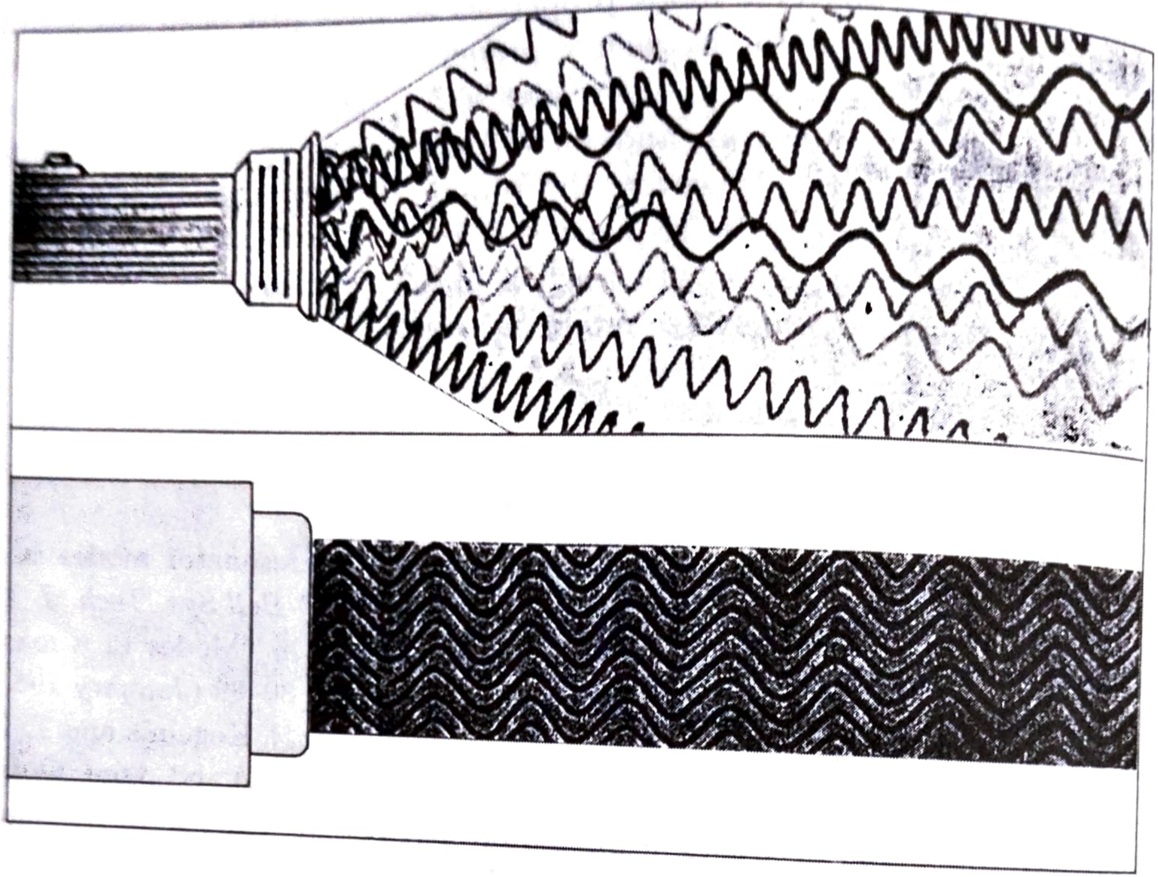


FIGURE 1.42
Incoherent light from a flashlight (top) and coherent light from a laser (bottom).

The output beams from most lasers ...

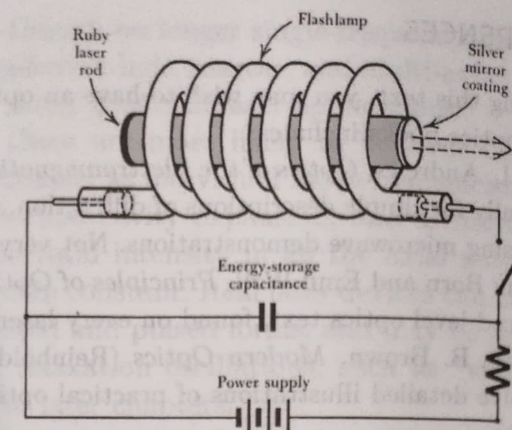


FIGURE 1.50
Design of the first pulsed ruby laser.

axis at large distance z in the far field will be $I = A_0 P_0/(z\lambda)^2$ *independent of the shape of the transmitting aperture.* Verify that this is compatible with the far-field angular spread $\Delta\theta \approx \lambda/d$ asserted in this section.

1.8 A FEW PRACTICAL EXAMPLES

Let us look at just a few practical examples of real lasers that illustrate some of the points we have been discussing, notably the ruby solid-state laser, and the helium-neon gas laser.

The Ruby Laser

The first laser of any type ever to be operated was in fact the flash-pumped ruby laser demonstrated by T. H. Maiman at the Hughes Research Laboratory in early 1960. We have already shown in Figure 1.10 the quantum energy levels associated with the unfilled $3d$ inner shell of a Cr^{3+} ion when this ion replaces one of the Al^{3+} ions in the sapphire or Al_2O_3 lattice. Up to $\sim$ 1% of such replacements can be made in the sapphire lattice to create pink ruby.

By placing such a ruby rod shaped roughly like a slightly overweight cigarette inside a spiral flashlamp filled with a few hundred Torr of xenon (Figure 1.50), and then discharging a high-voltage capacitor bank through this lamp, Maiman was able to use the blue and green wavelengths from this lamp to optically pump atoms from the $^4A_2$ ground level of the Cr^{3+} ions in the lattice into the broad $^4F_2$ and $^4F_1$ bands of excited levels. In ruby, atoms excited into these levels will relax very rapidly, and with close to 100% quantum efficiency, down into the comparatively very sharp ^2E levels, or R_1 and R_2 levels, lying $\sim$14,400 cm or 694 nm ($\sim$1.8 eV) above the ground level.

The ruby laser is, however, a three-level laser system, in which the lower laser level is also the ground energy level. By pumping hard enough, we can nonetheless cycle more than half of the Cr^{3+} ions from the ground level up through the pumping bands and into the highly metastable upper laser level, with its fluorescent lifetime of $\tau \approx 4.3$ msec. Thus, even though ruby is a three-level system rather than a four-level system, which is usually very unfavorable,

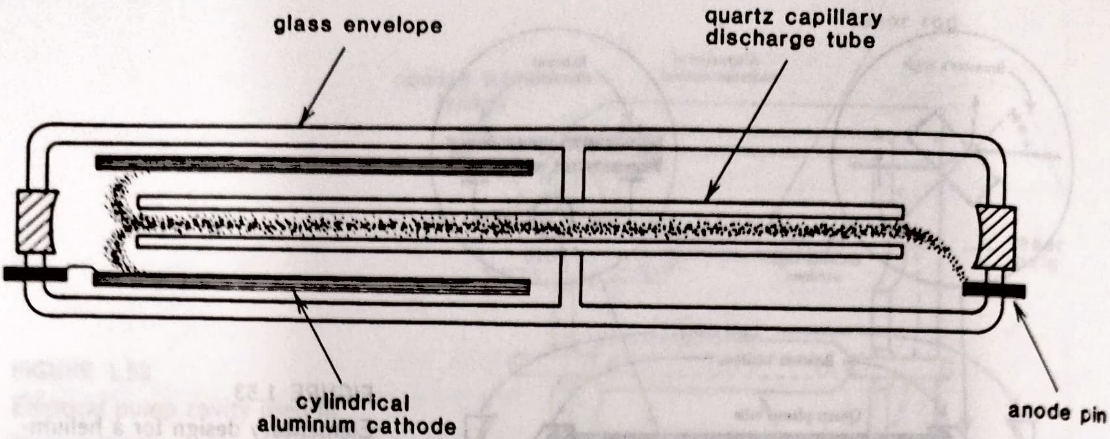


FIGURE 1.55
An internal-mirror He-Ne laser design.

the end mirrors are sealed directly onto the discharge tube, as part of the laser structure (Figure 1.55). Extreme cleanliness and purity of the laser gas fill is vital in the inherently low-gain He-Ne system; the tube envelope must be very carefully outgassed during fabrication, and a special aluminum cathode employed, at least in long-lived sealed-off lasers. The end mirrors themselves are carefully polished flat or curved mirrors with multilayer evaporated dielectric coatings, having as many as 21 carefully designed and evaporated layers to give power reflectivities in excess of 99.5% in some cases.

The pumping mechanism in the He-Ne laser is slightly more complex than those we have discussed so far. The helium gas, as the majority component, dominates the discharge properties of the He-Ne laser tube. Helium atoms have in fact two very long-lived or metastable energy levels, generally referred to as the 2^1S ("2-singlet-S") and 2^3S ("2-triplet-S") metastable levels, located ~20 eV above the helium ground level. Free electrons that are accelerated by the axial voltage in the laser tube and that collide with ground-state neutral helium atoms in the laser tube then can excite helium atoms up into these metastable levels, where they remain for long times.

There is then a fortuitous—and very fortunate—near coincidence in energy between each of these helium metastable levels and certain sublevels within the so-called $2s$ and $3s$ groups of excited levels of the neutral neon atoms, as shown in Figure 1.56. (The atomic energy levels in neon, as in other gases, are commonly labeled by means of several different forms of spectroscopic notation of various degrees of obscurity.)

When an excited He atom in one of the metastable levels collides with a ground-state Ne atom, the excited He atom may drop down and give up its energy, while the Ne atom simultaneously takes up almost exactly the same amount of energy and is thus excited upward to its near-coincident energy level. This important type of collision and energy-exchange process between the He and Ne atoms is commonly referred to as a "collision of the second kind." Any small energy defect in the process is taken up by small changes in the kinetic energy of motion of one or the other atom.

This process thus amounts to a selective pumping process, carried out via the helium atoms, which efficiently pumps neon atoms into certain specified excited energy levels. As Figure 1.56 shows, laser action is then potentially possible from these levels into various lower energy levels in the so-called $2p$ and $3p$ groups.