③ Construction of oscillator and the excitation process of He and Ne

When the He-Ne gas mixture is excited, all possible transitions occur at a steady rate due to spontaneous emission. However, most of the photons are emitted with a random direction and phase, and only light at one of these wavelengths is usually desired in the laser beam. At this point, we have basically the glow of a neon sign with some helium mixed in!

To turn spontaneous emission into the stimulated emission of a laser, a way of selectively amplifying one of these wavelengths is needed and providing feedback so that a sustained oscillation can be maintained. This may be accomplished by locating the discharge between a pair of mirrors forming what is known as a Fabry-Perot resonator or cavity. One mirror is totally reflective and the other is partially reflective to allow the beam to escape. One mirror may be perfectly flat (planar) or both may be spherical with a typical Radius of Curvature (RoC = 2 * focal length) slightly longer that the length of the cavity (L) or even longer. Where both mirrors have an RoC equal to L, the configuration is called 'confocal' (the focii of the two mirrors are coincident), but it is marginall stable, so the RoCs will be at least slightly longer than L. A cavity with two planar mirrors is borderline stable and essentially impossible to align or maintain in alignment over time, so it is never used in He-Ne lasers (but is in some pulsed solid state and other lasers). Curved mirrors result in an easier to align more stable configuration but are more expensive than planar mirrors to manufacture and are not as efficient since less of the lasing medium volume is used (think of the shape of the beam inside the bore). The confocal arrangement represents a good compromise between a true spherical cavity ($r = 1/2 * L$) which is easiest to align but least efficient and one with plane parallel mirrors (f = infinity) which is most difficult to align but uses the maximum volume of the lasing medium. (But as noted above, for a practical confocal cavity, RoCs slightly longer than L are used to assure stability.)

These mirrors are normally made so that the two mirrors together has peak reflectivity at the desired laser wavelength. (For technical reasons, it's sometimes easier to make mirrors like cliffs – high reflectivity that drops to low reflectivity at a given wavelength, in either direction – than to guarantee a particular peak reflectivity.) When a spontaneously emitted photon resulting from the transition corresponding to this peak happens to be emitted in a direction nearly parallel to the long axis of the tube, it stimulates additional transitions in excited atoms. These atoms then emit photons at the same wavelength and with the same direction and phase. The photons bounce back and forth in the resonant cavity stimulating additional photon emission. Each pass through the discharge results in amplification – gain – of the light. If the gain due to stimulated emission exceeds the losses due to imperfect mirrors and other factors, the intensity builds up and a coherent beam of laser light emerges via the partially reflecting mirror at one end. With the proper discharge power, the excitation and emission exactly balance and a maximum strength continuous stable output beam is produced.

Spontaneously emitted photons that are not parallel to the axis of the tube will miss the mirrors entirely or will result in stimulated photons that are reflected only a couple of times before they are lost out the sides of the tube. Those that occur at the wrong wavelength will be reflected poorly if at all by the mirrors and any light at these wavelengths will die out as well.

Summary of the He-Ne Lasing Process

The He-Ne laser is a 4 level laser (see the table above for the specific energy level transitions for the common wavelengths):

Collisions with excited helium atoms raise the neon atoms from level 1 (ground state) to level 4 (which is the 3s state for visible wavelengths).

The visible lasing transitions are from the 3s to various 2p states (depending on wavelength) or level 3.

The neon atoms then decay rapidly to the 1s state or level 2.

Return to the ground state or level 1 is aided by collisions with the He-Ne laser tube's bore/capillary walls.

For most common IR wavelengths, level 4 is the 2s state and level 3 are various 2p states. However, the very strong 3.93 um line originates from the 3s state just like the visible wavelengths – and is the reason it competes with them in long He-Ne tubes and must be suppressed to optimize visible output.

The 's' states of neon have about 10 times the lifetime of the 'p' states and thus support the population inversion since a neon atom can hang around in the 2s state long enough for stimulated emission to take place. However, the limiting effect is the decay back to level 1, the ground state, since the 1s state also has a long lifetime. Thus, one wants a narrow bore to facilitate collisions with its walls. But this results in increased losses. Modern He-Ne lasers operate at a compromise among several contradictory requirements which is one reason that their maximum output power is relatively low.

Approximate Reference Values for the Red (632.8 nm) He-Ne Laser

Here are some common values and relationships that may come in handy when doing calculations. These are not the most exact since they may depend on other factors like the precise gas-fill and environmental conditions but are generally good enough for government work.

Wavelength: 632.8 nm.

Optical Frequency: 474 THz.

Gain Bandwidth of Neon: 1.6 GHz or 2.136 nm.

1 nm at 632.8 nm: 749 GHz.

1 GHz at 632.8 nm: 1.335 nm.