ENGINEERING PHYSICS

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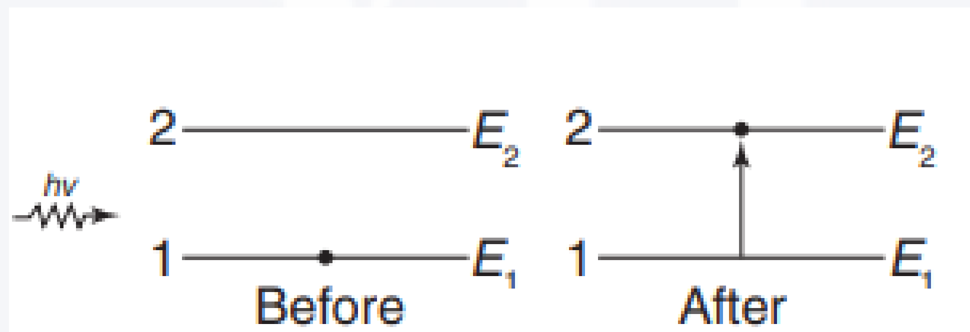
Excitation of an Atom

It is well known that an atom can be excited by supplying energy with an amount equal to the difference of its any two energy levels. Then after a very short duration of time the atom shall radiate energy when it comes down to its lower energy state. An electron undergoes a transition between two energy states E1 and E2 if the atom emits or absorbs a photon of appropriate energy as per the relation E2 – E1 = hv, where h is Planck constant and v is the frequency of radiation.

$$E_2 = E_1 + h\nu$$

$$E_2 - E_1 = \Delta E = h\nu$$



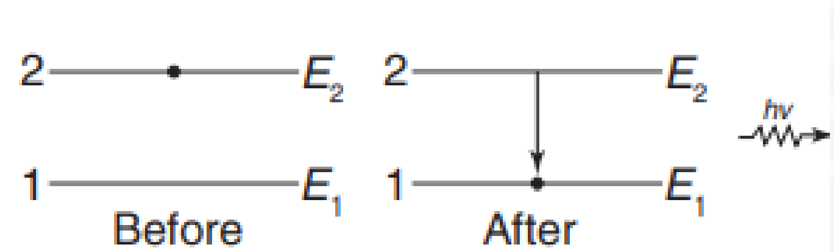
Probability of Occurrence: Absorption

The probability of occurrence of this absorption from state 1 to state 2 is proportional to the energy density u(v) of the radiation

P12 = B12 u(v)

Spontaneous Emission

This is the natural radiation decay process that is inherent in all excited states of all materials. However, such emission is not always the dominant decay process.

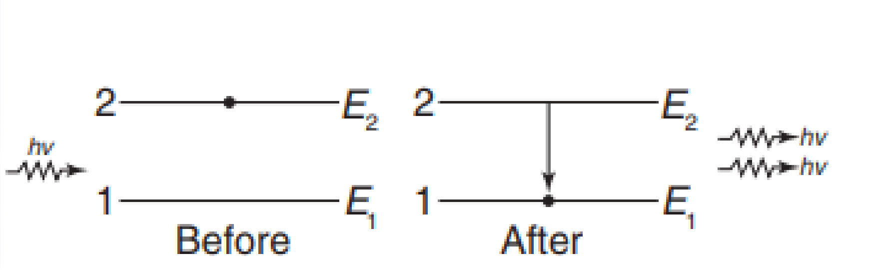


The probability of occurrence of this spontaneous emission transition from state 2 to state 1 depends only on the properties of states 2 and 1 and is given by

$$P'_{21} = A_{21}$$

Stimulated Emission

Einstein was the first to point out a third possibility of induced emission, in which an incident photon of energy hv causes a transition from upper state E2 to the lower state E1, as shown in Fig. 4.3. This occurs when hv = ΔE = $E_2 – E_1$



Normal Population: In a system of atoms in thermal equilibrium, the number of atoms in the ground state is generally much greater than in a higher energy state.

Population Inversion: A state in which the number of atoms in higher energy state is greater than that of lower energy state

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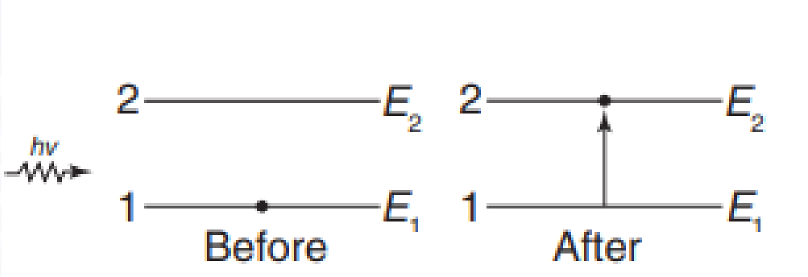

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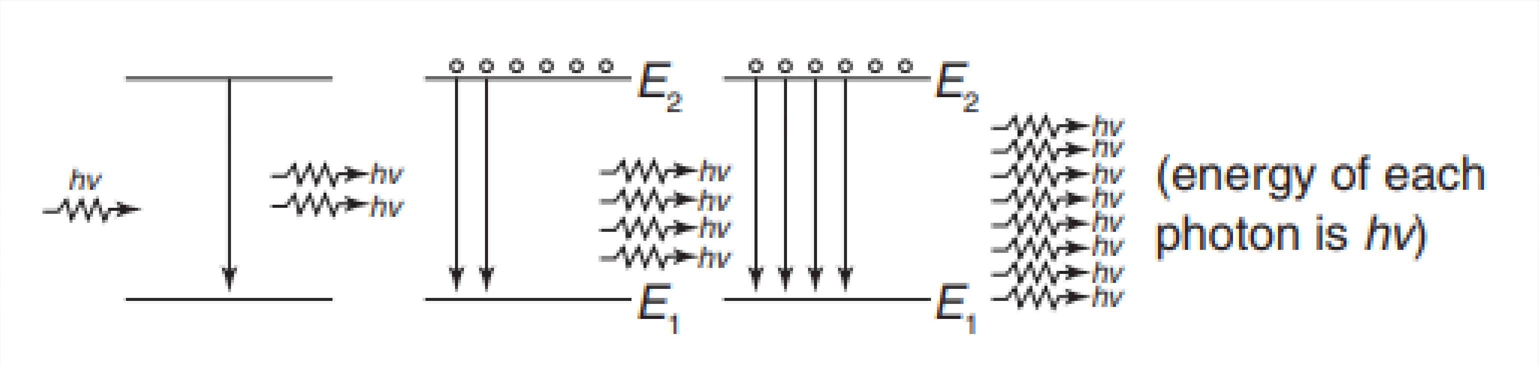
Stimulated Emission



Probability of occurrence of stimulated emission **= proportional to the energy density u(n) of the radiation.**

$$P''_{21} = B_{21}\, u(v)$$

There are two different possibilities for the emission (from 2 to 1). Therefore, the total probability of emission from upper level 2 to upper level 1

$$P_{21} = P'_{21} + P''_{21}$$

OR $$P_{21} = A_{21} + B_{21} u(v)$$

Relation: Einstein's Coefficients

Let N1 and N2 be the number of atoms at any instant in the state 1 and 2, respectively. The probability of absorption transition for number of atoms from state 1 to 2 per unit time is given by

$$N_1 P_{12} = N_1 B_{12} U(v)$$

The total probability of transition for number of atoms from state 2 to 1, either by spontaneously or by stimulated emission per unit time is given by

$$N_2 P_{21} = N_2 [A_{21} + B_{21} u(v)]$$

Relation: Einstein's Coefficients

In thermal equilibrium at temperature T, the absorption and emission probabilities are equal and thus

$$N_1 P_{12} = N_2 P_{21}$$

$$N_1 B_{12}\, u(v) = N_2[A_{21} + B_{21}\, u(v)]$$

$$u(v) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}}$$

$$u(v) = \frac{A_{21}}{B_{21}} \frac{1}{(N_1/N_2)(B_{12}/B_{21}) - 1}$$

$$u(v) = \frac{A_{21}}{B_{21}} \frac{1}{(N_1/N_2) - 1}$$

According to Boltzmann's law, the distribution of atoms among the energy states E1 and E2 at the thermal equilibrium at temperature T is given by

$$\frac{N_1}{N_2} = \frac{e^{-E_1/kT}}{e^{-E_2/kT}} = e^{(E_2 - E_1)/kT}$$

$$\frac{N_1}{N_2} = e^{hv/kT}$$

Relation: Einstein's Coefficients

Here k is the Boltzmann constant.

From Eq. (x), we can write

$$u(v) = \frac{A_{21}}{B_{21}} \frac{1}{e^{hv/kT} - 1}$$

Planck's radiation formula yields the energy density of radiation $u(v)$ as

$$u(v) = \frac{8\pi h v^3}{c^3} \frac{1}{e^{hv/kT} - 1}$$

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h v^3}{c^3}$$

Population Inversion

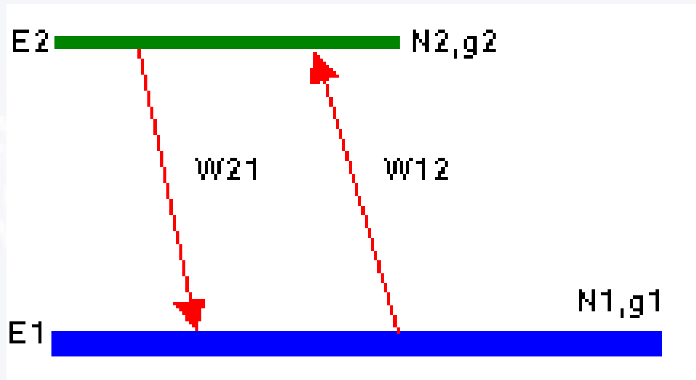
Suppose in a system, there are three energy states, E1 (population N1), E2 (population N2) and E3 (population N3) in equilibrium.

1. Energy Scenario - E1 < E2 < E3
2. Uppermost level E3 is populated least whereas the lowest level E1 is populated most. Since the population in these states follow the trend N1 > N2 > N3.
3. The system shall absorb photons rather than emitting them.

However, when a sizable population of electrons is achieved in the upper levels, the condition is known as population inversion (a non-equilibrium state). This condition sets the stage for stimulated emission of radiation, i.e., multiple photons, as the first few randomly emitted spontaneous photons trigger stimulated emission of more photons and those stimulated photons induce still more stimulated emissions, and so on.

Population Inversion: Schemes

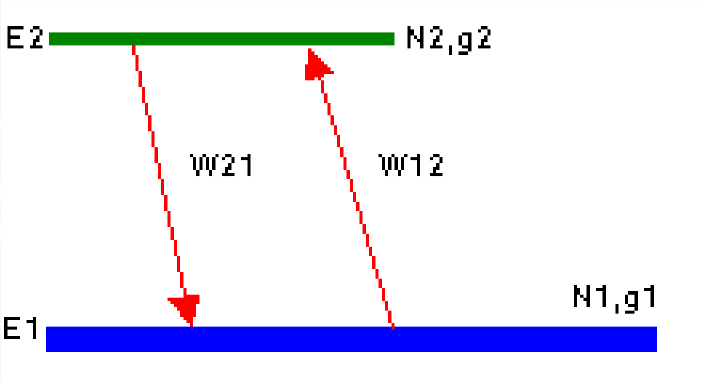
Two Level Systems



Consider the case of two-level system having energies E1 and E2 such that E2 > E1. We can easily find that the Einstein coefficients (or constants) for the upward (B12) and downward (B21) transitions are equal, i.e., B12 = B21. It means, even with strong pumping, the population distribution in upper and lower levels can only be made equal, i.e., the optical pumping will at most only achieve equal population of a two-level system. This is due to the fact that the probabilities for raising an electron to the upper level and inducing the decay of an electron to the lower level (stimulated emission) are exactly the same.

Population Inversion: Schemes

Two Level Systems

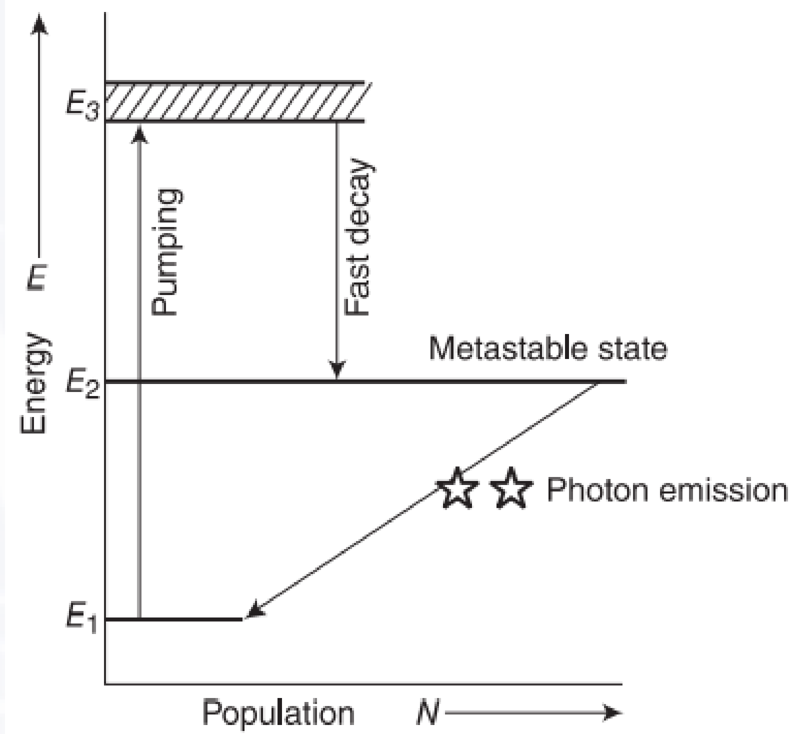


In other words,

We can say that the numbers of electrons going up and coming down will be the same when both the levels are equally populated. So, we cannot achieve population inversion in the case of two energy levels system. Therefore, optical as well as any other pumping method needs either three or four level systems to attain population inversion. The solution is to use a third metastable level, where the electrons can stay for longer duration

Population Inversion: Schemes

Three Level Systems



Bloembergen proposed a mechanism where atoms are pumped into an excited state by an external source of energy, for example by an electric pulse or an optical illumination. In addition to this excited state (say E3), the system has a metastable state (say E2) and the atoms from the upper level E3 decays spontaneously to this metastable state

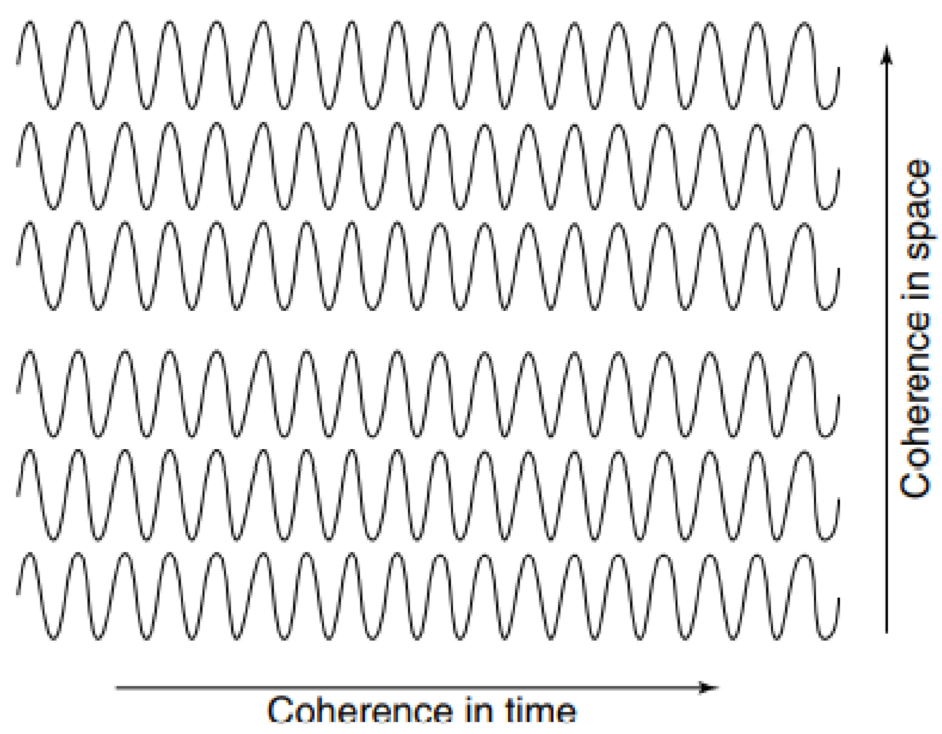
The population inversion can be achieved only by pumping into a higher lying level, followed by a rapid radiative or non-radiative transfer into the upper laser level.

Laser Light: Characteristics

laser radiation is achieved by the process of stimulated emission and the laser beam is highly intense and directional. This radiation of a very pure frequency has the following main characteristics.

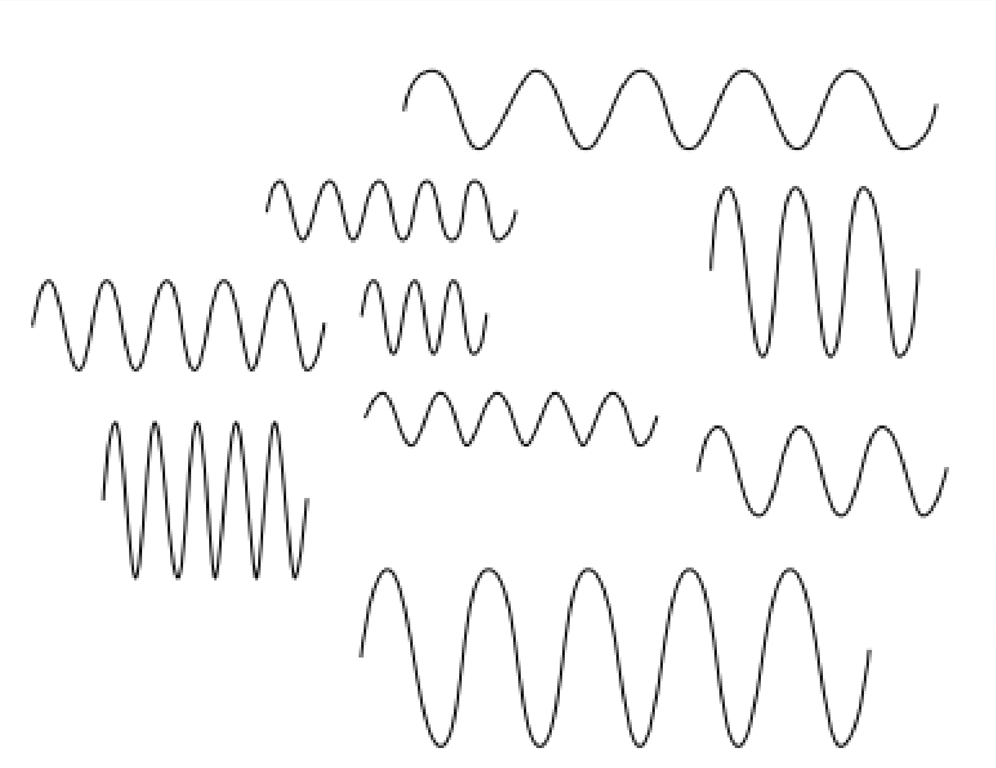
Coherent

In simple words, the meaning of coherent is highly ordered. The word coherent comes from another word "Cohero" which has the meaning "to stick together".



Laser Light: Characteristics

Not -Coherent



Ordinary light is not coherent because it comes from independent atoms which emit on the time scale of 10^{-8} seconds.

Laser Light: Characteristics

Monochromatic: The simple meaning of this word is that it is pure in colour or wavelength. The light from a laser typically comes from one atomic transition with a single precise wavelength.

Collimated: Collimated means it does not spread out much. The light from a typical laser emerges in an extremely thin beam with very little divergence, i.e, the beam is highly collimated.

Laser: Components

In order to understand the working principle of a laser, we should first know about the essential components of the laser. These are given below.

(I) Pumping: The method of raising the molecules or atoms from their lower energy state to higher energy state is known as optical pumping. The optical pumping is needed for achieving population inversion which is precondition for stimulated emission. In this case, the rate of stimulated emission will exceed the rate of stimulated absorption. Hence, the intensity of light will increase during each pass through the medium.

(II) Active System: A system in which the population inversion is to be achieved is called as active system or the gain medium for a laser. Laser systems are named based on the makeup of the gain medium, which may be a gas, liquid or solid. The energy levels in the gain medium, those participate in the radiation, determine the wavelength of laser radiation. Laser action has been observed in over half of the known elements. Two of the most popular transitions in gases are 632.8 nm visible radiation from neon and the 10.6 mm infrared radiation from the CO_2 molecule.

Laser: Components

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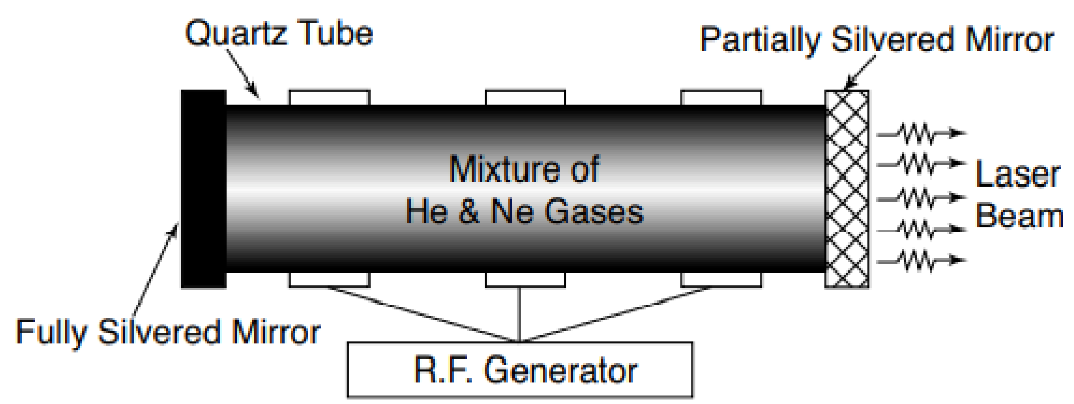
(iii) Resonant Cavity: In a laser, the active system or the gain medium is enclosed in an optical cavity (or resonant cavity) usually made up of two parallel surfaces, one of which is perfectly reflecting reflector and the other surface is partially reflecting reflector. In this resonant cavity, the intensity of photons is raised tremendously through stimulated emission process.

He-Neon Laser

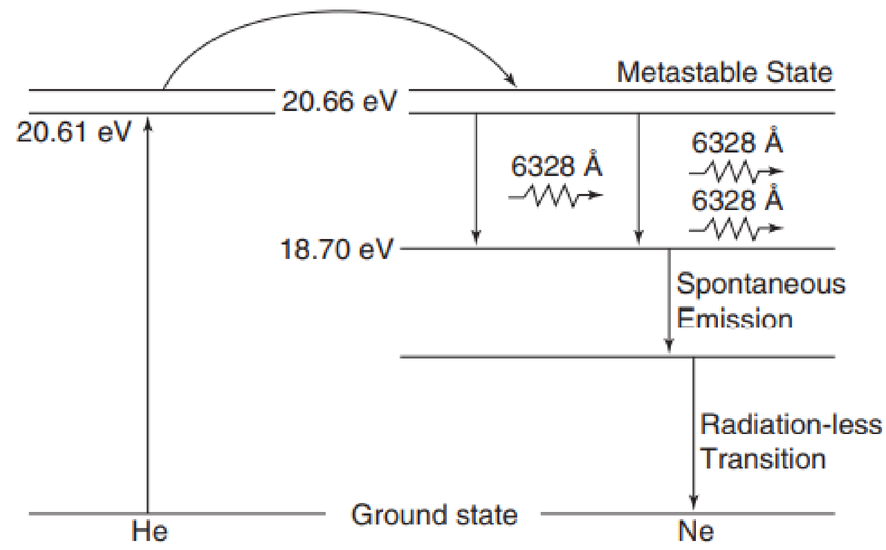
As we know that the output beam of the ruby laser is not continuous. To overcome this drawback, the gas filled laser was made by A. Javan, W. Bennett and D. Herriott in 1961.



He-Neon Laser

Mirrors: One of them being partially silvered (90% reflective) and the other one is fully silvered (100% reflective).

In this laser system, a quartz tube is filled with a mixture of helium and neon gases in the ratio 10:1 respectively, at a pressure of about 0.1 mm of mercury (Fig. 4.15). This mixture acts as the active medium. Helium is pumped upto the excited state of 20.61 eV by the electric discharge. The energy level diagram of He-Ne laser is shown in Fig. 4.16



Here, it can be seen that the excited level of He at 20.61 eV is very close to a level in Ne at 20.66 eV. It is so close that upon collision of a He and a Ne atom, the energy can be transferred from the He to the Ne atoms. Thus, the excited He atoms do not return to their ground state by spontaneously emitting photons rather they transfer their energy to the Ne atoms through collisions. As mentioned, such an energy transfer can take place when the two colliding atoms have identical states. Thus, the He atoms help achieving a population inversion in the Ne atoms.

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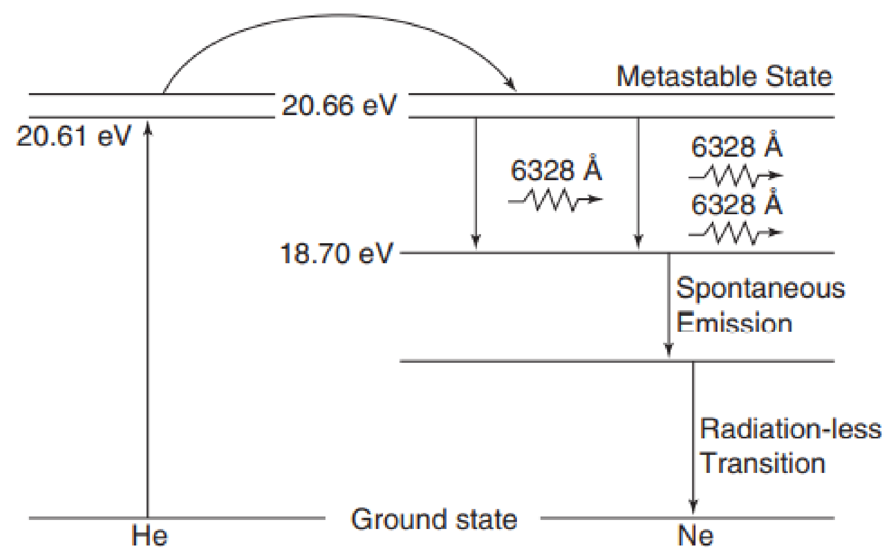

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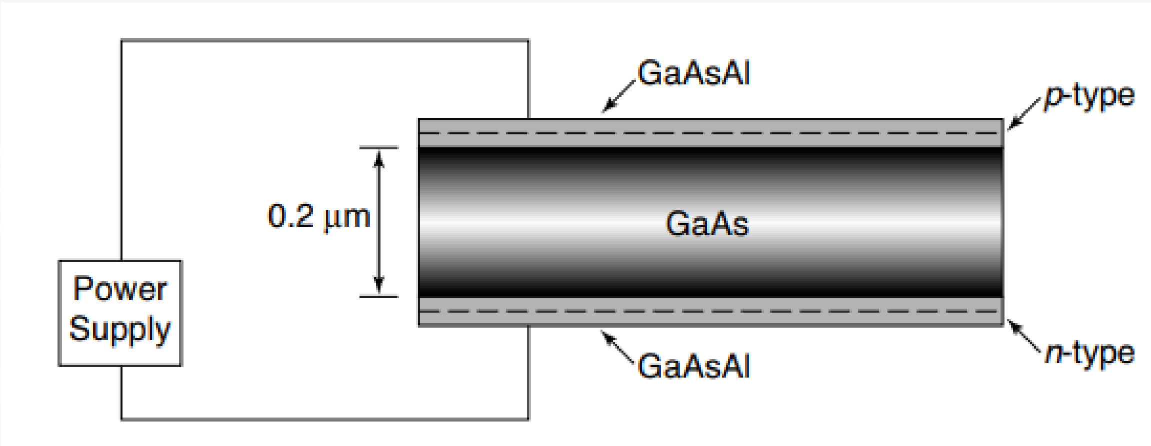
Semiconductor Lasers

Semiconductor laser differs from the solid state and gas lasers in many aspects. It has remarkably small size, exhibits high efficiency and can be operated at low temperature.

When the current is passed through a p-n junction diode in forward bias, holes move from p-region to n-region and the electrons move from n-region to p-region. These electrons and holes are recombined in the junction region and emit photons due to the transition of electrons from the conduction band to the valence band

This results in stimulated radiation coming from a very narrow region near the junction. The action is intensified by increasing the current and decreasing the junction thickness

Semiconductor Lasers



Semiconductor laser is made up of an active layer of gallium arsenide (GaAs) of thickness 0.2 microns. This is sandwiched in between a n-type GaAsAl and p-type GaAsAl layer as shown in Figure. The resonant cavity is provided by polishing opposite faces of the GaAs crystal and the pumping occurs by passing electrical current from an ordinary source (Power Supply). From this system GaAs semiconductor, laser beams of wavelength ranging from 7000 Å to 30,000 Å can be produced