UNIT I PART-A

LASERS

LASER:

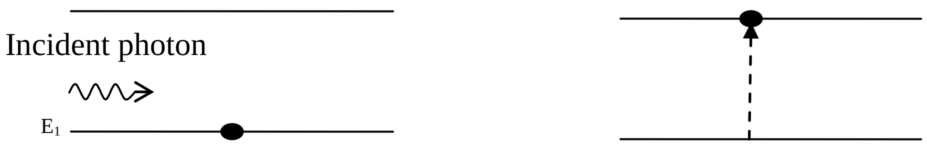
The acronym for LASER is **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

Interaction of Radiation with Matter:

Radiation Interacts with matter under appropriate conditions. The interaction leads to an abrupt transition from one energy level to another. There are 3 kinds of transition involving electromagnetic radiation is possible between two energy levels E_1 and E_2 in an atom.

1. **Induced Absorption:**

If the atom is initially in the lower state E_1, it can be raised to E_2 by absorbing a photon of energy $E_2 – E_1 = h\gamma$. This process is called induced absorption.

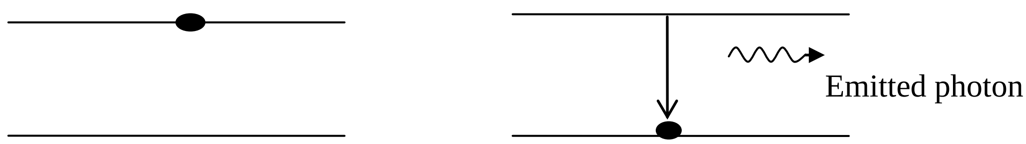


a) Before b) After

Atom + Photon ⟶ Atom*

2. Spontaneous emission:

If the atom is initially in the upper energy state E_2, it can drop to E_1 by emitting a photon of energy $h\gamma$, this is spontaneous emission.

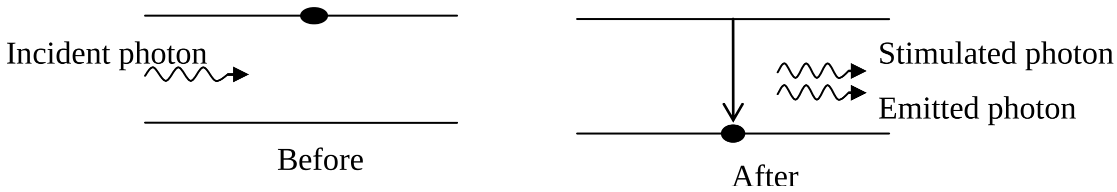


a) Before b) After

Atom* ⟶ Atom + Photon

3. Stimulated emission:

Einstein suggested that under certain conditions, it is possible to stimulate an excited atom to emit a photon by another matching photon. An atom in an excited state may under the influence of electromagnetic field of a photon of frequency γ incident upon it, jump to a lower energy state, emitting additional photon of same frequency γ. This is known as stimulated emission of radiation. The radiated light waves are exactly in phase with the incident ones. So the result is an enhanced beam of coherent light.



$$\text{Atom}^* + \text{Photon} \longrightarrow \text{Atom} + (\text{Photon} + \text{Photon})$$

Boltzmann factor:

At thermal equilibrium the ratio of population of the upper energy state to the lower energy state is given by,

$$\left(\frac{N_2}{N_1}\right) = e^{-\left(\frac{E_2 - E_1}{KT}\right)} = e^{-\frac{h\nu}{KT}}$$

$E_2 > E_1$, $e^{-(h\gamma/KT)} < 1$, Then $N_2 < N_1$

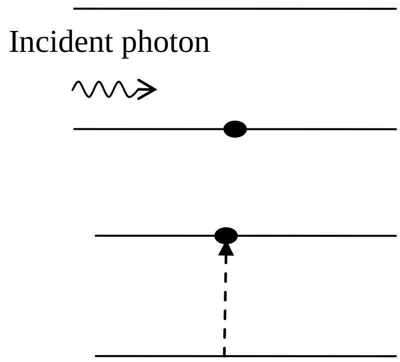
Einstein's coefficients [Expression for energy density at thermal equilibrium]

Consider two energy states E_1 and E_2 of a system of atoms. Let N_1 and N_2 be the atoms with energy E_1 and E_2 per unit volume of the system. N_1 and N_2 are called the number density of atoms in the states 1 and 2 respectively. Let the radiation be incident on the system. Let 'U_γ dγ' be the energy incident per unit volume of the system in the frequency range γ and $\gamma + d\gamma$. Here 'U_γ' is energy density.

Case i) Induced absorption

Here the radiation absorbed is a frequency γ. The number of such absorption per unit time, per unit volume is called rate of absorption. The rate of absorption depends upon,

a) the number density of lower energy state. i.e., N_1
b) energy density, i.e., U_γ



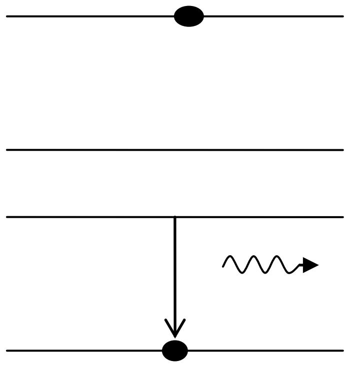
$\therefore$ Rate of absorption α N_1U_γ

Or, Rate of absorption = B_{12} N_1U_γ ---- (1)

Where 'B_{12}' is constant of proportionality called Einstein's coefficient of induced absorption,

Case ii) Spontaneous emission

Here transition is voluntary. The number of spontaneous emissions per unit time, per unit volume is called rate of spontaneous emission. It depends upon only the number density in the higher energy state, i.e., N_2

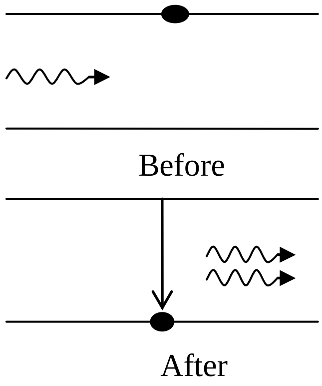


$\therefore$ Rate of spontaneous emission = $A_{21}N_2$ ---- (2)

Where 'A_{21}' is called Einstein's coefficient of spontaneous emission.

Case iii) Stimulated emission

Since the system requires an external photon of appropriate frequency γ, to stimulate the atom. The number of stimulated emissions per unit time, per unit volume, called rate of stimulated emission, is proportional to



a) the number density of the higher energy state, i.e., N_2
b) the energy density, i.e., U_γ

∴ Rate of stimulated emission = $B_{21}\, N_2\, U_\gamma$ ---- (3)

Where 'B_{21}' is called Einstein's coefficient of stimulated emission.

Under thermal equilibrium, the number of photons absorbed by the system per second must be equal to the number of photons it emits per second by both the stimulated and the spontaneous emission processes.

i.e., Rate of absorption = Rate of spontaneous emission + Rate of stimulated emission

From equations (1), (2) and (3),

$$B_{12}\, N_1 U_\gamma = A_{21} N_2 + B_{21}\, N_2\, U_\gamma$$

Or, $$U_\gamma\, (B_{12}\, N_1 - B_{21}\, N_2) = A_{21} N_2$$

Or, $$U_\gamma = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2}$$

By rearranging the above equation, we get,

$$U_\gamma = \frac{A_{21}}{B_{21}} \left[\frac{1}{\frac{B_{12}}{B_{21}} \frac{N_1}{N_2} - 1} \right] \qquad \text{---- (4)}$$

But, by Boltzmann's law, we have,

$$\left(\frac{N_2}{N_1} \right) = e^{-\left(\frac{E_2 - E_1}{KT} \right)} = e^{-\frac{h\nu}{KT}}$$

$$\therefore \qquad \frac{N_1}{N_2} = e^{\frac{h\gamma}{KT}}$$

$\therefore$ Equation (4) becomes,

$$U_\gamma = \frac{A_{21}}{B_{21}}\left[\frac{1}{\frac{B_{12}}{B_{21}}e^{\frac{h\gamma}{KT}} - 1}\right] \qquad \text{---- (5)}$$

According to Planck's law, the equation for 'U_γ' is

$$U_\gamma = \frac{8\pi h\gamma^3}{c^3}\left[\frac{1}{e^{\frac{h\gamma}{KT}} - 1}\right] \qquad \text{---- (6)}$$

By comparing equations (5) and (6), we have,

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\gamma^3}{c^3} \qquad \text{and} \qquad \frac{B_{12}}{B_{21}} = 1 \qquad \text{or } B_{12} = B_{21}$$

i.e., The probability of induced absorption is equal to the probability of stimulated emission.

$\therefore$ At thermal equilibrium the equation for energy density is

$$U_\gamma = \frac{A}{B\left[e^{\frac{h\gamma}{KT}} - 1\right]}$$

Discussions of Einstein's coefficients

i) Dependence of emission on frequency

We know that, $\frac{A_{21}}{B_{21}} = \frac{8\pi h\gamma^3}{c^3}$ --- (1)

Where 'A_{21}' is called Einstein's coefficient of spontaneous emission.

and 'B_{21}' is called Einstein's coefficient of stimulated emission.

$$\Rightarrow \frac{A_{21}}{B_{21}}\ \alpha\ \gamma^3$$

Since $\gamma = \left(\frac{\Delta E}{h}\right)$, When the energy difference between the two levels E_1 and E_2 is large,

Then, $\left(\frac{A_{21}}{B_{21}}\right) >> 1 \quad OR \quad A_{21} >> B_{21}$

$\Rightarrow$ For higher ΔE values, the probability of spontaneous emission is more.

ii) System in thermal equilibrium

We know that, $U_{\gamma} = \frac{8\pi h\gamma^3}{c^3}\left[\frac{1}{e^{\frac{h\gamma}{KT}}-1}\right]$ -- (2) and $\frac{A_{21}}{B_{21}} = \frac{8\pi h\gamma^3}{c^3}$

$$\Rightarrow \frac{A_{21}}{B_{21}U_{\gamma}} = \left(e^{\frac{h\gamma}{KT}}-1\right) \text{--- (3)}$$

Case (a): hγ >> KT: $e^{\frac{h\gamma}{KT}} >> 1$

Hence equ (3) $\Rightarrow \left(\frac{A_{21}}{B_{21}}\right) >> 1 \quad OR \quad A_{21} >> B_{21}$

Spontaneous emissions are much larger.

Case (b): hγ = KT: Here $e^{\frac{h\gamma}{KT}}$ will be low and comparable to 1. ∴ A_{21} and B_{21} are comparable, which means that stimulated emission becomes significant

$B_{21} >> A_{21}$

Case (c): hγ << KT: $\left(e^{\frac{h\gamma}{KT}}-1\right) << 1$ and $\left(\frac{A_{21}}{B_{21}}\right) << 1 \quad OR \quad B_{21} >> A_{21}$

Hence for lower frequencies, stimulated emissions dominate. This is what we observe at room temperature.

iii) Non-equilibrium conditions leading to amplification

We know that, Rate of emissions = $A_{21}N_2 + B_{21} N_2 U_{\gamma}$ ---- (4)

Rate of absorption = $B_{12} N_1 U_{\gamma}$ ---- (5)

$$\frac{\text{Rate of emissions}}{\text{Rate of absorption}} = \frac{A_{21}N_2 + B_{21}N_2U_{\gamma}}{B_{12}N_1U_{\gamma}} = \frac{N_2}{N_1}\left[\frac{A_{21}+B_{21}U_{\gamma}}{B_{12}U_{\gamma}}\right]$$

Since $B_{12} = B_{21}$

$$\frac{\text{Rate of emissions}}{\text{Rate of absorption}} = \frac{N_2}{N_1}\left[\frac{A_{21}}{B_{12}U_{\gamma}}+1\right] \text{--- (6)}$$

If ΔE < < KT i.e., hγ < < KT (Case 1)

$$\text{Then} \quad \left[\frac{A_{21}}{B_{12}U_{\gamma}} << 1\right]$$

Then equation (6) becomes

$$\frac{\text{Rate of emissions}}{\text{Rate of absorption}} = \frac{N_2}{N_1}$$

We know that in normal condition $N_2 < N_1$. If we made $N_2 > N_1$ by some means, the system will be in non equilibrium condition since by Boltzmann factor.

In this case, rate of emission exceeds the rate of absorptions. Further if the photons emitted in a particular direction are returned in to the system by reflecting them back and forth, then the rate of stimulated emission exceeds the absorption rate. If right conditions are provided, all the stimulated emissions could be arranged to be identical in respect of wavelength, phase and direction to the starting stimulating radiation, then that itself has been amplified. To achieve this we should maintain $N_2 > N_1$ always. This forms the basis for functioning of every laser.

Characteristics features of lasers:

Laser light is characterized by

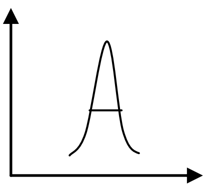
1. Directionality.

Laser light is highly directional and highly collimated beam of light.

2. Monochromaticity.

Laser light is characterized by a high degree of monochromatic.

$$\Delta\lambda = 10^{-7} \text{ Å}$$



3. Coherence.

Laser light has high degree of coherence. There are two types of coherence,

a) Temporal coherence

If we consider two waves in the same wavefront, and the difference between the wavelengths of them is less, then the source is said to be highly temporal coherence. Since laser light is highly monochromatic, it has a high temporal coherence.

b) Spatial coherence

Consider phase difference between two points in a wave at any time, separated by some distance. If the phase difference between the same two points in a wave at later time, separated by same distance is constant, then one can say that the light is highly spatially coherent.

4. Light intensity.

Because of the phase correlation and high monochromaticity, the laser light is more intense among all the known sources.

5. Focussability.

Since the laser light is highly monochromatic and also a highly collimated beam, it can brought to a sharp focus by using lens. It is so sharp that, the diameter of the spot will be close to the wavelength of the focused light.

Laser action:

Conditions for Laser action

The system should have

1. Population inversion
2. Metastable state

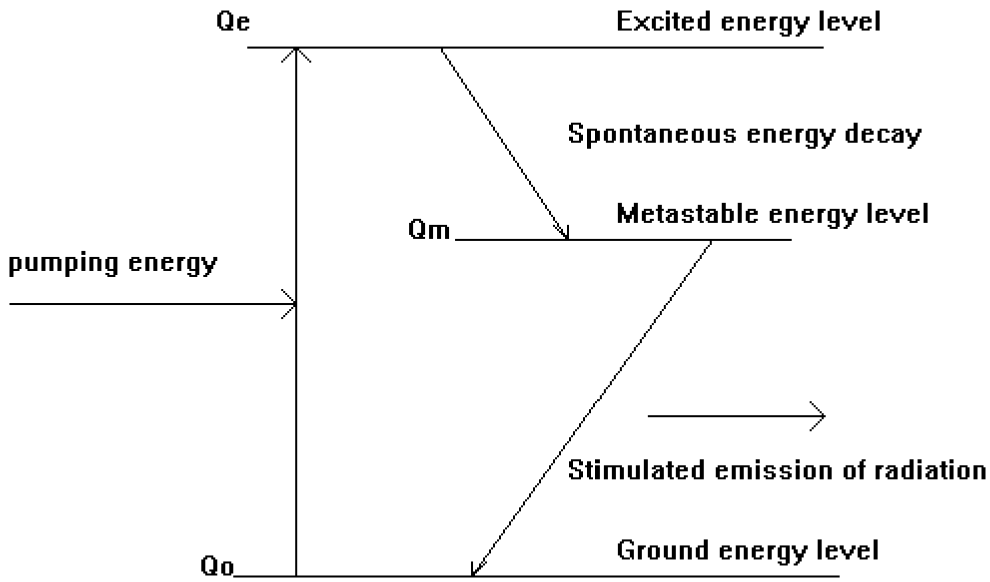
Population inversion:

Any material consists of collection of atoms, molecules or ions. Under normal circumstances there is always a large number of atoms in the lower energy state than in the excited state. Then by some means, we can make number of atoms (N_2) in the excited state is grater than the number of atoms (N_1) in lower state, then one can say that population inversion is attained by the atomic system.

Metastable State

A Metastable state is one which has a relatively longer lifetime and electrons excited to these levels will come down to lower energy levels at a much smaller rate than the rate at which they are excited.

As shown in figure, a lasing medium must have at least one metastable state where atoms can be trapped long enough (microseconds to milliseconds) for a population inversion to occur. Although laser action is possible with only two energy levels, most lasers have three or more levels.



Three level laser energy diagram

Basic Requisites of a Laser system

The important requisites of a typical laser system are

1. Active medium and matrix
2. Pumping
3. Optical resonance cavity or Laser cavity

1.**Active medium and matrix**

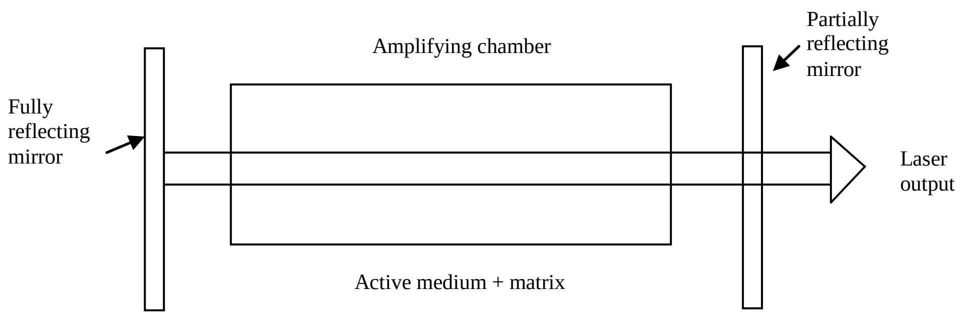
For interaction of matter with radiation, we need suitable atoms. Generally, the group of atoms required for laser action is present in some other group of atoms. The material in which laser action takes place is called active material. The group of atoms in which the active material is embedded is called matrix. The matrix provides the energy levels for the active material for laser action to take place.

2.**Pumping**

The process through which the atoms of the active medium are induced to absorb energy is called pumping. The pumping can be achieved by photons-optical pumping, by electric discharge-electrical pumping, or by chemical reaction-chemical pumping.

3.**Laser cavity**

The photons emitted by stimulated emission must be made to increase in number. This is done inside a chamber called laser cavity or the resonant cavity. The laser cavity consists of a chamber in which the active material and matrix are present. The chamber is fixed with two mirrors, one fully reflecting, the other one partially reflecting. When the stimulated emissions occur, the photons undergo repeated reflections and the population builds up inside the chamber and ultimately the final beam emerges.



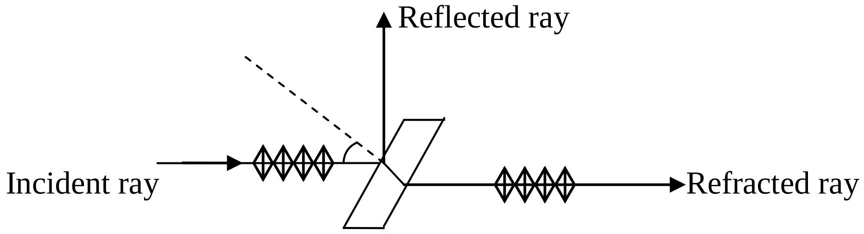
Collision of first kind

$$e_1 + A \longrightarrow e_2 + A^*$$

Collision of second kind

$$A^* + B \longrightarrow A + B^*$$

Brewster window:



Brewster angle 'α' satisfies the condition, $\tan\alpha = \mu$, Where μ is RI of the material.

Semi Conductor Laser

A semi conductor diode laser is a specially fabricated PN junction device that emits coherent light when it is forward biased.

Construction:

A schematic diagram of semi conductor laser is shown in figure below.

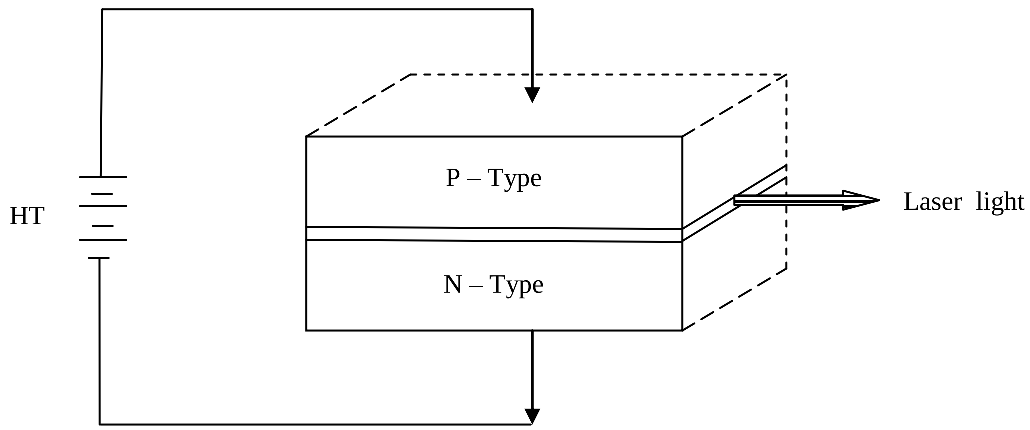


Fig: Schematic diagram of semiconductor laser

The diode is extremely small in size with sides of the order of 1 mm. The junction lies in a horizontal plane through the center with thickness 1 μm. A pair of parallel planes are cleaved or polished perpendicular to the plane of the junction. The top and bottom faces are roughened to prevent lasing action in that direction.

Working:

When a forward bias is applied to the semiconductor, perpendicular to the plane of the junction a forward current flows. As the bias is increased, eventually a threshold current is reached at which the stimulated emissions occurs and a monochromatic and highly directional beam of light is emitted from the junction.

Condition to achieve laser action is, we have to pass a large current and both P – type and N – type semiconductors are heavily doped. Because of large forward current a holes moves from the P – to N – side and an electron moves from N – to P – side. At the junction a recombination of electron and holes takes place and the energy is released in the form of light, which is a stimulated radiation.

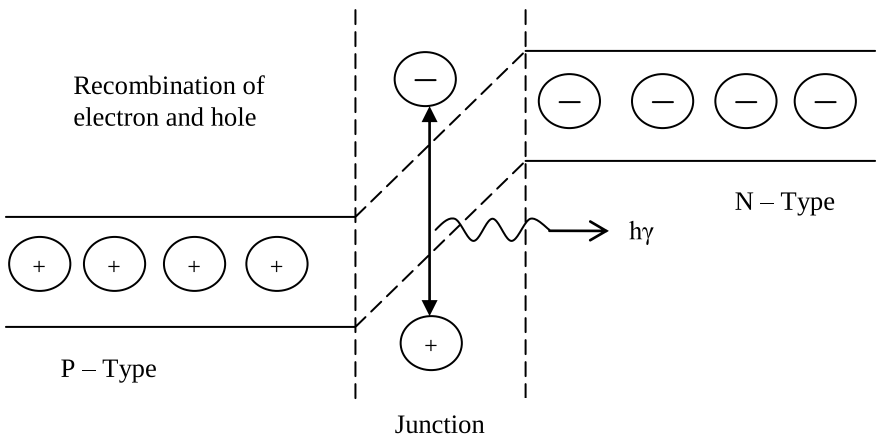


Fig: Energy level diagram

Here $h\gamma = E_g$

Where E_g is the energy gap

The frequency of the emitted light is given by

$$\gamma = \frac{E_g}{h}$$

Advantages of semiconductor laser:

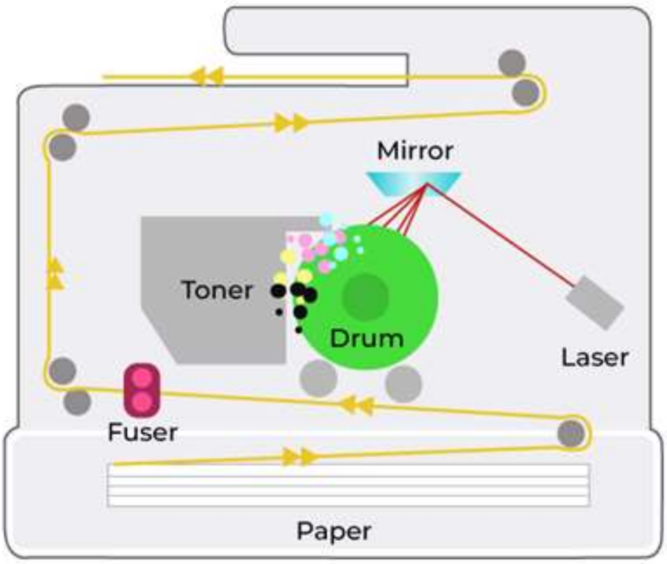
1. They are compact
2. They are efficient
3. They are highly stable
4. They can be easily fabricated

Applications of Lasers

Lasers find remarkable applications in the fields such as medicine (eye surgery, cancer treatment, stomatology, plastic surgery, etc.), material processing (welding, cutting, drilling etc.), communications (optical fibers), energy resource, photography, defense, laser fusion, holography, LASER printer, LASER Barcode scanner etc,.

<u>LASER PRINTER:</u>

Laser printing is an electrostatic digital printing process. As with digital photocopiers, laser printers employ a xerographic printing process. A laser beam that can emit red or infrared light projects an image of the page to be printed onto an electrically-charged, selenium-coated, rotating, cylindrical drum.



The following are the processes involved in laser printing:

Charging:

In older printers, a corona wire positioned parallel to the drum or, in more recent printers, a primary charge roller, projects an electrostatic charge onto the photoreceptor (otherwise named the photoconductor unit), a revolving photosensitive drum or belt, which is capable of holding an electrostatic charge on its surface while it is in the dark.

Exposing:

A laser printer uses a laser because lasers are able to form highly-focused, precise, and intense beams of light, especially over the short distances inside of a printer. The laser is aimed at a rotating polygonal mirror which directs the light beam through a system of lenses and mirrors onto the photoreceptor drum, writing pixels at rates up to sixty-five million times per second

Developing:

As the drums rotate, toner is continuously applied in a 15-micron-thick layer to the developer roll. The surface of the photoreceptor with the latent image is exposed to the toner-covered developer roll. Toner consists of fine particles of dry plastic powder mixed with carbon black or coloring agents. The toner particles are given a negative charge inside the toner cartridge, and as they emerge onto the developer drum they are electrostatically attracted to the photoreceptor's latent image (the areas on the surface of the drum which had been struck by the laser). Because negative charges repel each other, the negatively-charged toner particles will not adhere to the drum where the negative charge (imparted previously by the charge roller) remains.

Transferring:

A sheet of paper is then rolled under the photoreceptor drum, which has been coated with a pattern of toner particles in the exact places where the laser struck it moments before. The toner particles have a very weak attraction to both the drum and the paper, but the bond to the drum is weaker and the particles transfer once again, this time from the drum's surface to the paper's surface.

Fusing:

The paper passes through rollers in the fuser assembly under high temperatures and pressure are used to permanently bond the toner to the paper. One roller is usually a hollow tube (heat roller) and the other is a rubber-backed roller (pressure roller).

Advantages of Laser Printer

1. Performance: Laser printers are designed for printing large volumes without experiencing jams and other problems.

2. Speed: The laser beam which the laser printer uses is known to move at very fast rate, thus making the printing process more faster. Compared to an inkjet or a dot matrix printer, laser printers are way faster. High speed in essence can lead to more productivity and efficiency as well.

3. Reliability: Even though laser printer is a mechanical device, they are more reliable and durable. Unlike ink cartridges, toners are free from drying out and evaporating.

4. Overall Cost: Al though the initial cost of a laser printer is higher, a laser printer can print more papers for a cheaper price. The toners can generally last for printing 1500-60,000 pages.

5. Quality: In terms of sharpness and quality, there is nothing that can beat a laser printer. Especially texts can be seen more sharp and precise.

6. Noise Emission: Most at times while in operations, a laser printer produce no noise. It is optimized in such a way that rarely emits noises.

Disadvantages of Laser Printer

1. Implementation Cost: Laser printers involve high implementation costs. The average price of a laser printer is almost 3 times that of an inkjet printer.

2. Paper Options: Specifically designed papers are used for printing. The low quality papers can lead to risk of damaging your printer and also cause jams on a laser printer.

3. Physical Size: Generally laser printers are much heavier and bulkier compared to an inkjet printer.

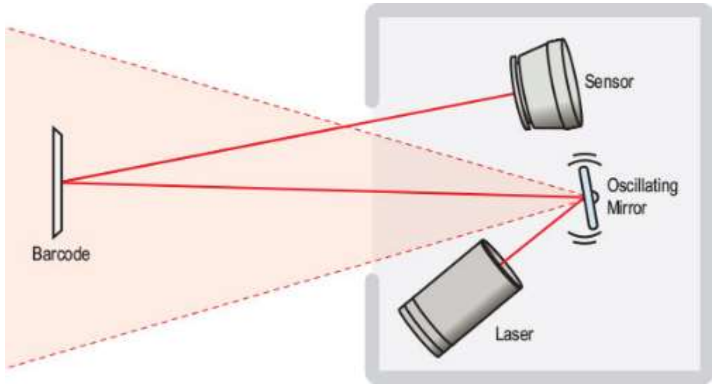
4. Graphics Handling: Al though laser printers are able to produce simple color prints, they cannot handle high quality graphics images. The only preferred option is the inkjet printer.

5. Power Consumption: Laser printers consumes high amount of power even when it is in idle. However latest models of laser printers comes with **" Power Saver "** mode that helps printer save some power.

6. Health Issues: Toner which the laser printer uses is dangerous to humans. This toner contains powder particles that can be inhaled causing some health risks including respiratory diseases. Additionally, since high amount of voltages are required for the printers functioning, there are also ozone released constituting to ozone layer depletion.

BARCODE SCANNER

- A barcode is used to encode information consisting of bars and spaces in a visual pattern readable by a machine. Barcodes are used for a variety of reasons including tracking products, prices, and stock levels for centralized recording in a computer software system. In June of 1974, the first barcode appeared on a pack of Wrigley Company chewing gum
- Barcode scanner usually consists of three different parts including the illumination system, the sensor, and the decoder. In general, a barcode scanner "scans" the black and white elements of a barcode by illuminating the code with a red light, which is then converted into matching text. More specifically, the sensor in the barcode scanner detects the reflected light from the illumination system (the red light) and generates an analog signal that is sent to the decoder.



- The decoder interprets that signal, validates the barcode using the check digit, and converts it into text. This converted text is delivered by the scanner to a computer software system holding a database of the maker, cost, and quantity of all products sold.
- Most barcodes display a twelve-digit number, usually printed underneath as a backup for possible complications. Here are what the numbers represent:

- First Number: Product Type. The product type is typically denoted by 0,1,6,7 or 8.
- Following 5 Numbers: The Manufacturer Code. The five numbers are a unique code that identifies the manufacturer or distributor of the product.
- Following 5 Numbers on the Right: Product Code. This part of the code is unique to the individual product.
- Final Number: Check Digit (a Self-Policing System). The final digit of a barcode number is a computer check digit which makes sure the barcode is correctly composed.

- However, there are a variety of diverse types of barcodes. The most common type is UPC or Universal Product Number restricted to around 20 alpha-numerical characters. Any more than that would need a QR (2D Barcode) code.
- A QR code has two dimensions that can support different kinds of data. Numeric data, alphanumeric characters, and Kanji are the three main data types. The components of the QR code include indicators and data code. The QR code has many applications in our life, such as payment, product packaging, and advertising.