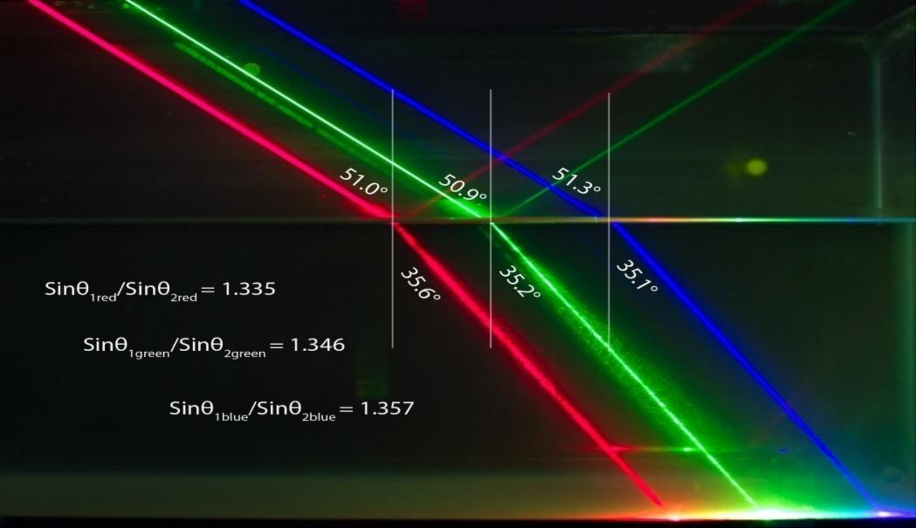
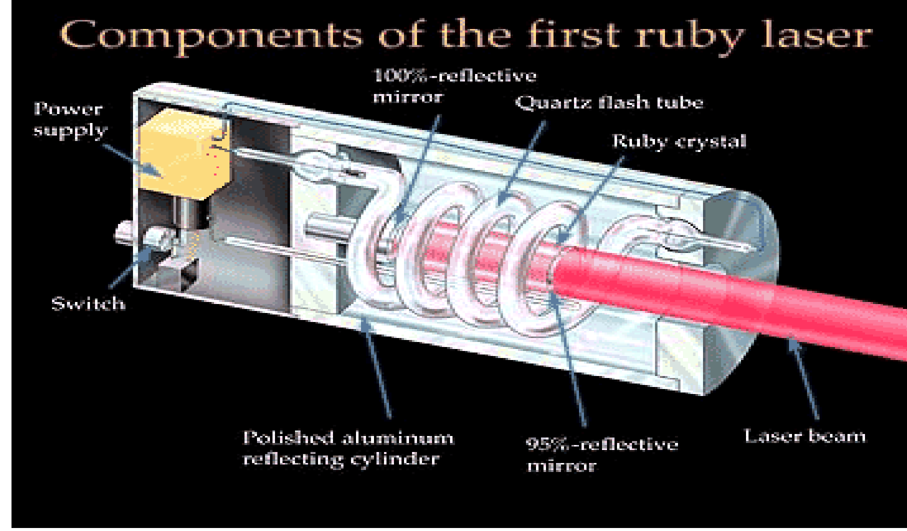
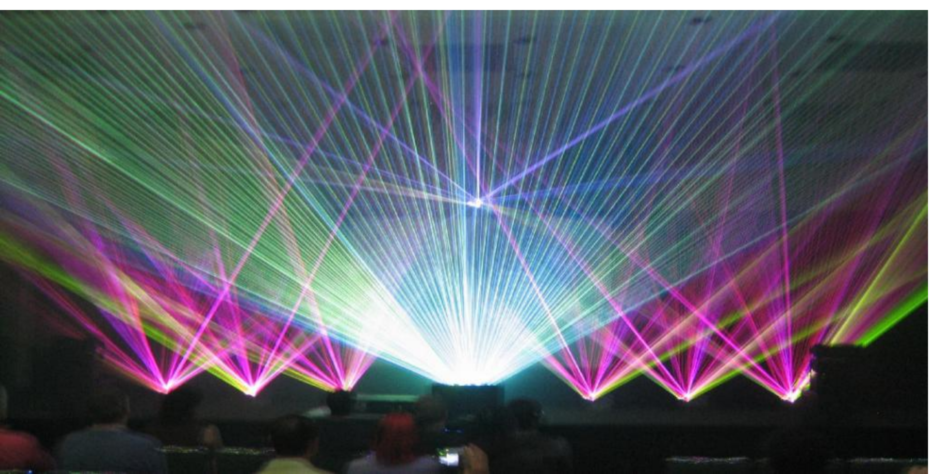

51.0°
50.9°
51.3°
35.6°
35.2°
35.1°
$\mathrm{Sin}\theta_{1red}/\mathrm{Sin}\theta_{2red} = 1.335$
$\mathrm{Sin}\theta_{1green}/\mathrm{Sin}\theta_{2green} = 1.346$
$\mathrm{Sin}\theta_{1blue}/\mathrm{Sin}\theta_{2blue} = 1.357$


Components of the first ruby laser
100%-reflective mirror
Quartz flash tube
Power supply
Ruby crystal
Switch
Polished aluminum reflecting cylinder
95%-reflective mirror
Laser beam


WE ARE...
LASERS
– LUPE FIASCO



LASER

1. LASER
2. Incoherent Light
3. Coherent Light
4. Atomic Interactions Related to LASER
   - Induced Absorption
   - Spontaneous Emission
   - Stimulated Emission
   - Population Inversion and Optical Pumping
5. Components of Laser Devices
6. Principle of Laser
7. Types of Lasers
8. Characteristics of Laser Light
9. Applications of Laser

LASER

LASER stands for '*Light Amplification by Stimulated Emission of Radiation*'

Laser is a very intense, concentrated, highly parallel and monochromatic beam of light.

<u>Coherence is very important property of Laser</u>.

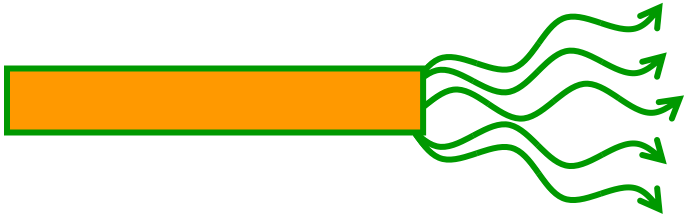
<u>Incoherent Light:</u>

The light emitted from the Sun or other ordinary light sources such as tungsten filament and fluorescent tube lights is spread over a wide range of frequencies.

For example: Sunlight is spread over Infra Red, Visible light and Ultra Violet spectrum. So, the amount of energy available at a particular frequency is very less and hence less intense.

Such light is irregular and mixed of different frequencies, directions and durations, and is incoherent.

Incoherent light is due to spontaneous and random emission of photons by the atoms in excited state. These photons will not be in phase with each other.

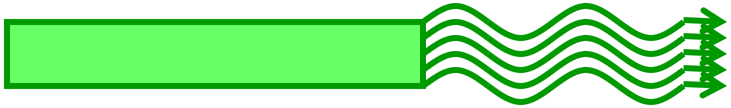


Incoherent Light

Coherent Light:

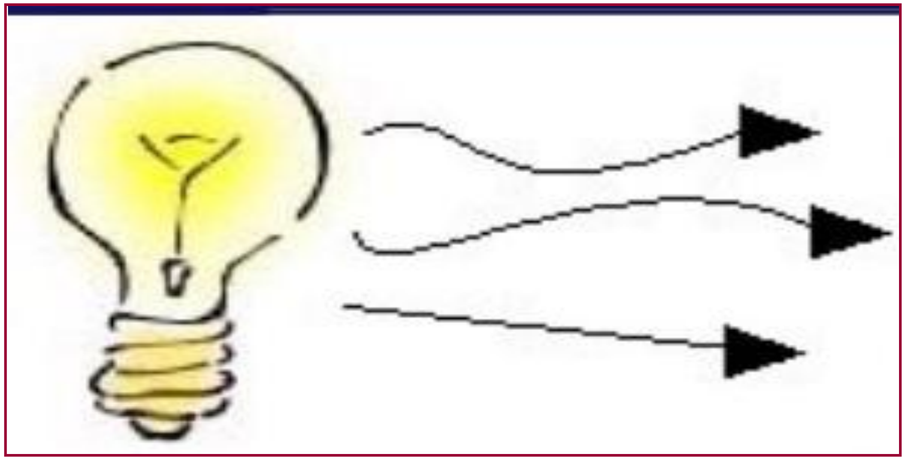
Coherent light is uniform in frequency, amplitude, continuity and constant initial phase difference.

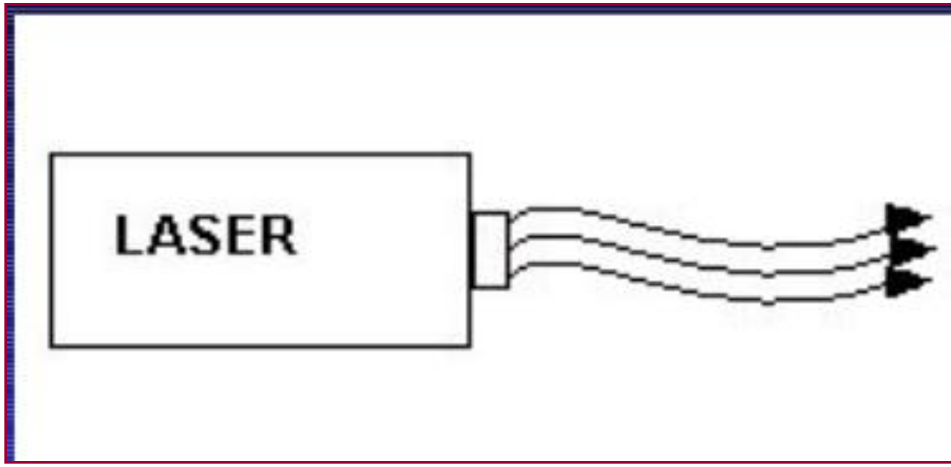
Coherent beam of light is obtained due to stimulated emission of photons from the atoms jumping from meta-stable state to lower energy state.



Coherent Light

Incandescent Vs Laser Light





1) Many Wavelengths
2) Multidirectional
3) Incoherent

1) Monocromatic
2) Directional
3) Coherent

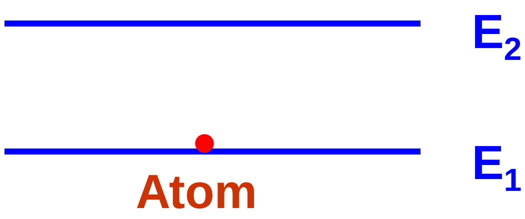
Various Atomic Interactions Related to LASER

a) Induced /stimulated Absorption: Or Absorption of Radiation:

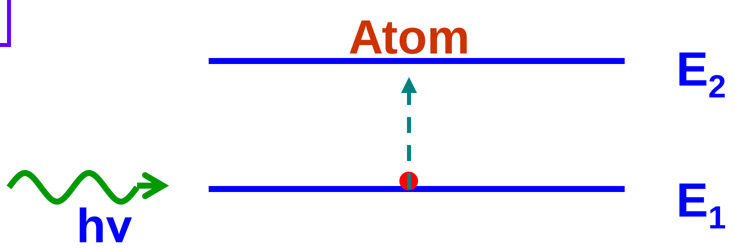
Photons of suitable size (energy) are supplied to the atoms in the ground state. These atoms absorb the supplied energy and go to the excited or higher energy state. If E_1 and E_2 are energies of ground state (lower energy) and excited state (higher energy), then the frequency of required photon for absorption is

$$\boxed{\nu = \frac{E_2 - E_1}{h}}$$

where 'h' is Planck's constant



Before absorption

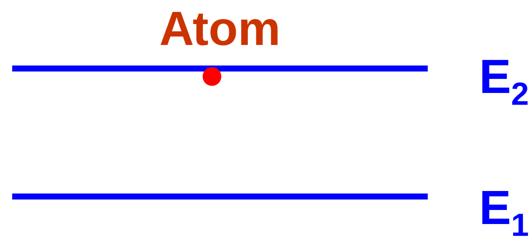


After absorption

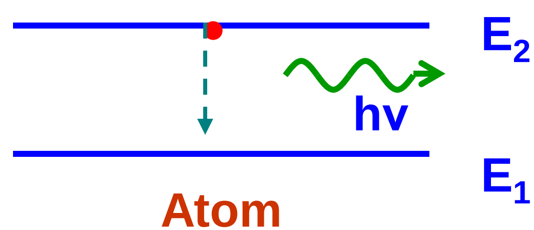
b) Spontaneous Emission:

An excited atom can stay in the higher energy state only for the time of 10^{-8} s. After this time, it returns back to the lower energy state by emitting a photon of energy $h\nu = E_2 - E_1$. This emission is called '**spontaneous emission**'.

During spontaneous emission, photons are emitted randomly and hence they will not be in phase with each other. Therefore, the beam of light emitted is **incoherent**.



Before emission

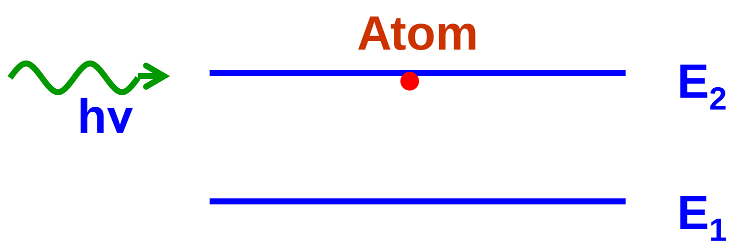


After emission

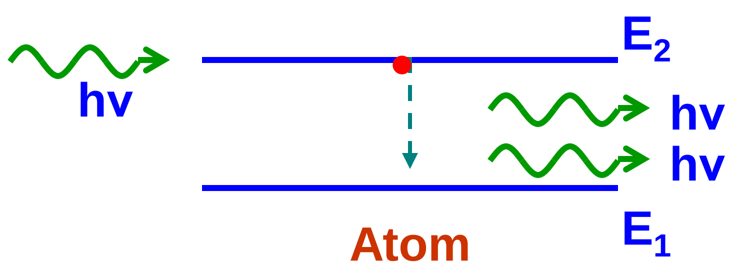
c) Stimulated Emission:

When photon of suitable size (energy) is showered (made to fall) on an excited atom in the higher energy state, the atom falls back to the ground state by emitting a photon of energy $h\nu = E_2 - E_1$ which is in phase with the stimulating (incident) photon.

Thus, it results in the appearance of one additional photon. This process is called <u>'stimulated or induced emission'.</u>

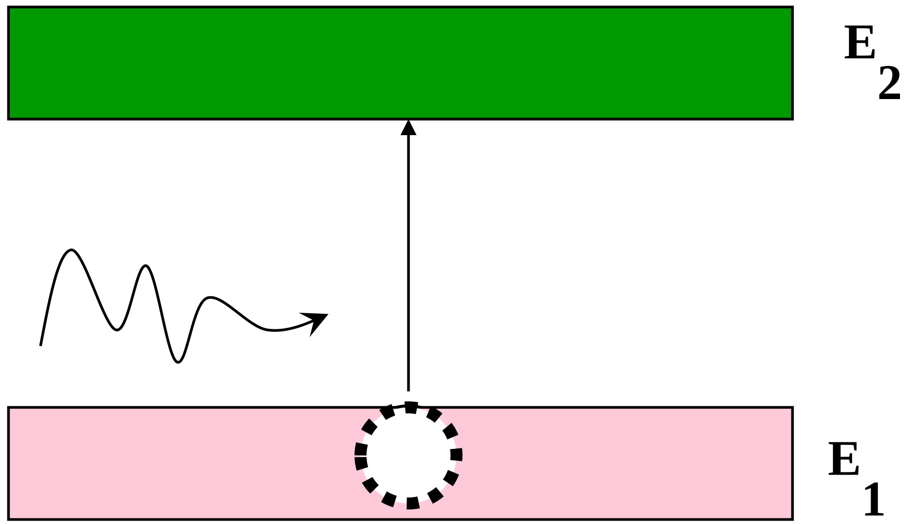


Before emission



After emission

Absorption of Radiation



$$E_2 = E_1 + h\nu$$

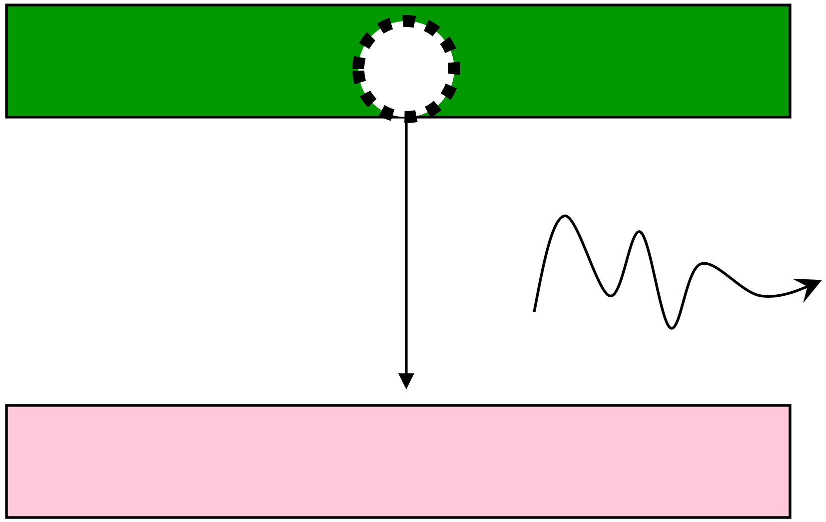
$$E_2 - E_1 = \Delta E = h\nu$$

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

$$P_{12} = B_{12}\, u(\nu)$$

Where Proportionality constant B_{12} is known as Einstein coefficient of absorption of radiation

Spontaneous Emission

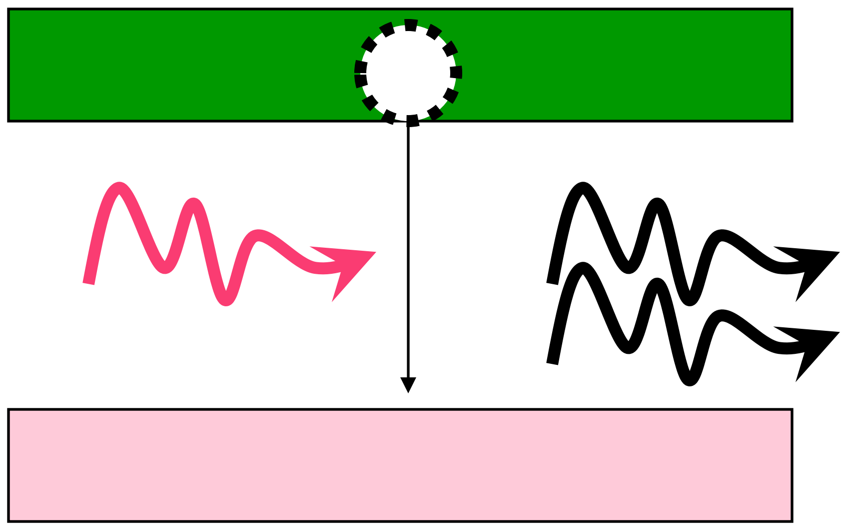


The probability of occurrence of spontaneous emission transition from state 2 to state 1 depends only on the properties of states 2 and 1 and is given by

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

Where proportionality constant A_{21} is known as Einstein coefficient of spontaneous emission of radiation.

Stimulated Emission



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

The probability of occurrence of stimulated emission transition from the upper level 2 to the lower level 1 is proportional to the energy density u(ν) of the radiation and is expressed as

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

Where proportionality constant B_{21} is known as Einstein coefficient of stimulated emission of radiation.

Question?????

Enlist three point of difference between spontaneous and stimulated emission

Total Probability of emission of transition from upper level <u>2</u> to the lower level <u>1</u> is given by

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

Or

$$\boxed{P_{21} = A_{21} + B_{21}\, u(\nu)}$$

Relation between Einstein's Coefficients

Let N_1 and N_2 be the number of atoms at any instant in the state 1 and 2, respectively. The probability of absorption for number of atoms from state 1 to 2 per unit time is given by

$$N_1 P_{12} = N_1 B_{12}\, u(\nu)$$

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

$$N_2 P_{21} = N_2 [A_{21} + B_{21}\, u(\nu)]$$

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

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

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

$$u(\nu) = \frac{A_{21}}{B_{21}\left(\frac{N_1}{N_2} \frac{B_{12}}{B_{21}} - 1 \right)}$$

But according to Einstein

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

$$u(\nu) = \frac{A_{21}}{B_{21}} \frac{1}{\left(\frac{N_1}{N_2} - 1 \right)}$$

According to Boltzmann's law, the distribution of atoms among the energy states E_1 and E_2 at the thermal equilibrium at temperature T is given by

$$\boxed{\begin{gathered}\frac{N_1}{N_2} = \frac{e^{-\frac{E_1}{kT}}}{e^{-\frac{E_2}{kT}}} = e^{\frac{(E_2 - E_1)}{kT}} \\ \frac{N_1}{N_2} = e^{\frac{(h\nu)}{kT}}\end{gathered}}$$

$$\boxed{u(\nu) = \frac{A_{21}}{B_{21}} \frac{1}{\left(e^{\frac{h\nu}{kT}} - 1\right)}}$$

where k is Boltzmann constant

Plank's radiation formula yields energy density of radiation

$$u(\nu)=\frac{8\pi h\nu^3}{c^3}\frac{1}{\left(e^{\frac{h\nu}{kT}}-1\right)}$$

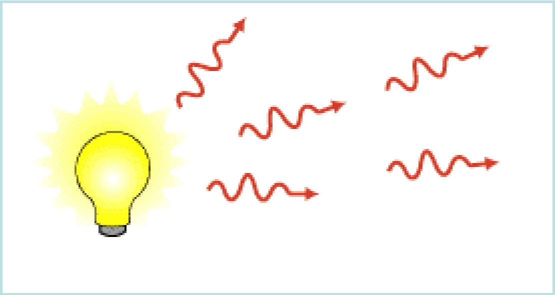
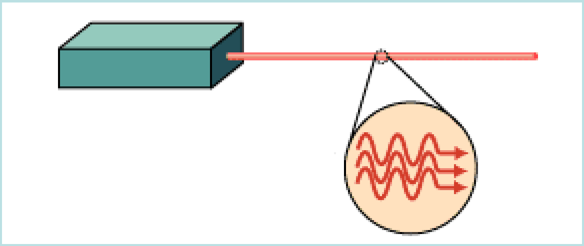
Relation Between Einstein Coefficients A and B

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

$$\frac{B_{21}}{A_{21}}=\left(\frac{c^3}{8\pi h}\right)\frac{1}{\nu^3}$$

That is B_{21}/A_{21} is inversely proportional to frequency of the resonant radiation. Therefore, higher the frequency smaller is the value of B_{21}.That is, it is comparatively difficult to obtain the stimulated emission at higher frequencies.

Difference between

Spontaneous Emission	Stimulated Emission
	
• In the case of spontaneous emission, the atom emits an electromagnetic wave which has no definite phase or directional relation with that emitted by another atom.	• In case of stimulated emission, since the process is forced by the incident electromagnetic wave, the emitted light by atom is in phase with that of incident electromagnetic wave. • The emitted light is also in same direction as that of incident light.

Population Inversion and Pumping:

Usually , the number of atoms in the lower energy state is more than that in the excited state. According to Boltzmann, the ratio of atoms in the energy states 2 and 1 at a temperature T is given by

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

For population inversion **: $N_2 > N_1$ i.e.**

$$\left(\frac{N_2}{N_1}\right) > 1$$

$$\exp\left(\frac{-(E_2-E_1)}{k_B T}\right) > 1$$

$$1 - \frac{(E_2-E_1)}{k_B T} + \text{higher terms} > 1$$

$$1 - \frac{(E_2-E_1)}{k_B T} > 1$$

$$-\frac{(E_2-E_1)}{k_B T} > 0$$

$$\frac{\Delta E}{k_B T} < 0$$

Here; ΔE is +ve quantity, k_B is also +ve quantity, The only option left is T is –ve, it means the population is inverted or we have achieved the population inversion.

The rate of stimulated Absorption of photons is given by

$$R_a = N_1 P_{12} = N_1 B_{12} u(\nu) \quad \text{and}$$

The rate of stimulated emission of photons is given by

$$R_{ste} = N_2 P_{21} = N_2 B_{21} u(\nu)$$

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

$$\boxed{\frac{R_{ste}}{R_a} = \frac{N_2}{N_1}}$$

That is, if $N_2 > N_1$, the rate of stimulated emission is more than the rate of stimulated absorption. This results in the increase of $u(\nu)$ and hence amplification of light becomes possible. The state of the matter radiation system in which $N_2 > N_1$ called Population inversion.

To emit photons which are coherent (in same phase), the number of atoms in the higher energy state must be greater than that in the ground state (lower energy).

The process of making population of atoms in the higher energy state more than that in the lower energy state is known as 'population inversion'.

The method by which a population inversion is achieved is called 'pumping'. In this process atoms are raised to an excited state by injecting into system photon of frequency different from the stimulating frequency.

Population inversion can be understood with the help of 3-energy level atomic systems.

Numerical

Find the relative population of the two states in a ruby laser that produces a light beam of wavelength 6943 Å at 300 K and 500 K. **Ans**: 8×10^{-31}

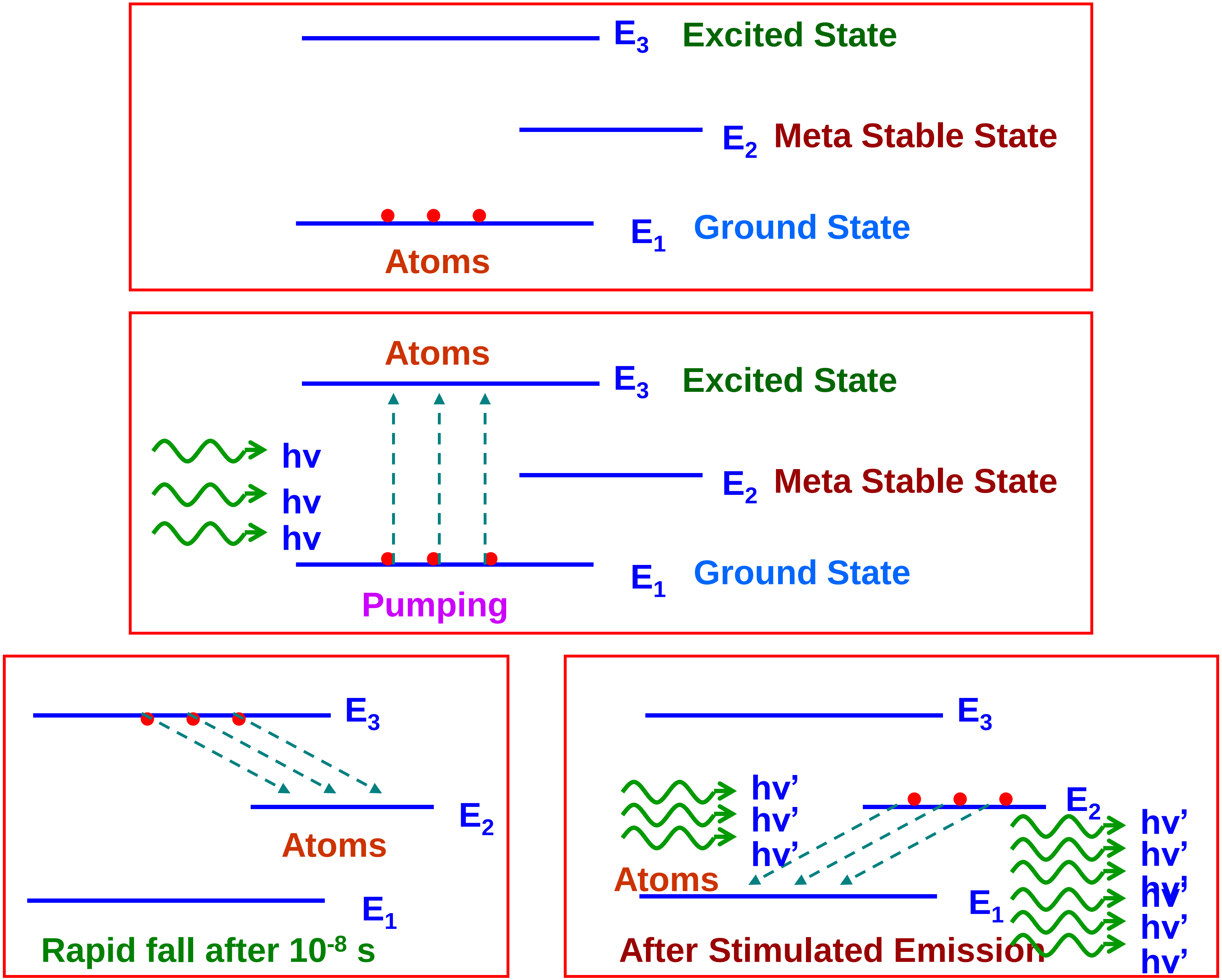
8.7×10^{-19}.

The He-Ne laser is capable of emitting lights at wavelength 6328 Å. Determine the energy difference between the upper and the lower levels for this wavelength. **Ans**: 1.9633 eV.

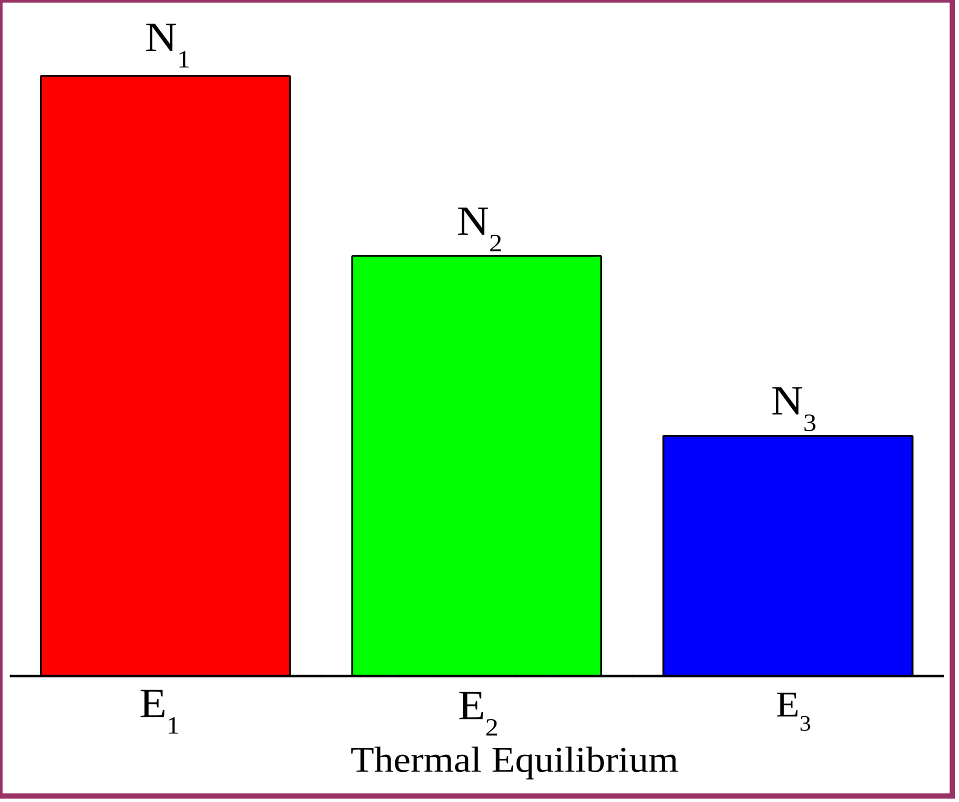
A pulsed laser is constructed with a ruby crystal as the active element. The ruby rod contains typically a total of 3×10^{19} Cr^{3+} ions. If the wavelength of light emitted from ruby laser is 6940 Å then calculate

(a) The energy of one emitted photon. **Ans**: 1.79 eV.

(b) The total energy available per laser pulse. **Ans**: 8.5929 J.

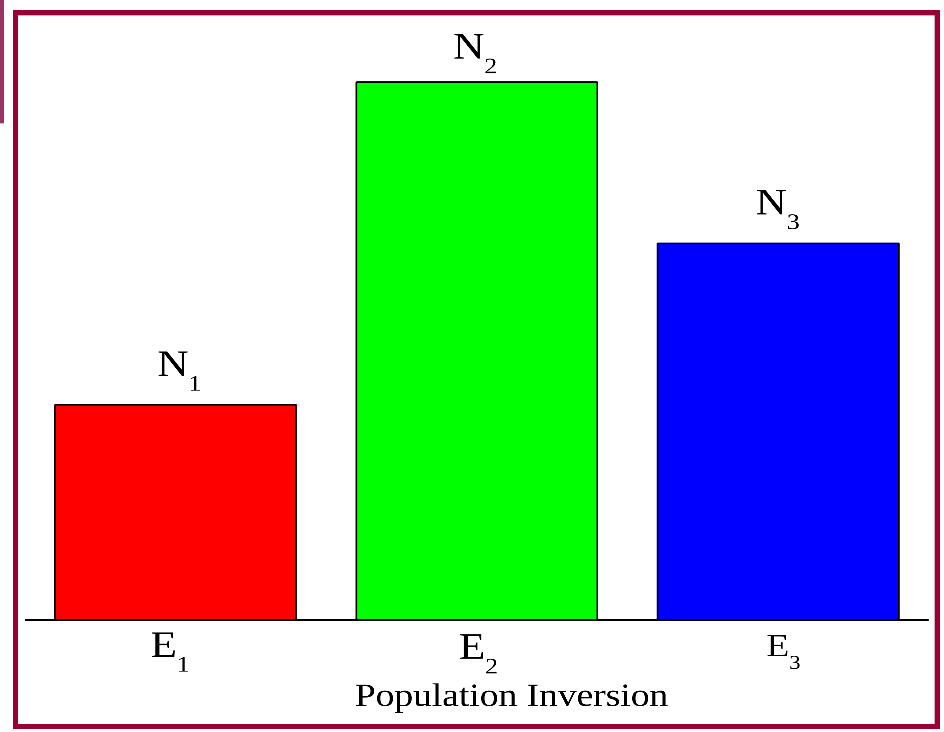


E3
Excited State
E2
Meta Stable State
E1
Ground State
Atoms
Atoms
E3
Excited State
hv
hv
hv
E2
Meta Stable State
E1
Ground State
Pumping
E3
E2
Atoms
E1
Rapid fall after 10-8 s
E3
hv’
hv’
hv’
E2
Atoms
E1
hv’
hv’
hv’
hv’
hv’
hv’
After Stimulated Emission



Thermal Equilibrium

Population Inversion



Key: ***Bar represents the population of atoms***

The atoms by induced absorption reach excited state E_3 from E_1. They stay there only for 10^{-8} seconds.
After this time they fall to meta-stable state where they stay for quite a longer time (10^{-3} seconds). Within this longer time more number of atoms get collected in the meta-stable state which is large than that at lower energy level. Thus population inversion is achieved.

In atomic systems such as chromium, neon, etc, meta-stable states exist.

Pumping: **A system in which population inversion is achieved is called an active medium. The method of raising a particle from lower state to higher energy state is called pumping.**

1. **Electrical Pumping:** **Atoms can be excited by electron impact in sufficiently intense gaseous discharge, known as electrical pumping. The electrical pumping is suited to gas and semiconductor lasers.**
2. **Optical Pumping:** **In this case atoms are excited by powerful lamp or a laser source whose light populates excited states by photon absorption. This method is particularly suitable to solid state or liquid lasers.**
3. **Chemical Pumping:** **Here population inversion is achieved from an exothermic chemical reaction. Chemical pumping usually applies to material in the gas phase and it generally requires highly reactive and often explosive gas mixtures.**

Three Components of Laser Devices:

1. The Pump:

I. It is an external source which supplies energy to obtain population inversion. The pump can be optical, electrical or thermal. In Ruby Laser, we use optical pumping and in He - Ne Laser, we use electric discharge pumping.

II. The energy supplied by the pump excites the atoms to higher energy levels and through spontaneous emission of through non-radiative processes the population inversion occurs.

III. The lifetime of the metastable energy state, in which population inversion occurs must be very large as compared to the normal life time of the excited atom in any other energy state.

2. **<u>The Laser Medium:</u>** **It is material in which the laser action is made to take place. It may be solid, liquid or gas. The very important characteristic requirement for the medium is that inversion should be possible in it.**

Many lasers are named after the material used.

<u>For Example:</u> **Solid Sate Laser:** **The output of Ruby laser is at 694.3 nm;** **Gas Lasers:** **In He-Ne laser the output is at 632.8 nm and in CO_2 laser is at 10.6 µm.**

<u>Note:</u> **Laser action has been observed in more than half of the known atoms and laser wavelength may extend from ultraviolet region to the infra-red region. The most important charactristic requirement for the laser medium is that we should be able to obtain the population inversion in it. According to Boltzmann condition if N_1 and N_2 be the number of atoms in the energy state E_1 and E_2**

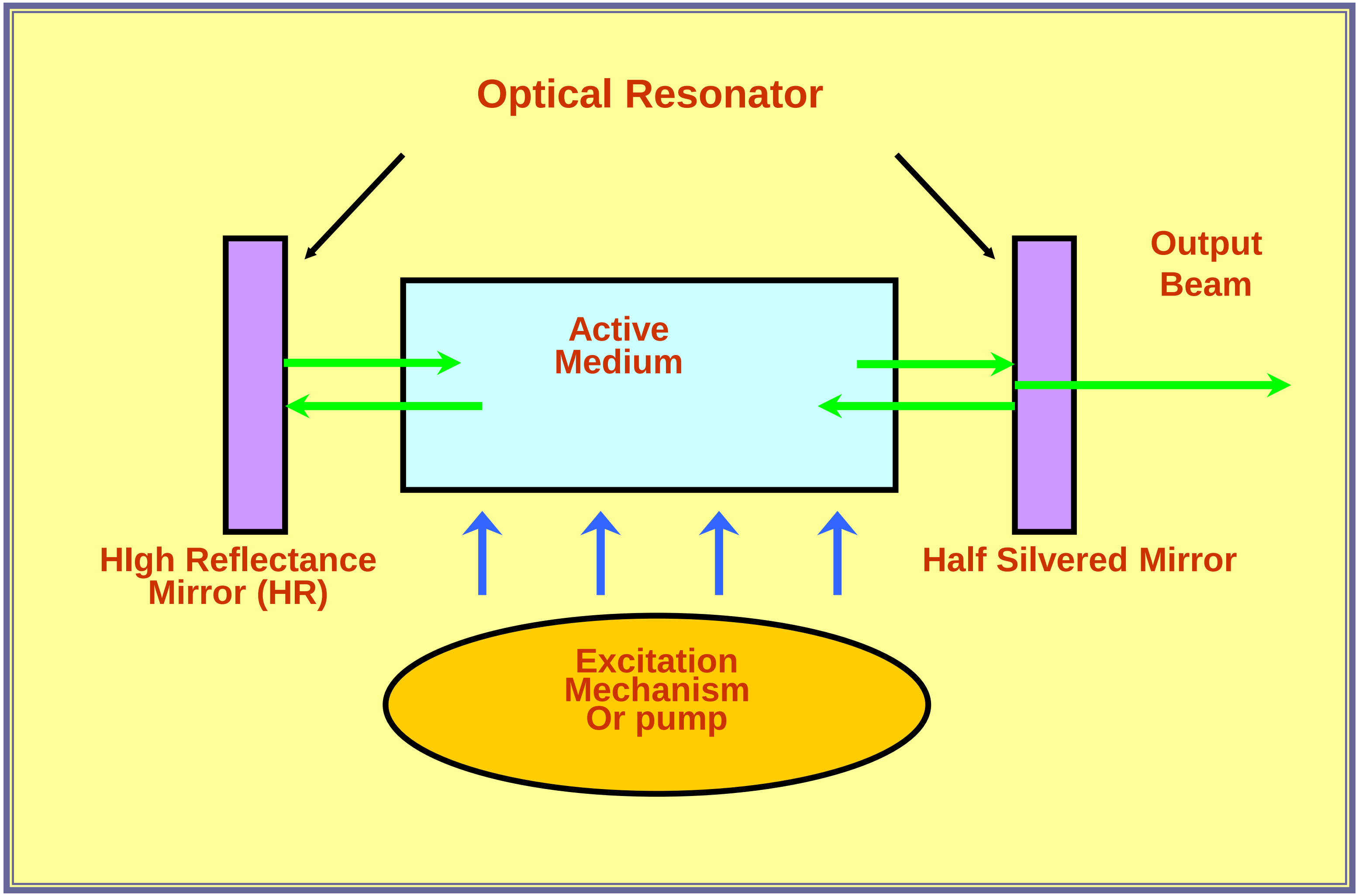
$$\frac{N_2}{N_1} = e^{\frac{-h\nu}{kT}}$$

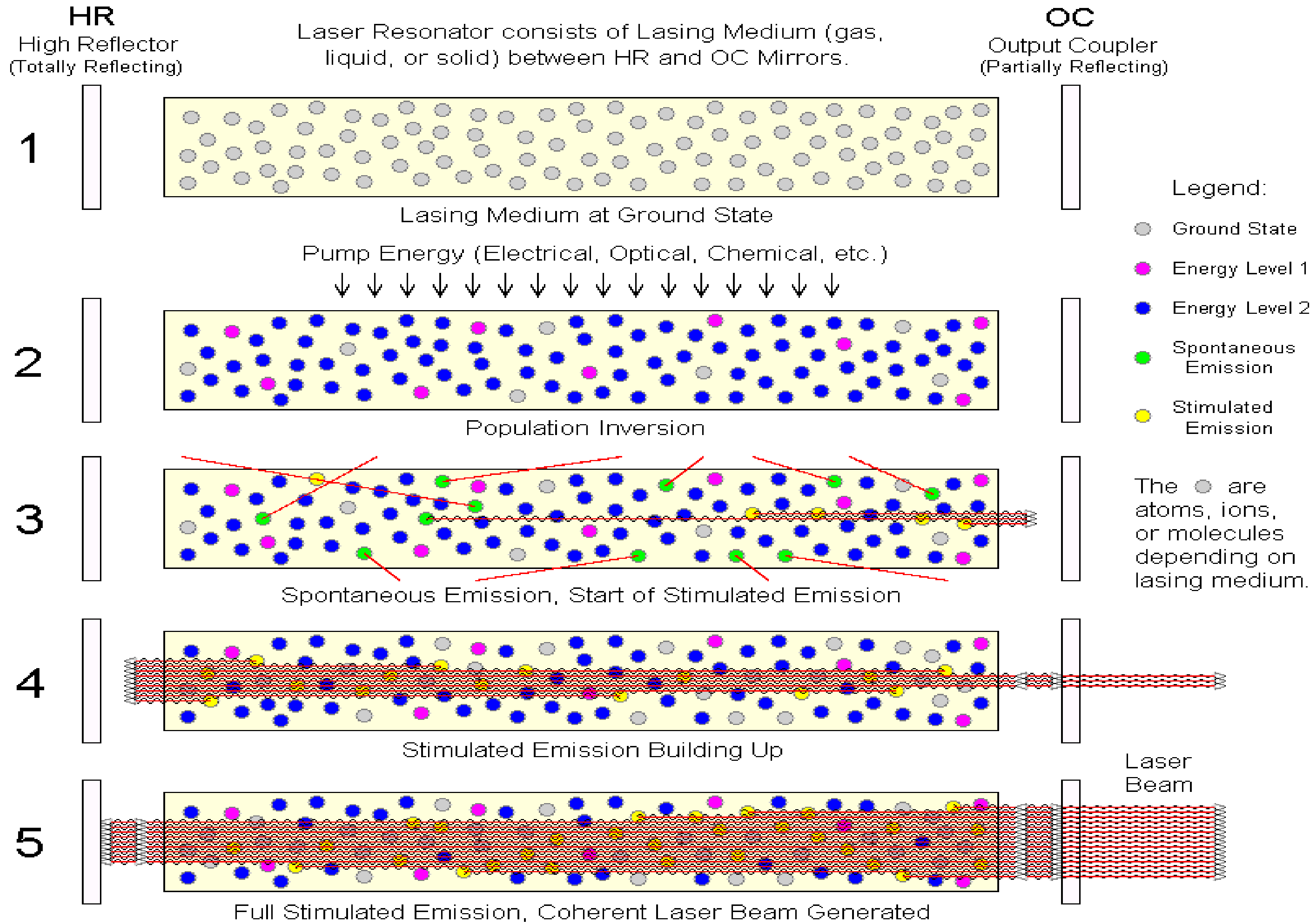
Where, $h\nu = E_2 - E_1$

Therefore, N_2 is in general less than N_1 . Because of this reason vigorous pumping may be required for sustaining the population inversion and so only certain pairs of energy levels with appropriate lifetime can be inverted.

3. The Resonator: **It consists of a pair of plane or spherical mirrors having common principal axis. The reflection coefficient of one of the mirrors is very near to 1 and that of the other is kept less than 1. The resonator is basically a feed-back device, that directs the photons back and forth through the laser medium and in the process, the number of photons is multiplied due to stimulated emission.**

LASER COMPONENTS





Basic Laser Operation

Principle of Laser:

An atomic system having one or two **meta-stable states** is chosen. Normally, the number of atoms in the lower energy state is greater than that in the meta-stable state.

This population is inverted by a technique known as **pumping.**

The atoms are made to fall from meta-stable state to lower energy state and photons are emitted by stimulated emission.

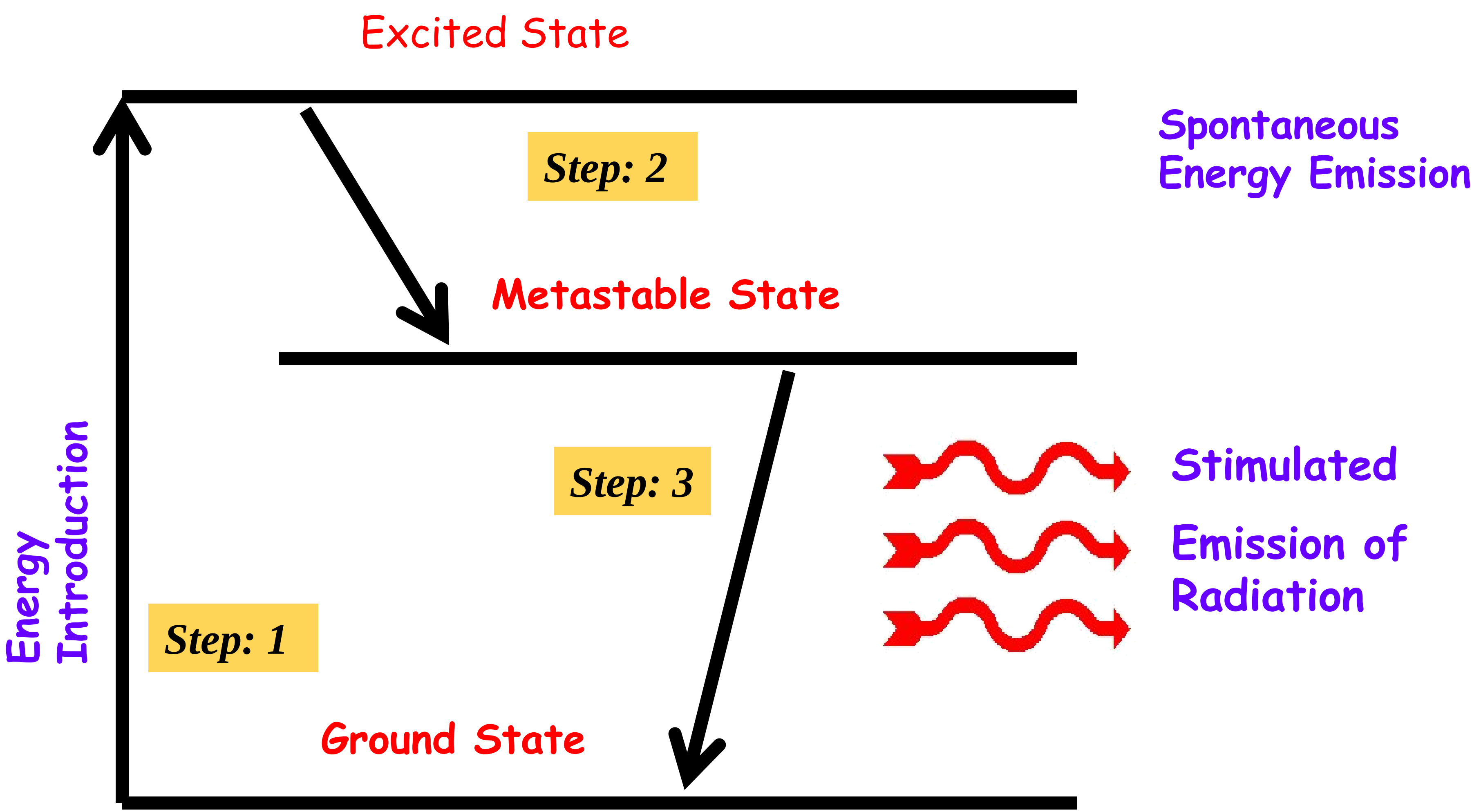
The photons are reflected back and forth in the active medium to excite the other atoms.

Thus a large number of photons are emitted simultaneously which possess the same energy, phase and direction. This process is called 'amplification of light'.

<u>To produce laser beam, the following two conditions must be fulfilled:</u>

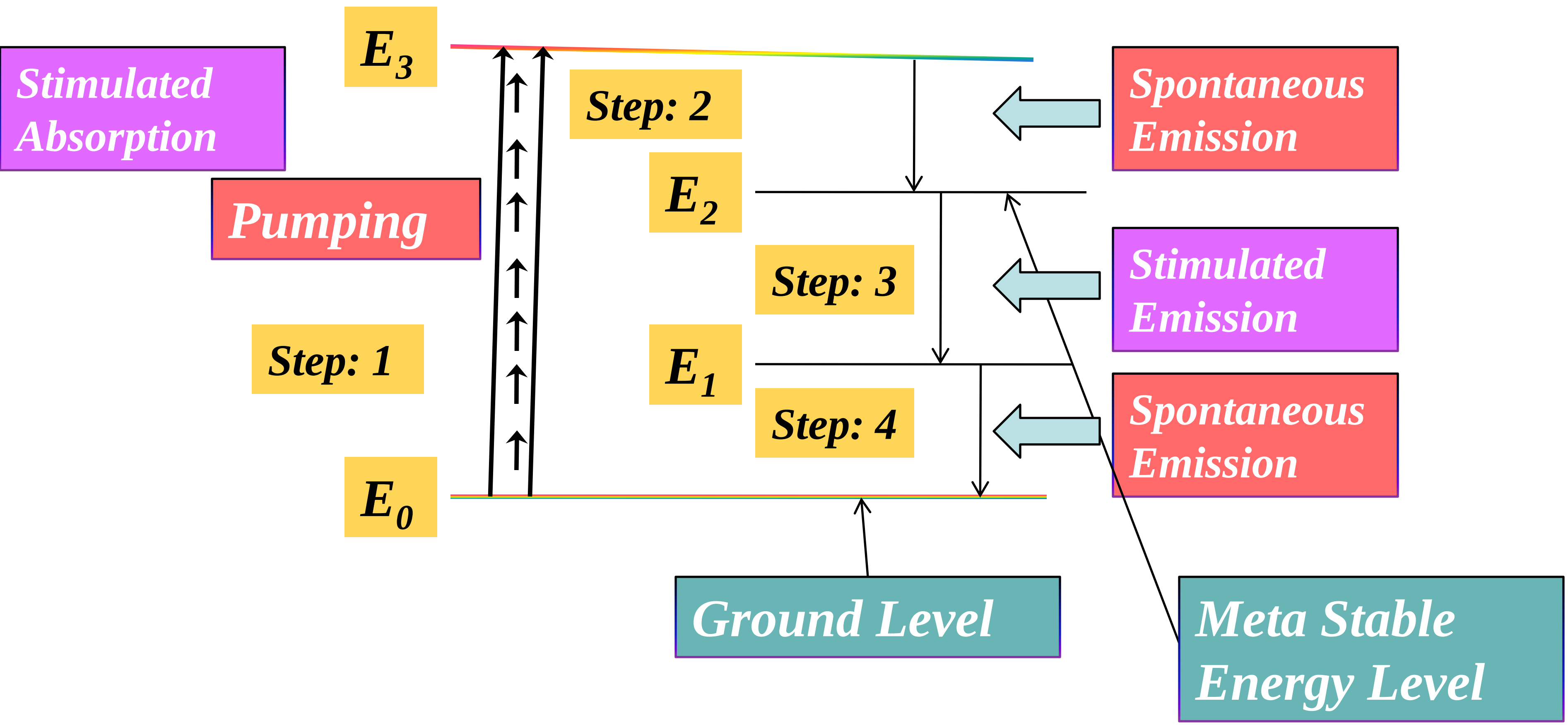
1. The meta-stable state should all the time have larger number of atoms than the number of atoms in lower energy state.
2. The photons emitted due to stimulated emission should stimulate other atoms to multiply the photons in the active medium.

Three level Laser



Laser Action or Laser Process

Laser Process can be divided into four steps



Principle of Laser

- **Step 1:** Atoms in ground state are pumped to excited state by photons of suitable frequency.
- **Step2:** Rapid transition to metastable state by spontaneous emission of radiation.
- **Step3:** Now metastable state is populated and population inversion is achieved.
- **Step4:** Stimulated emission occurs when photons of suitable frequency are incident to produce highly intense coherent beam.

Different Lasers

Classification in number of ways:

1. **According to the state of laser medium: Gas, Liquid and Solid Laser.**

2. **According to the type of pumping: Flash light, Chemical Action, and Electric Discharge Lasers**

3. **According to the nature of output: Pulsed (P) or Continuous Wave (CW) Lasers**

4. **Classification on the basis of Spectral region of the light: Ultra-Violet, Visible or Infra-Red Lasers.**

5. **Based on the mechanism in which Population**

Different Types of Lasers

Sr. No.	Name of Laser	Wavelength	Classification on the basis of		
			State of Laser Medium	Nature of Output	Spectral Region
1.	Ruby Laser	694.3 nm	Solid	Pulsed	Visible
2.	He-Ne Laser	632.8 nm	Gas	Continuous wave	Visible
3.	CO_2 Laser	10.6 µm	Gas	continuous wave	Infra-red
4.	Diode Laser				

1. Ruby Laser
2. He-Ne laser
3. Semiconductor Laser (Diode Laser)
4. Carbon dioxide Laser

RUBY LASER

First laser to be operated successfully

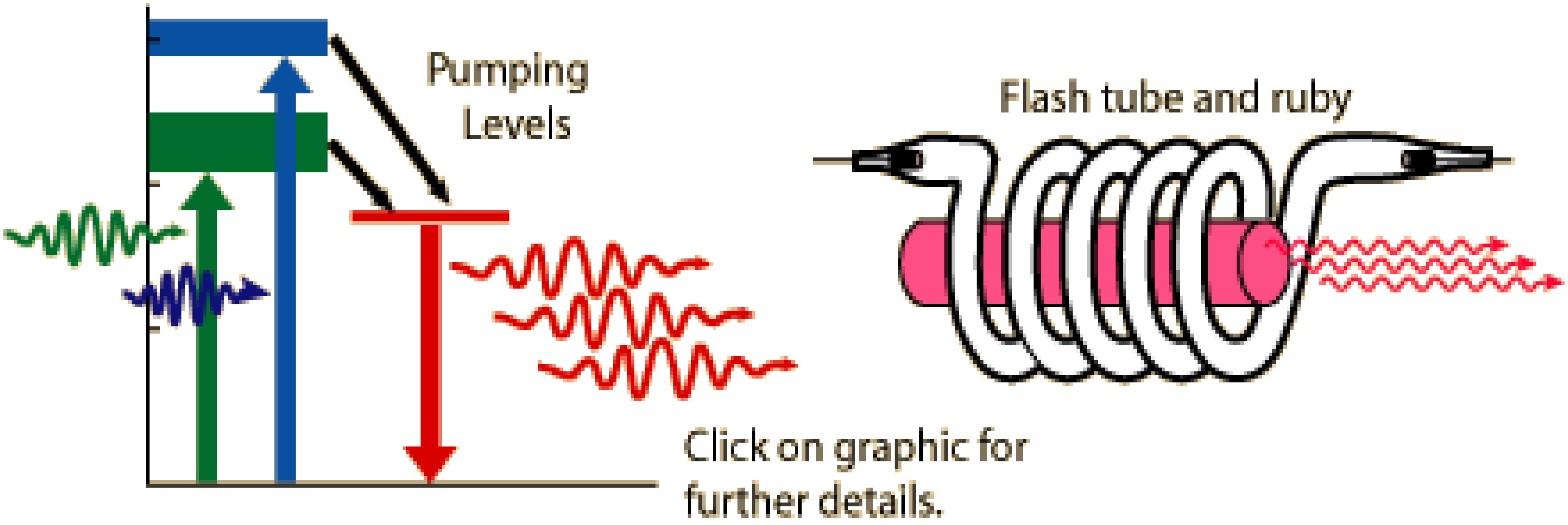
Ruby is rod of synthetic ruby as lasing medium. It is made of aluminum oxide (Al_2O_3) doped with Chromium Oxide (Cr_2O_3)

- Lasing medium: Aluminum oxide doped with chromium ions
- Energy levels of the chromium ions take part in lasing action
- A three level laser system

Working:

Ruby is pumped optically by an intense flash lamp.This causes Chromium ions to be excited by absorption of radiation around 5500 Å.

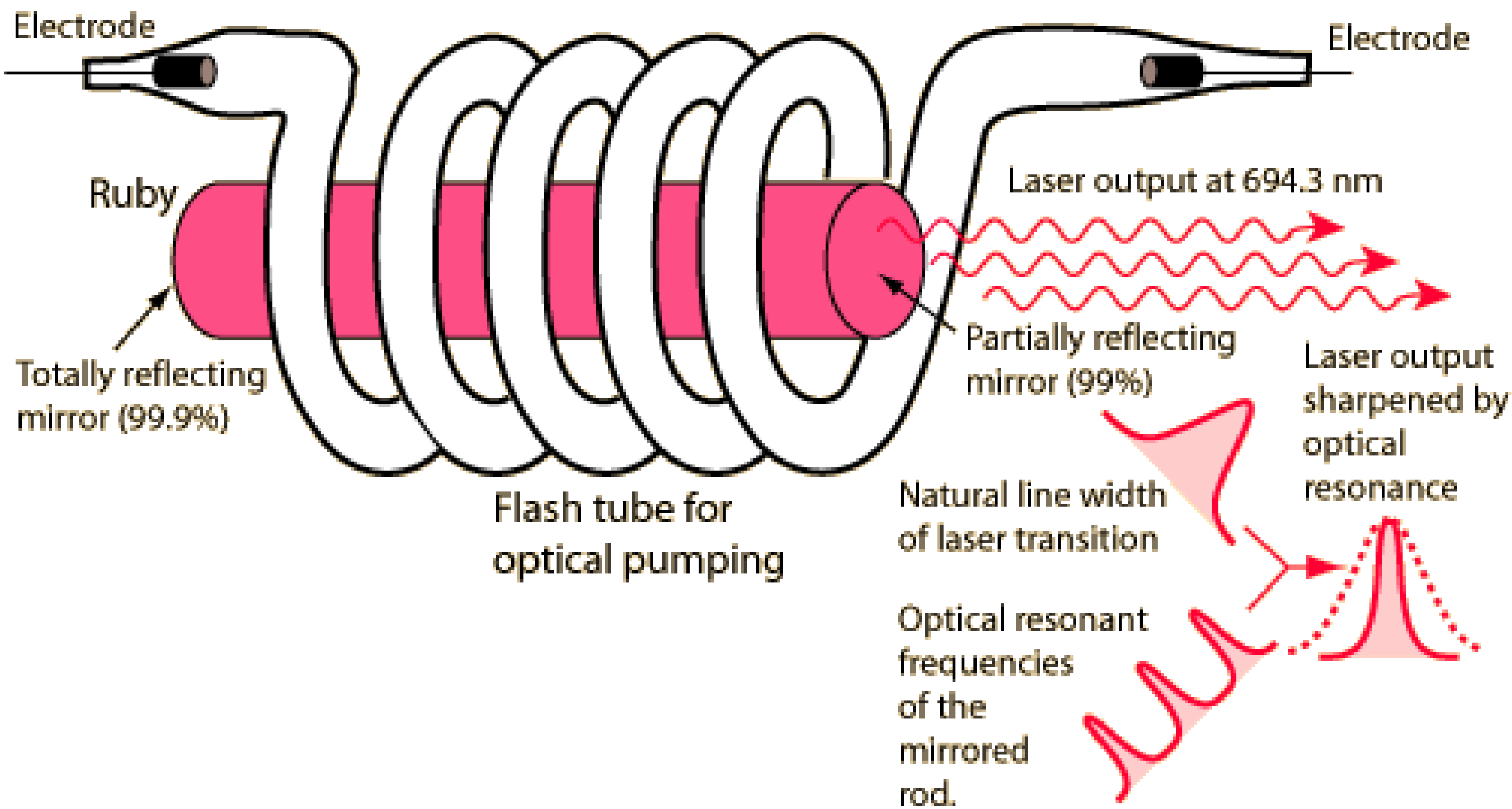
The ruby laser is used as a pulsed laser, producing red light at 694.3 nm. After receiving a pumping from the flash tube, the laser light emerges for as long as the excited atoms persist in the ruby rod, which is typically about a millisecond.



Chromium atom play the active role for laser action and aluminum and oxygen atoms remain inert .

It is a three level laser

Ruby Laser and Flash Tube



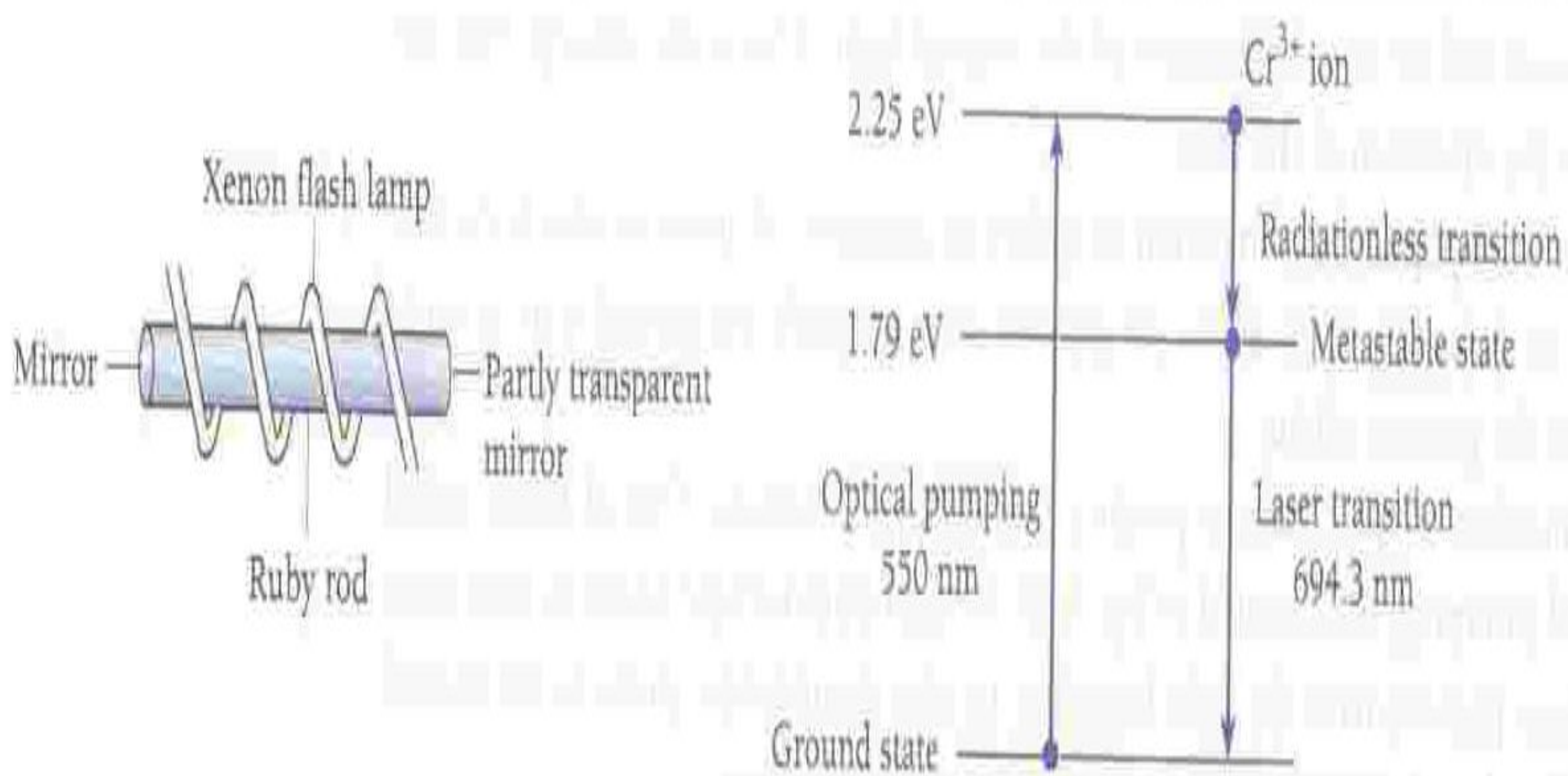


Figure 4.27 The ruby laser. In order for stimulated emission to exceed stimulated absorption, more than half the Cr^{3+} ions in the ruby rod must be in the metastable state. This laser produces a pulse of red light after each flash of the lamp.

Advantages

1. Easy to construct and operate.

2. Produce very strong and intense beam upto a power of 10 kW.

Disadvantage

1. Its laser beam is only pulse like.

2. Its operation duration is very less (few hrs.)

Four Layer Lasers

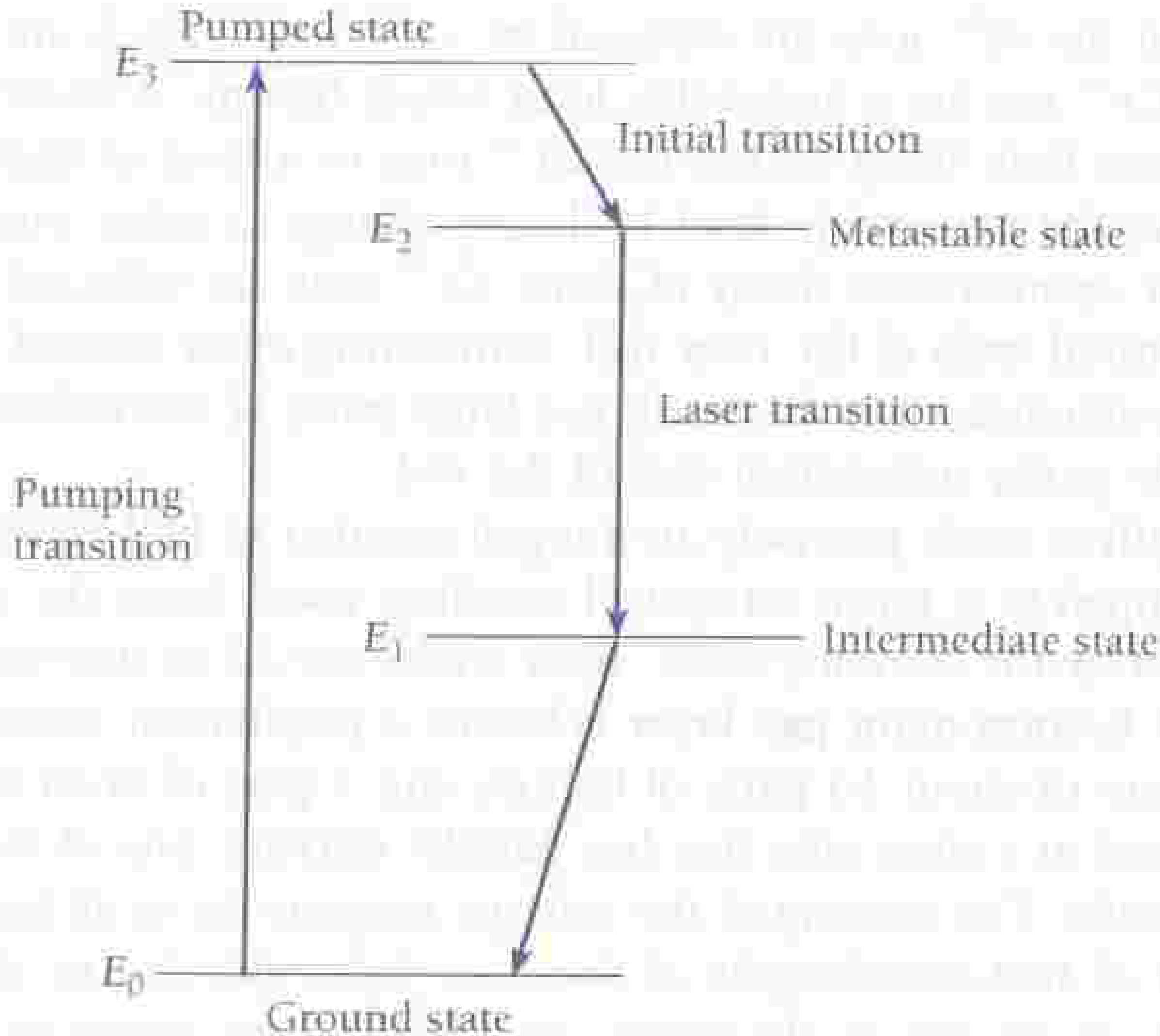
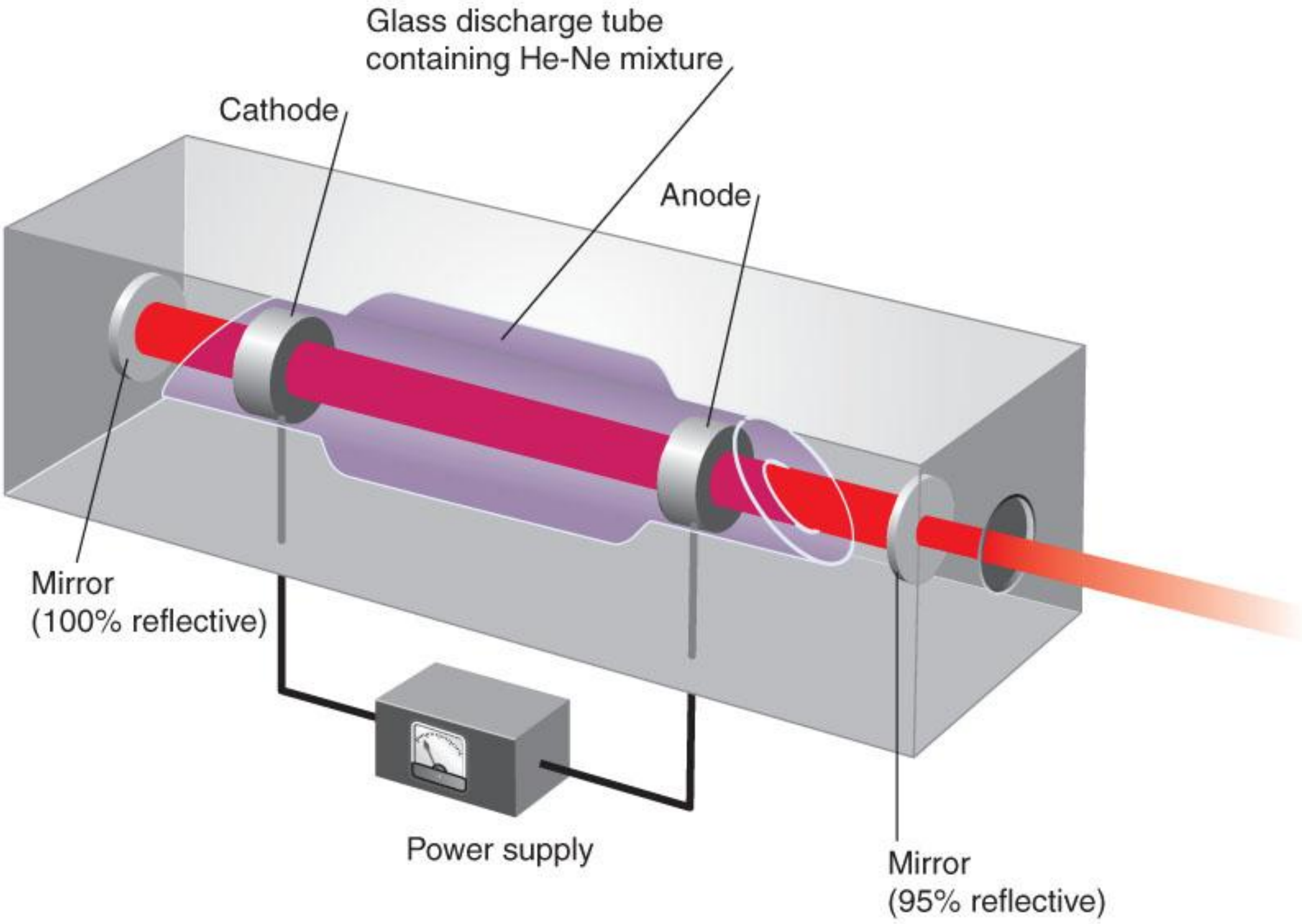


Figure 4.28 A four-level laser.

He-Ne Laser


Glass discharge tube
containing He-Ne mixture
Cathode
Anode
Mirror
(100% reflective)
Power supply
Mirror
(95% reflective)

Introduction

- A helium-neon laser, usually called a He-Ne laser, is a type of small gas laser. He-Ne lasers have many industrial and scientific uses, and are often used in laboratory demonstrations of optics.
- He-Ne laser is a four-level laser.
- Its usual operation wavelength is 632.8 nm, in the red portion of the visible spectrum.
- It operates in Continuous Working (CW) mode.

He-Ne Laser

- He-Ne Laser is a four layer gas laser.
- Laser medium is mixture of Helium and Neon gases in the ratio 7:1
- In gas, atoms are characterized by sharp energy levels compared to solids.
- Actual lasing atoms are the Neon atoms
- **Pumping Action:** Electric discharge is passed through the gas and electrons are accelerated, collide with He and Ne atoms and excite them to higher energy levels.

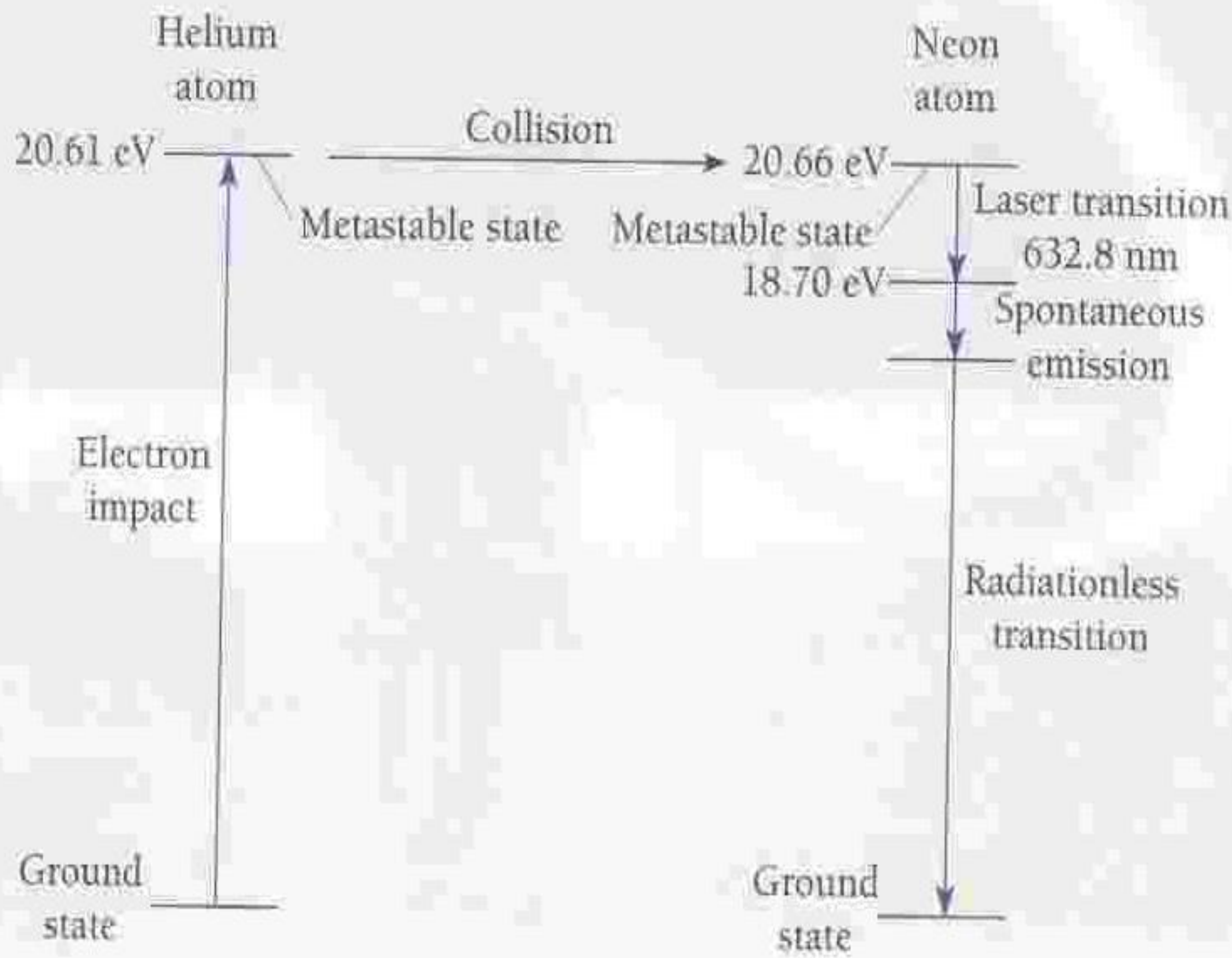


Figure 4.29 The helium-neon laser. In a four-level laser such as this, continuous operation is possible. Helium-neon lasers are commonly used to read bar codes.

Applications of He-Ne laser

- The Narrow red beam of He-Ne laser is used in supermarkets to read bar codes.

- Measuring distances

- Red He-Ne lasers have many industrial and scientific uses. They are widely used in laboratory demonstrations of optics in view of their relatively low cost and ease of operation compared to other visible lasers.

- A consumer application of the red He-Ne laser is the Laser Disc player, made by Pioneer. The laser is used in the device to read the optical disk.

- guided “smart” weapons

- The He- Ne Laser is used in Holography in producing the 3D images of objects.

Advantages

1. Easy to construct and operate.
2. Continuous beam
3. Exceptionally monochromatic beam with high operation duration

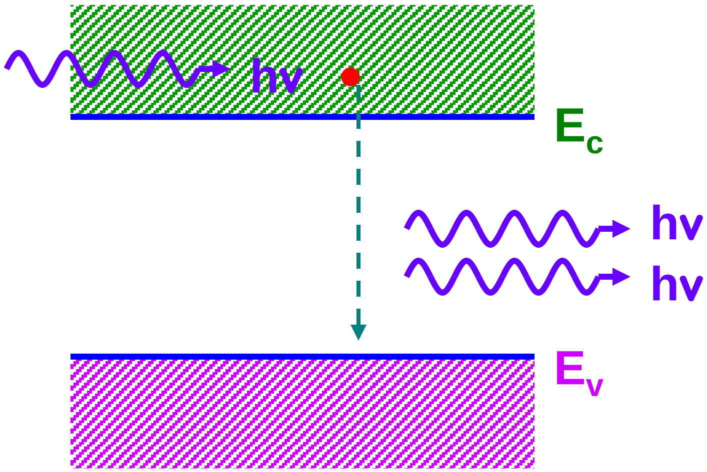
Diode Laser: Semiconductor laser

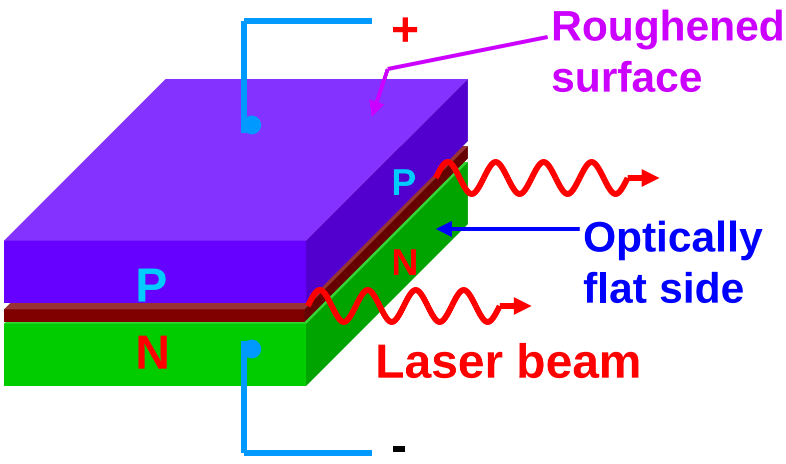
Laser Diode is an interesting variant of LED in which its special construction help to produce stimulated radiation as in laser.

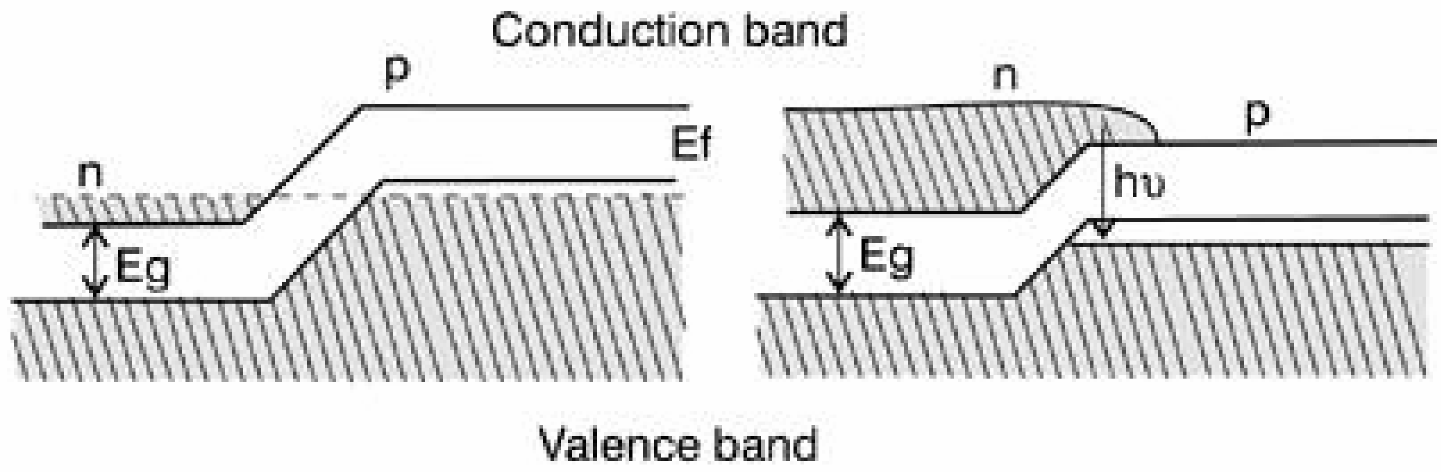
In conventional solid state or gas laser, discrete atomic energy levels are involved whereas in semiconductor lasers, the transitions are associated with the energy bands.

In forward biased p-n junction of LED, the higher energy level (conduction band) is more populated than the lower energy level (valence band), which is the primary requirement for the population inversion.

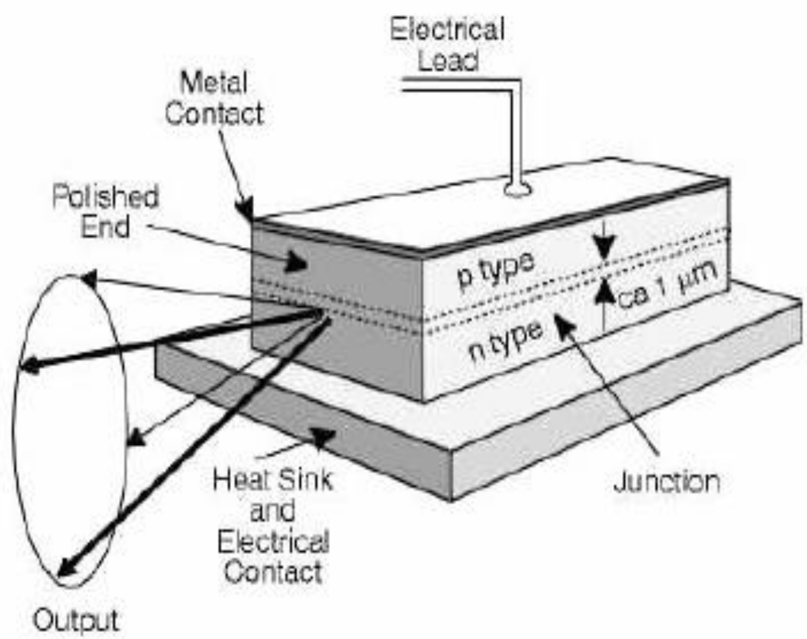
When a photon of energy $h\nu = E_g$ impinges the device, while it is still in the excited state due to the applied bias, the system is immediately stimulated to make its transition to the valence band and gives an additional photon of energy $h\nu$ which is in phase with the incident photon.

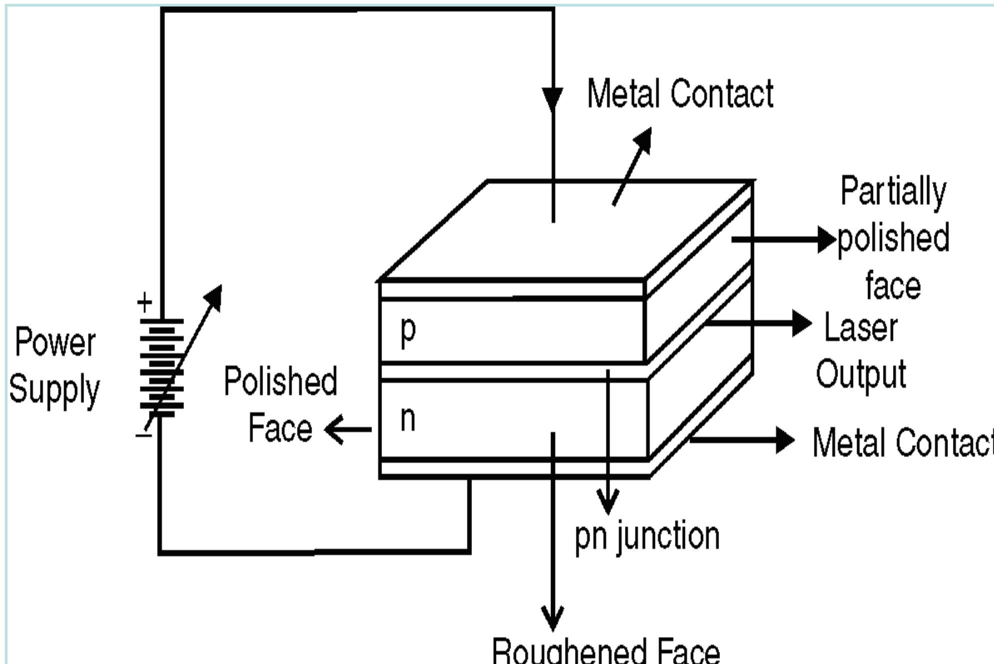






Band structure near a semiconductor p-n junction.
Left: No forward-bias voltage. Right: Forward-bias voltage present

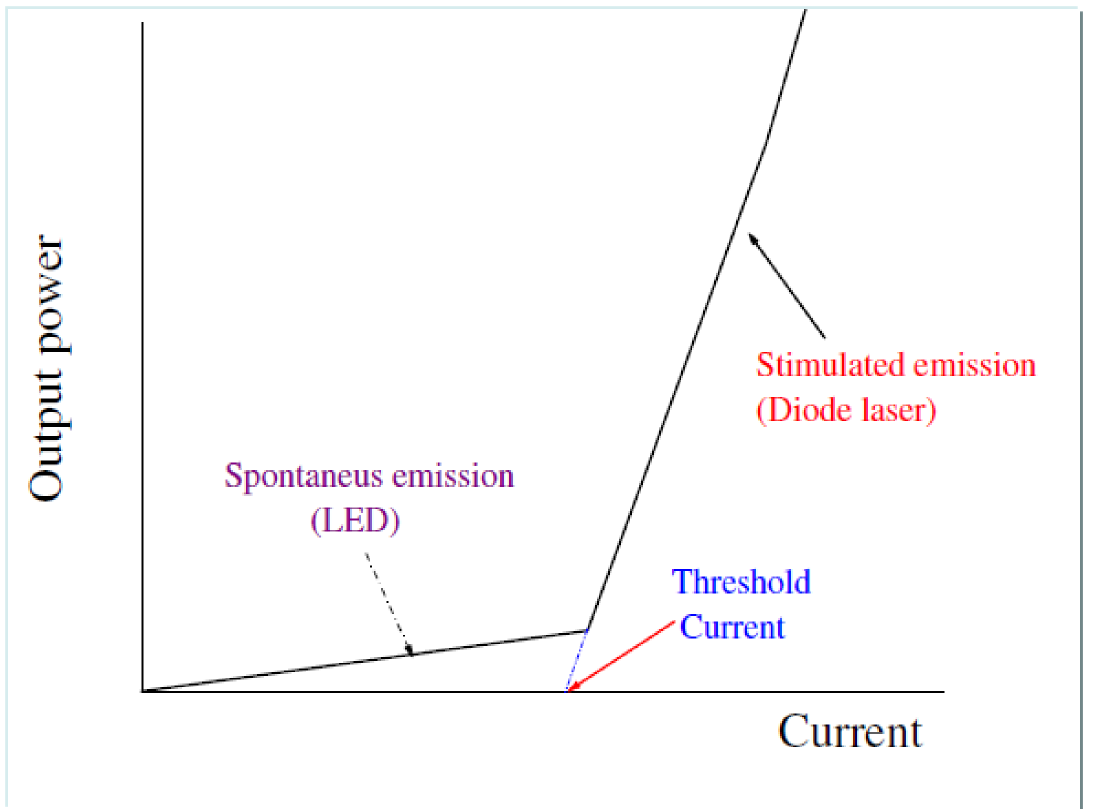




The perpendicular to the plane of the junction are polished. The remaining sides of the diode are roughened.

When a forward bias is applied, a current flows. Initially at low current, there is spontaneous emission (as in LED) in all the directions. Further, as the bias is increased, a threshold current is reached at which the stimulated emission occurs.

Output power from a diode laser as a function of input current



Due to the plane polished surfaces, the stimulated radiation in the plane perpendicular to the depletion layer builds up due to multiple reflections in the cavity formed **by these surfaces and a highly directional coherent radiation is emitted.**

Diode lasers are low power lasers used as optical light source in optical communication.

Advantages

1. **Very High Efficiency (more than 20 % of input energy is emitted as Laser transition)**
2. **High reliability**
3. **Very long life time**
4. **Very cheap price**
5. **Small volume, small weight**

Carbon dioxide Laser:

Introduction

- CO_2 laser emits an invisible infrared beam of a single wavelength in the form of a small, intense beam. Specifically, CO_2 emits photons at 10.6 and 9.6 um.

- The laser gases for CO_2 lasers normally contain a mixture of helium, nitrogen, and carbon dioxide.

- Gas Mixtures are pumped from one end of the tube and out other to provide fresh gas to replace the CO_2 depleted mix due to the separation of gas molecules.

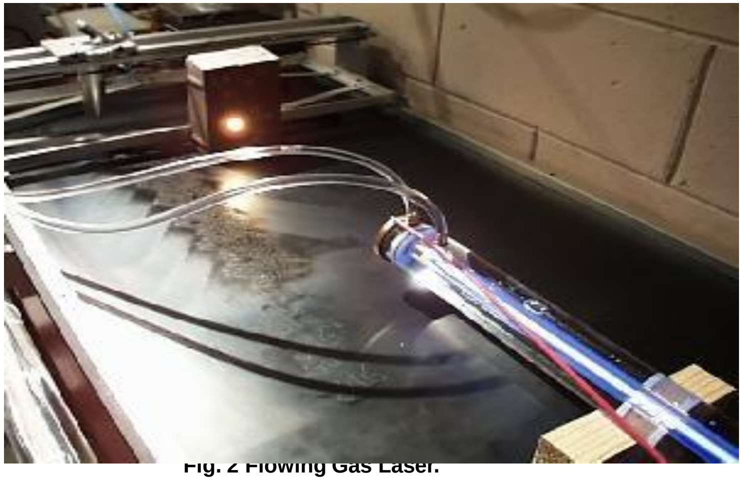


Fig. 2 Flowing Gas Laser.

- He and N_2 are added to the mixtures to boost efficiency the laser.

Fig. 3 CO2 mix bottle and primary regulator

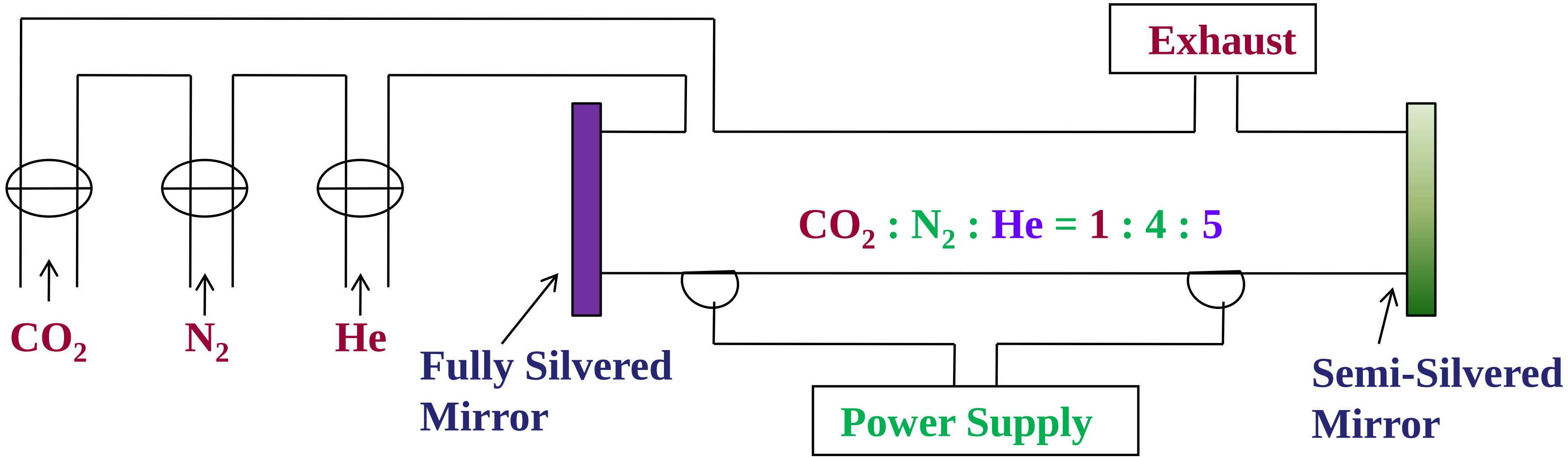
It is one of the earliest high power molecular gas laser that uses carbon dioxide molecule.

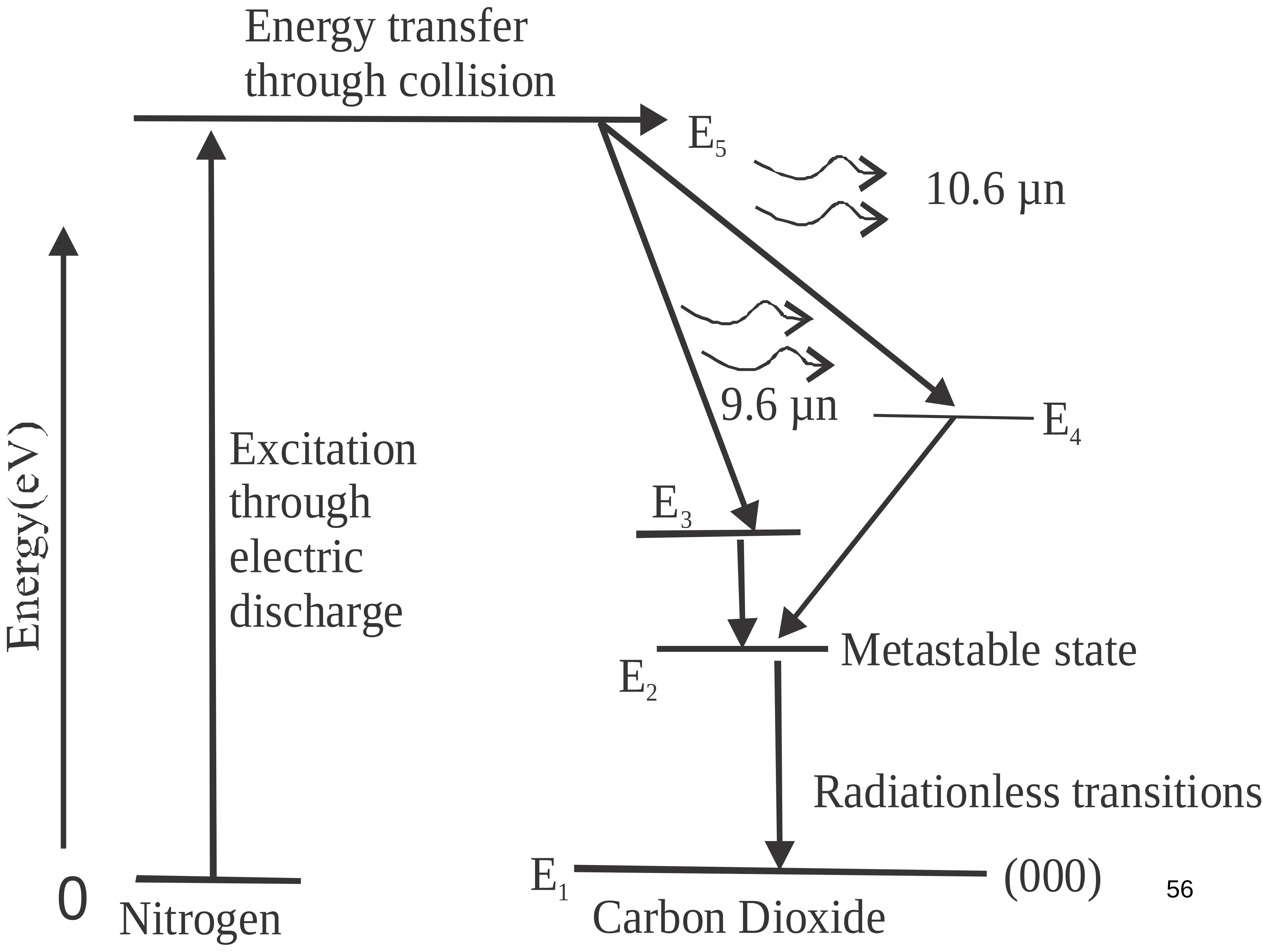
It gives continuous output power above 10 kW.

It is also capable of extremely high power pulse operation.

It consists of discharge tube of size of about 2.5 cm diameter and 5.0 cm is length.

Both ends of the tube are sealed by optically plane and parallel mirrors, one of them being semi-silvered and other one is fully silvered.





Energy transfer
through collision
E5
10.6 μn
9.6 μn
E4
Excitation
through
electric
discharge
Energy(eV)
E3
E2
Metastable state
Radiationless transitions
E1
(000)
0
Nitrogen
Carbon Dioxide

CO_2 laser……

- CO_2 laser possesses an extremely high efficiency
- *Atomic quantum efficiency* – Ratio of energy difference corresponding to the laser transition to the energy difference of the pump transition
- Atomic quantum efficiency is very high for a CO_2 laser
- Large portion of input power is converted into useful output power
- Output power of several watts to several kilowatts can be obtained

It is one of the most efficient lasers, capable of operating at more than 30% efficiency. Hence this laser is suitable for industrial applications both in terms of energy efficiency and high output beam; it is used for welding and cutting.

Applications

- The beam for a CO2 Gas Laser produces a very high temperature that may be used for engraving, cutting, drilling, marking, welding and in various medical applications such as dermatology and as a medical tool for producing clean cuts with little bleeding.

Fig. 14 Laser cuts/breaks and or inscribes based upon power settings

Fig. 15 Laser cutting thin piece of wood

http://www.repairfaq.org/sam/laserpic/laserpic.htm

Characteristics of Laser Light:

1. **Laser light is highly directional.**

   A laser beam departs from strict plarallelism only because of diffraction effects. Light from other sources can be made into an approximately parallel beam by a lens or a mirror, but the beam divergence is much greater than for laser light.

2. **Laser light is highly coherent.**

   Wave trains for laser light may be several hundred kilometre long. Interference fringes can be set up by combining two beams that have followed separate paths whose lengths differ by as much as this amount. The corresponding coherence length for light from a tungsten filament lamp or a gas discharge tube is typically considerably less than 1 m.

3. **Laser light is highly monochromatic.**

   Tungsten light, spread over a continuous spectrum, gives us no basis for comparison. The light from selected lines in a gas discharge tube, however, can have wavelengths in the visible region that are precise to about 1 part in 10^6. The sharpness of laser light can easily be thousand times greater, or 1 part in 10^9.

4. **Laser light can be sharply focussed. Flux densities for focussed laser light of 10^{15} W cm^{-2} are readily achieved. An oxyacetylene flame, by contrast, has a flux density of only 10^3 W cm^{-2}.**

5. **Tuning: Some lasers can be used to emit radiation over a range of wavelengths. Laser tunability leads to applications in photochemistry, high resolution and Raman spectroscopy.**

6. **Brightness: The primary characteristic of laser radiation is that lasers have a higher brightness than any other light source. Brightness is defined as the power emitted per unit area per unit solid angle.**

Applications of Laser Light:

1. The smallest lasers used for telephone communication over optical fibres have as their active medium a semiconducting gallium arsenide crystal about the size of the pin-head.
2. The lasers are used for laser fusion research. They can generate pulses of laser light of 10^{-10} s duration which have a power level of 10^{14} W.
3. It is used for drilling tiny holes in diamonds for drawing fine wires.
4. It is used in precision surveying.
5. It is used for cutting cloth (50 layers at a time, with no frayed edges).
6. It is used in precise fluid-flow velocity measurements using the Doppler effect.
7. It is used precise length measurements by interferometry.
8. It is used in the generation of holograms.
9. It is used to measure the x, y and z co-ordinates of a point by laser interference techniques with a precision of $\pm 2 \times 10^{-8}$ m. It is used in measuring the dimensions of special three-dimensional gauges which, in turn are used to check the dimensional accuracy of machine parts.
10. Medical applications: It has been used successfully in the treatment of detached retinas and cancer. A single pulse of laser beam of duration of a thousandth of a second only is needed for welding the retina.

Applications of Laser Light:

1. **Communication:** Modulated laser beams are being used for transmitting messages. Due to high degree of coherence, the loss of transmitted energy is comparatively much less.

2. **Surgery:** Laser beam has been used successfully for bloodless surgery. For Example:

    - It can be used to weld the detected retinas. The Laser beam can be used for drilling the teeth, removal of tumors, removal of infected cell etc.

    - It can further be used fro preventing the tooth decay by depositing hard materials on the surface of the tooth.

3. **Industry:** Laser can be focus into very fine beam, resulting in raising of temperature to about 1000 K and can be used for drilling holes and fusing and melting of metals

Applications of Laser Light:

4.**Measurement of Long Distances:** During Apollo flight no 11, on July 20, 1969, Armstrong and Aldrin planted a previously designed array of triple prisms on the moon. The laser beam sent from the earth was reflected from these prisms and was received on the earth. It enable us to determine the distance of the moon from the earth with an error within 6 m. Later, experiments lowered the error to within 30 cm.

5. **Nuclear Fusion:** Laser beam can be used to induce the nuclear fusion. By concentrating the laser beam to a very very narrow spot, temperature may rise to about 10^8 K and nuclear fusion can occur at this temperature.

6. **Scientific Research:** Used in Michelson Morley Experiment. This experiment was conducted to test ether drift. In this experiment, the beam of two infra-red laser of slightly different frequencies were obtain by means of a beam splitter and the beat frequency was determined.

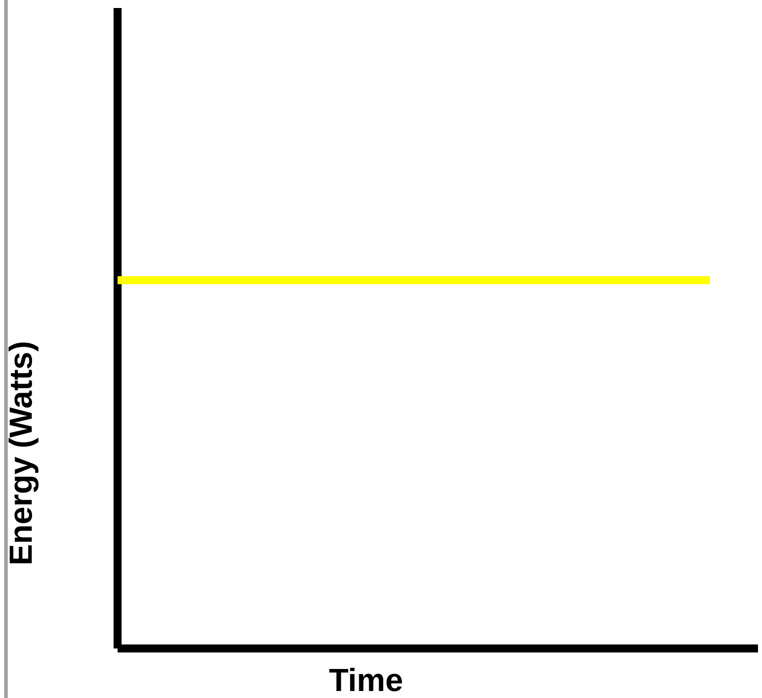
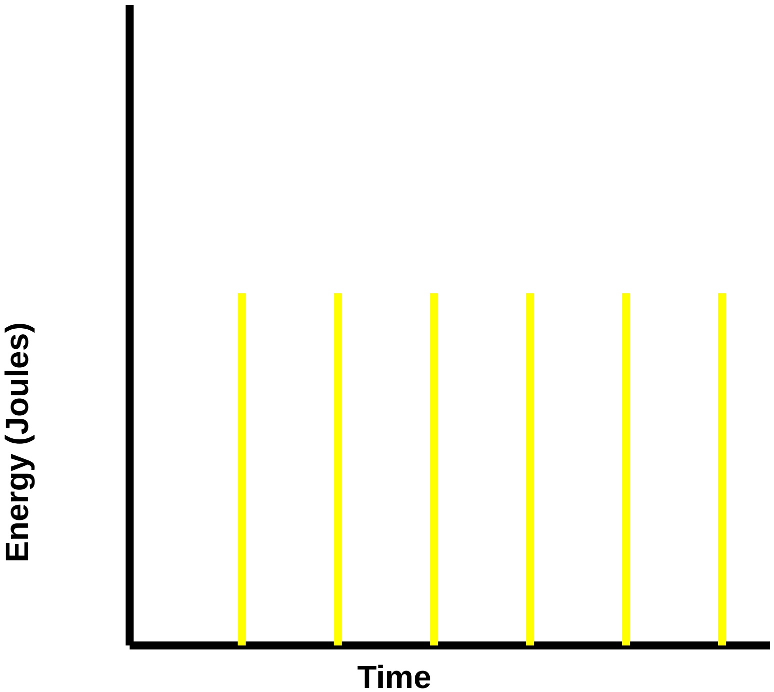
Quantum Efficiency

Two Level Laser: **In this type of laser, E_1 is the ground state and E2 is the excited state, where the electron is pumped. The quantum efficiency (η) is given by**

$$\eta = \frac{h\nu_{\text{Output}}}{h\nu_{\text{Pumped}}} = \frac{E_2 - E_1}{E_2 - E_1} = 1$$

Thus in this type of laser, the quantum efficiency is 100% e.g. p-n junction laser.

Laser Output

Continuous Output (CW)	Pulsed Output (P)
	

***Watt (W)* -** **Unit of power or radiant flux (1 watt = 1 joule per second).**

***Joule (J)* - A unit of energy**

Energy (Q) The capacity for doing work. Energy content is commonly used to characterize the output from pulsed lasers and is generally expressed in Joules (J).

***Irradiance (E)* - Power per unit area, expressed in watts per square centimeter.**