*Lectures in Laser & Fiber Optics*

# LASER

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## My sincere acknowledgments to

- **Lasers and Nonlinear Optics**,
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- **Concepts of Modern Physics**, 6th Ed.,
  A. Beiser, S. Mahajan, McGraw-Hill, New Delhi (2011).
- **A Textbook of Engineering Physics**,
  M.N. Avadhanulu and P.G. Kshirsagar,
  S. Chand Publishers, New Delhi (2014).
- **and many other free & copyright internet resources.**

# Introduction to Spectroscopy

## Spectroscopy

- **Method of "Seeing the Unseeable"!**

  *USING*

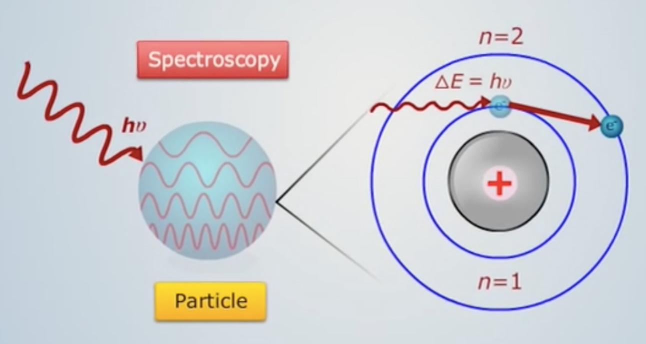
- **Electromagnetic radiation** to obtain information about atoms and molecules.

## Spectroscopy...

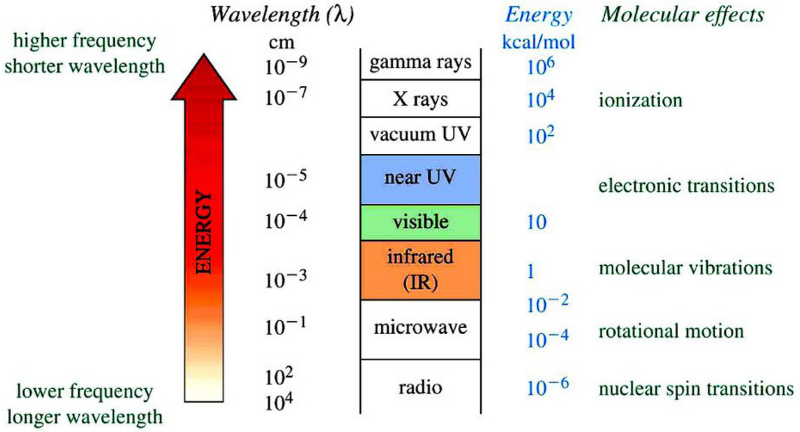
- **An instrumentally aided study of the interactions between matter and energy to obtain information about atoms and molecules.**
  Here **matter**: given sample (atom/molecule).
  **energy**: supplied by any portion of the electromagnetic spectrum.

## Spectroscopy...

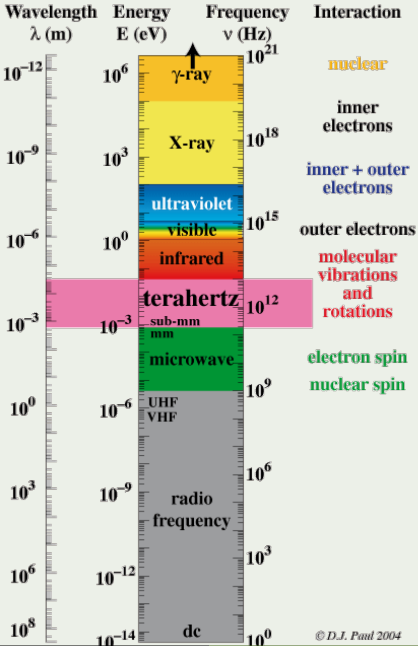
**Interaction of electromagnetic radiation with matter!**



## Electromagnetic Radiation

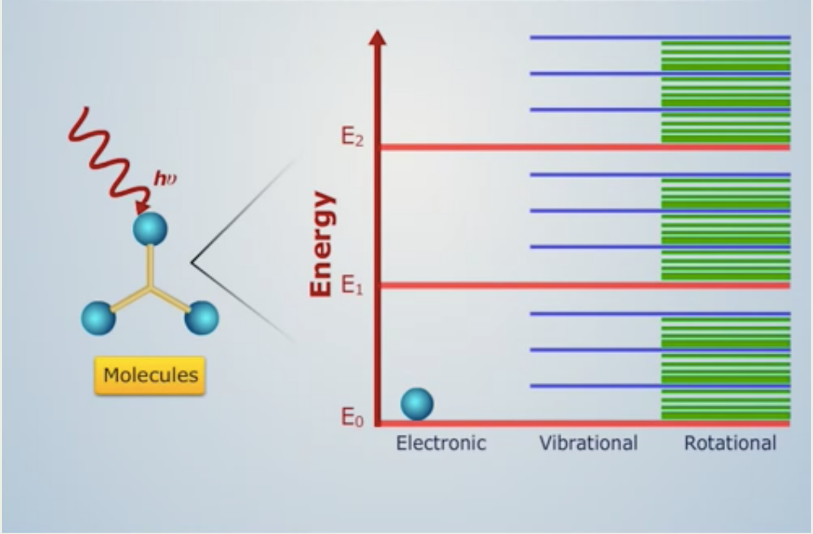



Graphics source: Wade, Jr., L.G. *Organic Chemistry*, 5th ed. Pearson Education Inc., 2003


Wavelength λ (m)
Energy E (eV)
Frequency ν (Hz)
Interaction
10^-12
10^-9
10^-6
10^-3
10^0
10^3
10^6
10^8
10^6
10^3
10^0
10^-3
10^-6
10^-9
10^-12
10^-14
γ-ray
X-ray
ultraviolet
visible
infrared
terahertz
sub-mm
mm
microwave
UHF
VHF
radio
frequency
dc
10^21
10^18
10^15
10^12
10^9
10^6
10^3
10^0
nuclear
inner
electrons
inner + outer
electrons
outer electrons
molecular
vibrations
and
rotations
electron spin
nuclear spin
© D.J. Paul 2004

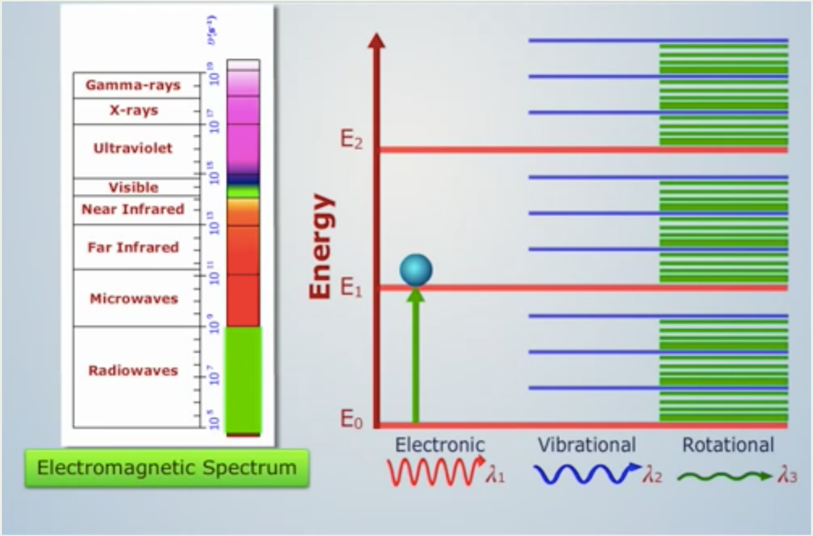
## Effect of Electromagnetic Radiation: Spectroscopy

**Three types of spectra in molecular transitions!**



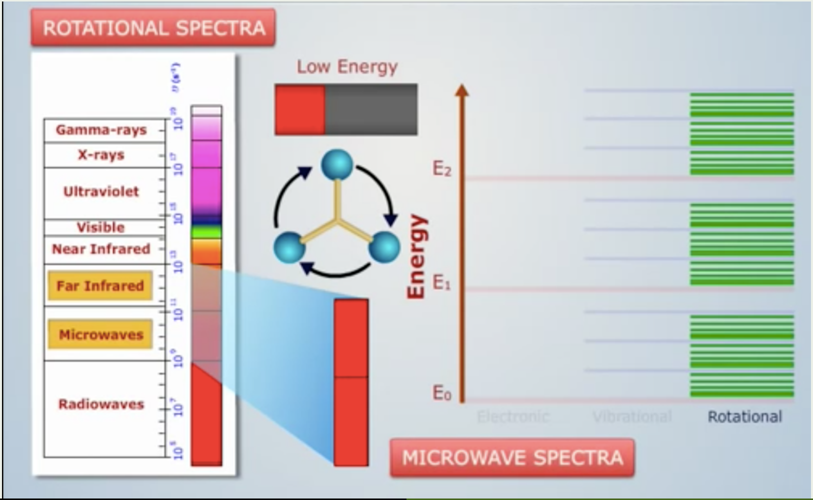
## Spectroscopy...

**Three types of spectra in molecular transitions!**



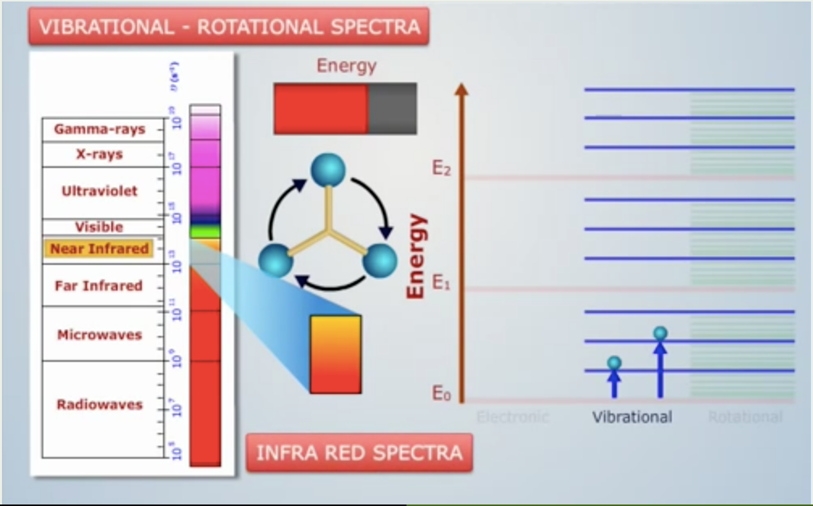
## Rotational/MW Spectroscopy

**Low energy EMR (MW/Far-IR) can change rotational levels only!**



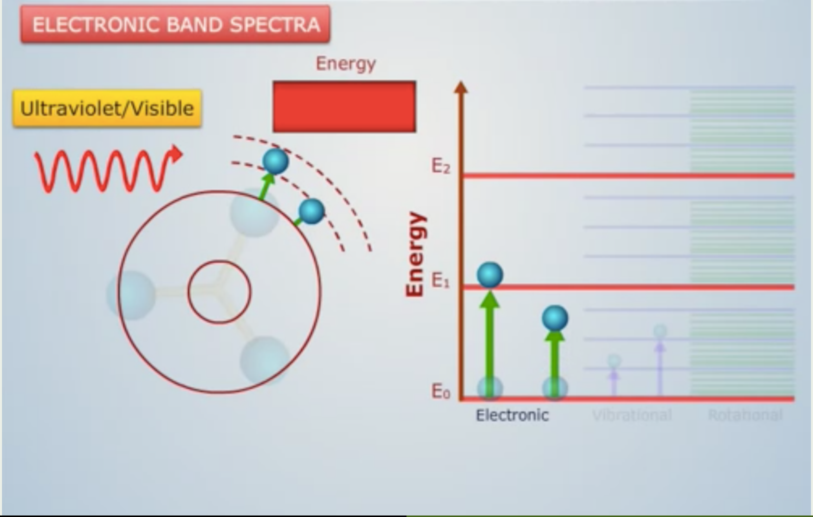
## Vibrational/IR Spectroscopy

**Medium energy EMR (Near-IR) can change vibrational levels and rotational sublevels!!**



# Electronic Spectroscopy

**High energy EMR (UV/Vis) can change electronic levels along with vibrational and rotational sublevels!!!**



# Electronic Spectroscopy...

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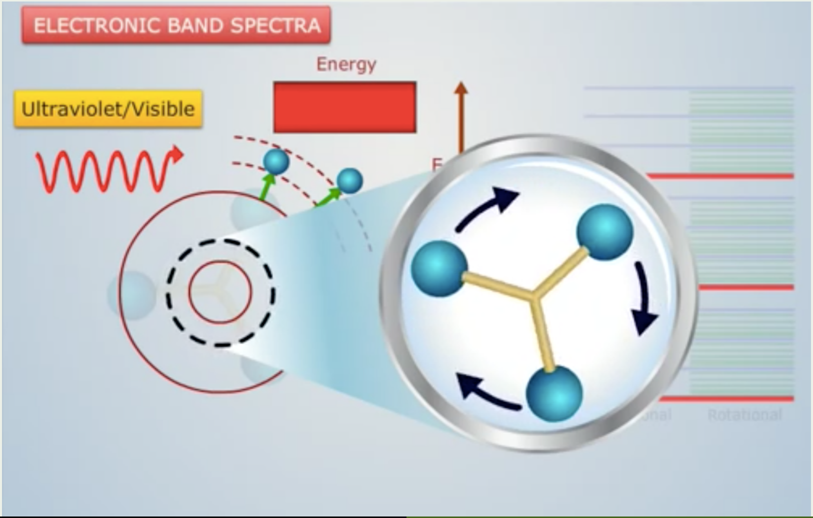
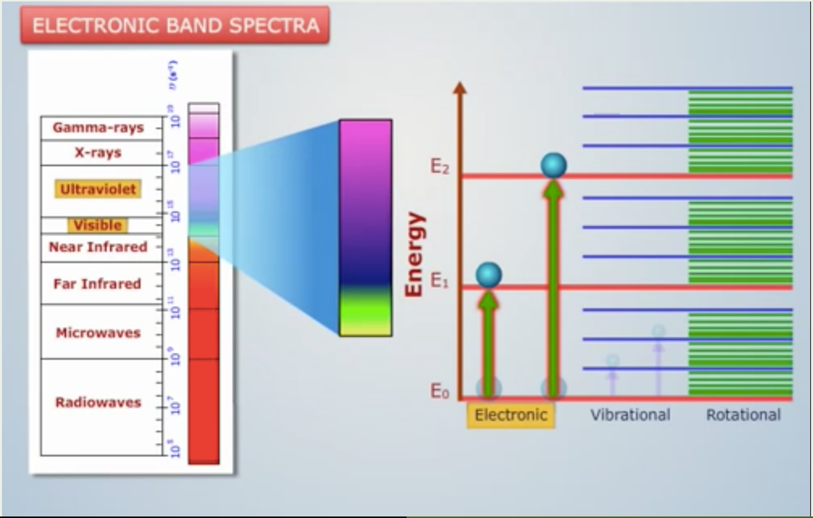


# Electronic Spectroscopy...

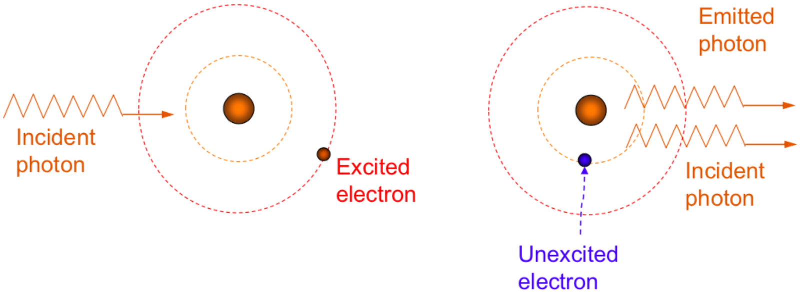
**High energy EMR (UV/Vis) can change electronic levels along with vibrational and rotational sublevels!!!**



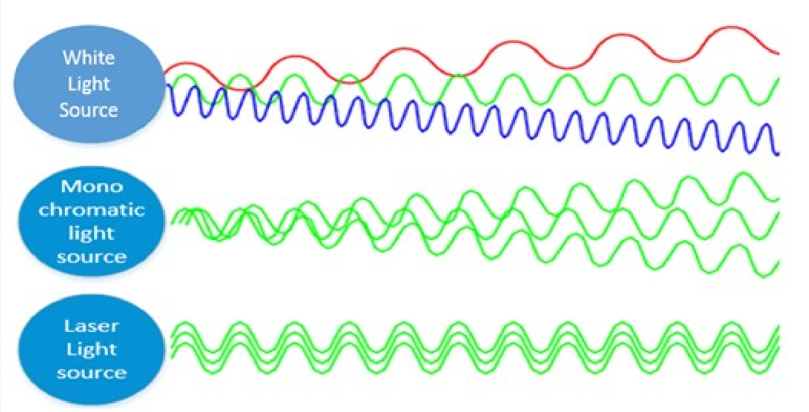
## Laser

**Light Amplification by Stimulated Emission of Radiation.**

- Invented in 1960 by the physicist Maiman.
- One of the most influential technological achievements of the 20th century.
- Lasers are basically excited light waves.

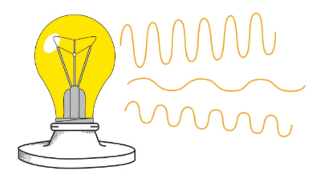


## Light sources



## Incandescent Light

1. Many wavelengths
2. Multidirectional
3. Incoherent



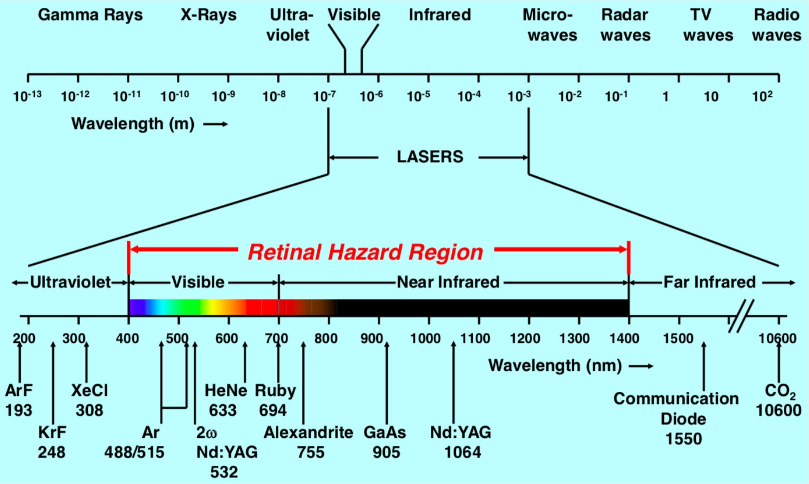
## Laser: Characteristics

- **Monochromatic**
- **Coherent**
- **Directional**

**The combination of these three properties makes laser light exemplary.**

**Laser light is highly powerful and capable of propagating over long distances.**

## Laser Range of wavelength



## Laser: Important Achievements

- **Stimulated Emission**: 1917–Einstein.
- 1951–Joseph Weber: Stimulated emissions for MW amplifier (idea/concept).
- 1953 – Charles Hard Townes, J.P. Gordon & H.J. Zeiger: Designed first Microwave amplifier – MASER *Microwave Amplification by Stimulated Emission of Radiation.*
- 1955 – Prokhorov & Basov: Optical pumping of a multi-level system as a method for obtaining the population inversion (laser pumping)
- 1957/58 – C.H. Townes and A.L. Schawlow @ Bell Labs filed for US patent for “optical maser" (granted in 1960)

## Laser: Important Achievements...

- 1957 – Gordon Gould: Thesis work @ Columbia University. Coined the name “LASER" & filed for US patent (granted only in 1977 & 1987)

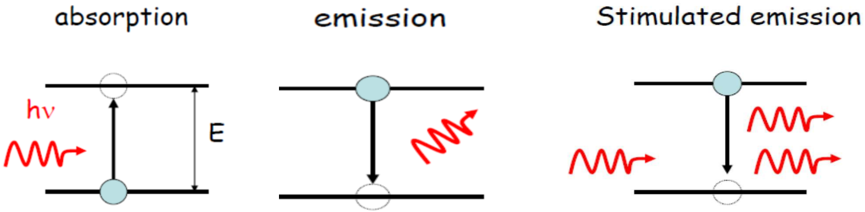
- Ruby Crystal Laser: 1960–Maiman,California.
- He-Ne Laser: 1961–Ali Javan.
- Diode Laser: 1962–Hallin.
- Many more findings...

- 1964 Nobel Prize – C.H. Townes, N. Basov & A. Prokhorov “*for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle*".
- Nobel Prize 1981: N. Bloembergen & A.L. Schawlow “*for their contribution to the development of laser spectroscopy*"

## Laser: Actions involved

- Absorption
- Spontaneous Emission
- Stimulated Emission
- Population Inversion
- Optical Pumping

* $E_1$ = Ground state
* $E_2$ = Excited State
* $E = E_2 - E_1 \Rightarrow h\nu$ (Photon Energy)



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## Laser: Population Inversion

- The process of increasing exited electrons in higher energy levels.
- This process is necessary for the production of laser.
- The energy level between the ground state $E_1$ and exited state $E_3$ is known as metastable state $E_2$. ($E_3 > E_2 > E_1$)
- By optical pumping electrons from ground state jumps to exited state by absorbing photons.
- The electrons remain only for $10^{-8}$ sec in exited state $E_3$, so most of them jumps back to the ground state $E_1$ by emitting photons. But some of them jumps to the metastable state $E_2$.
- Electron stay in metastable state for more then $10^{-3}$ sec.
- So, electron density increases in metastable state.
- Thus the transitions are possible. It takes more no. of electrons together and $\nu_{12}$ photon beam is produced.

## Laser: Pumping

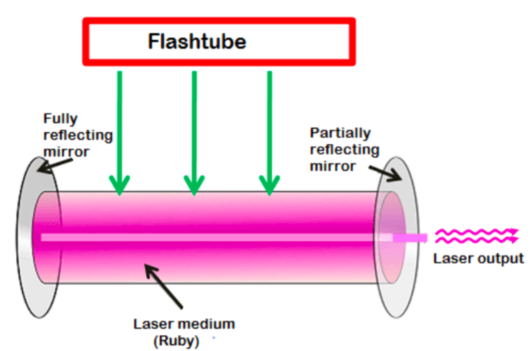
**There are no of techniques for pumping a collection of atoms to an inverted state.**

- **Optical pumping**: Light energy in the form of short flashes is supplied. The ground state atoms absorb this light energy (photons) and excite to higher energy state. Ex. Ruby laser.
- **Electrical discharge**: Gas is ionized by means of a suitable potential difference. Strong electric fields accelerate the cathode emitted electrons which collide with the gaseous atoms of the medium. Ex. He–Ne laser.
- **Direct conversion**: Electric current directly creates enough mobile charges (population) at the inter-phase of two different types of semiconductors. Ex. Ga-As laser.
- **Chemical pumping**: The exothermic chemical reactions generate enough heat or light energy to utilize for pumping the atoms to higher energy levels. Ex. $CO_2$ laser.

## Ruby Laser

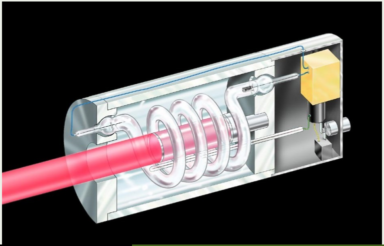
* Solid-state laser uses the synthetic ruby crystal as medium.
* Ruby laser is the first successful laser – Maiman in 1960.
* Ruby laser is one of the few solid-state lasers that produce visible light. It emits deep red light of wavelength 694.3 nm.

- **Laser medium or gain medium**:
  * A single crystal of ruby ($Al_2O_3 : Cr^{3+}$) in the form of cylinder. The ruby has good thermal properties.



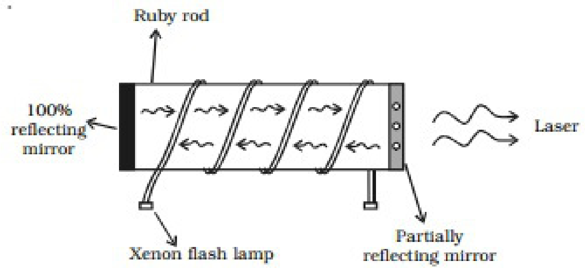
## Ruby Laser...

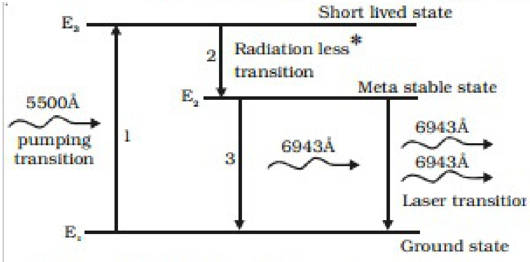
- **Pump source or energy source**:
  * A flashtube as the energy source or pump source.
- **Optical resonator**:
  * The ends of the cylindrical ruby rod are flat and parallel.
  * The cylindrical ruby rod is placed between two mirrors.
  * Optical coating is applied to both the mirrors (silvering).
  * Each mirror is coated or silvered differently.
  * At one end of the rod, the mirror is fully silvered (for completely reflect) whereas, at another end, the mirror is partially silvered (to allow a small portion of light through



# Ruby Laser...

## Energy Level Diagram



## Ruby Laser: Advantages

- Ruby lasers are economical.
- Beam diameter is comparatively less than $CO_2$ gas lasers.
- Output power is not as less as in He-Ne gas lasers.
- Since the ruby is in solid form therefore there is no chance of wasting material of active medium.
- Construction and function is self explanatory.

## Ruby Laser: Disadvantages

- No significant stimulated emission occurs, until at least half of the ground state electrons are excited to the Meta stable state.
- Efficiency is comparatively low.
- Optical cavity is short as compared to other lasers.

## Ruby Laser: Applications

- Due to low output power they are class-I lasers: Safe

## Nd:YAG Laser

**Solid-State laser: Four-level system.**

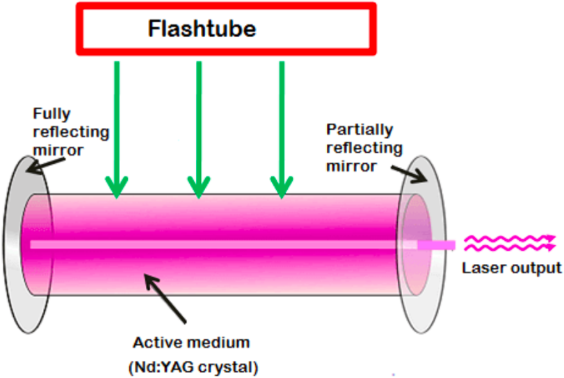
**Neodymium-doped Yttrium Aluminum Garnet**

Many different applications in the medical and scientific fields.

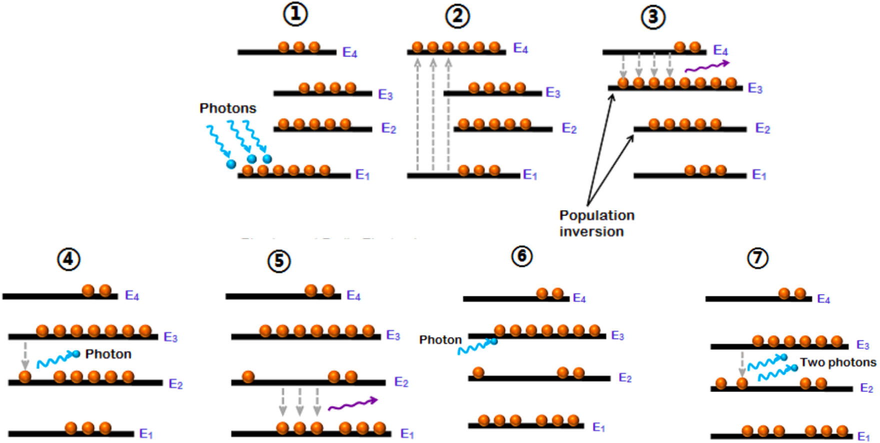
Nd: YAG laser generates laser light in the near-IR region.

Mostly Nd:YAG laser output is at 1064 nm.

Additional lasers at 1440 nm, 1320 nm, 1120 nm, and 940 nm.



# Nd:YAG Laser: Working



## He-Ne Laser

*** He-Ne laser: Gas laser!**
*** Active medium contains "two non-interacting gases" & do not interact to form a molecule!**

* Gain medium with of 75% Helium & 25% Neon.
* The best-known and most widely used.

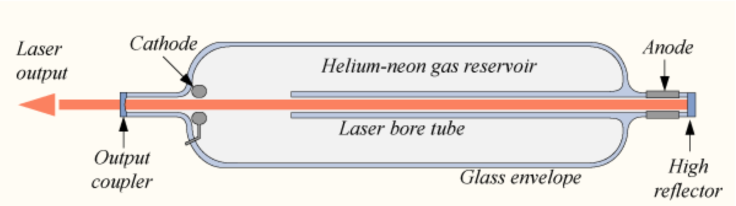
* The first HeNe lasers emitted infrared at 1.15 $\mu m$.
* Need & demand for visible laser???

* 632.8 nm (red) wavelength HeNe laser @ Bell Telephone Laboratories in 1962 by Ali Javan, Bennett, and Herriott.

* Many industrial and scientific uses.
Often used in laboratory demonstrations.

## HeNe Laser: Design

- **Laser medium or gain medium**:
  * Glass tube with a narrow capillary tube through center.
  * Capillary tube: To direct the electrical discharge through its small bore to produce very high current densities.



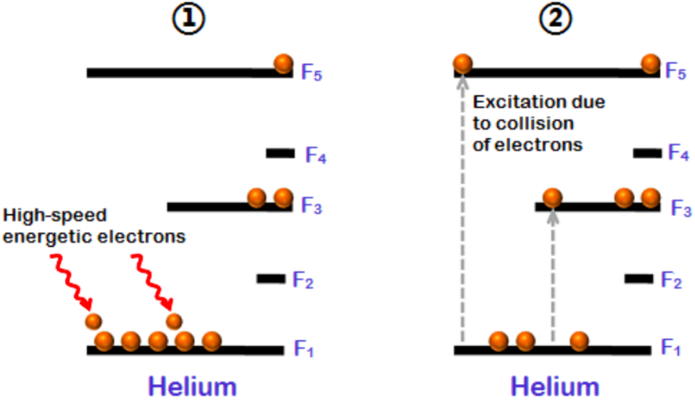

  * The output coupler and high reflective mirror are located at the opposite ends. (economical & accurate).
  * A large cylindrical metallic cathode & a smaller metallic anode. The current is directed from cathode to anode.
  * The gas reservoir provides a supply of extra gas.
  *Helps to maintain a uniform pressure over long time and provides extra gas to replace any gas that may escape*

## HeNe Laser: Working

**Pumping Energy: Electrical discharge**

**Electrical energy ⇒ Energetic electrons ⇒ Helium atoms ⇒ He electrons excitation (ex. to $F_5$ level)!**

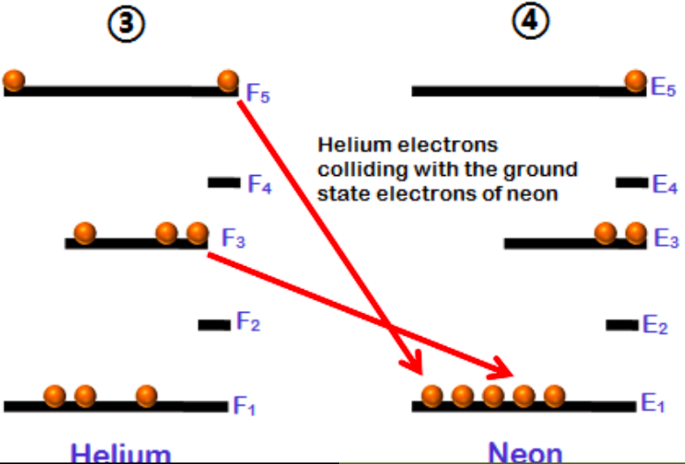
$$E + He + Ne \rightarrow He^{*} + Ne$$



## HeNe Laser: Working...

**Energy transfer from He electron to Ne electron during its return to ground $F_1$ state!**

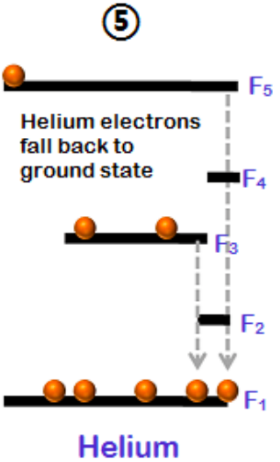
$$He^* + Ne \to He + \Delta E + Ne$$

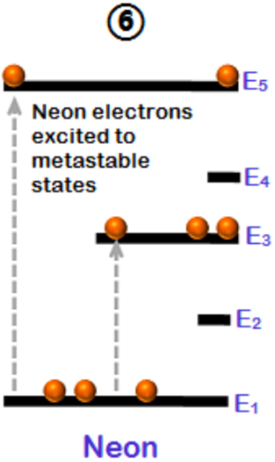


## HeNe Laser: Working...

**Ne electrons absorb energy and excite to $E_3$ & $E_5$ levels! Helium atoms help Neon atoms in achieving population inversion!!**

$$He + \Delta E + Ne \rightarrow He + Ne^*$$

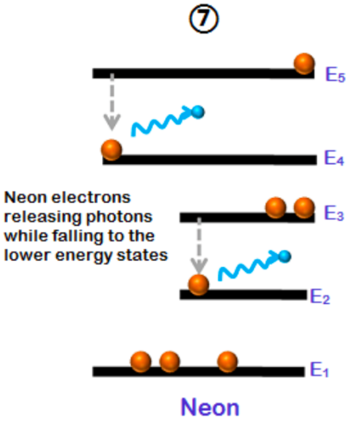


## HeNe Laser: Working...

**The metastable Ne electrons ($E_3$ & $E_5$) spontaneously fall into the next lower energy states ($E_2$ & $E_4$) by releasing photons or red light: Spontaneous emission!**

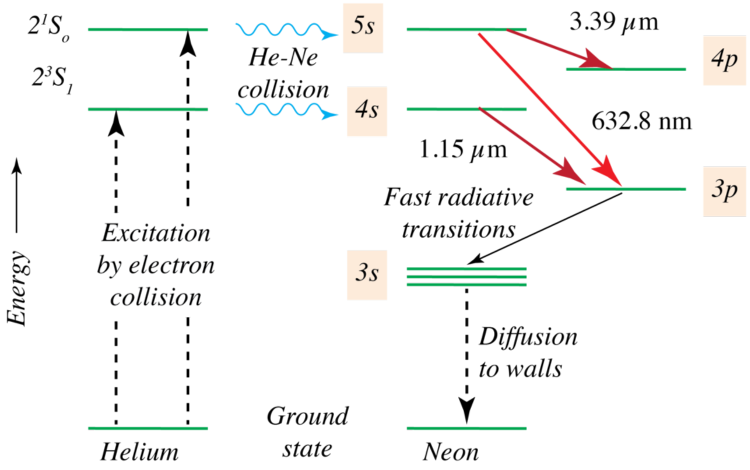
$$He + Ne^* \rightarrow He + Ne + h\nu$$




* The Ne excited electrons continue on to the ground state through radiative and non-radiative transitions.

* The light or photons emitted from the Ne atoms will moves back and forth between two mirrors until it stimulates other excited Ne electrons and causes them to emit light.
* Optical gain is achieved through stimulated emission.

## HeNe Laser: Energy Level Diagram




**Most common wavelength by He-Ne lasers is 632.8nm!**

Also, two lower power ($1.152\mu m$ and $3.391\mu m$) IR wavelengths!!

## HeNe Laser: Advantages

- HeNe laser light in the visible portion of the spectrum
- He-Ne laser tube has very small length $\approx$ 10 to 100cm and best life time of 20,000 hours.
- Cost of He-Ne laser is less from most of other lasers.
- Construction of He-Ne laser is also not very complex.
- He-Ne laser provide inherent safety due to low power output
- Low cost & High stability
- Operates without damage at higher temperatures

## HeNe Laser: Disadvantages

- Less efficiency & Low gain
- High voltage requirement is its main disadvantage.
- Helium-neon lasers are limited to low power tasks
- Escaping of gas from laser plasma tube

## HeNe Laser: Applications

- Widely used for many industrial applications (*Metrology, Cleanroom Monitoring Equipment, Food Sorting, Flow Cytometry, Confocal Microscopy, Imaging and Medical Equipment, Opacity Monitoring, Alignment tool, Maritime Visual Guidance Systems*)
- Used in schools, colleges, universities for science programs.
- Used by newspapers for reproducing transmitted photographs.
- He-Ne lasers are used in Guns for targeting.

## HeNe Laser: Suppressing Unwanted Wavelengths

- The He-Ne laser produces three different wavelengths $1.152 \mu m$, $3.391 \mu m$ and $632.8 nm$.
- IR photons - less energy & $632.8 nm$ more energetic photon of red color.
- The red output is most desirable, need to suppress the IR wavelengths.
- In small He-Ne laser, suppression is done with proper coatings on the mirrors.
- For high power He-Ne lasers, magnet is placed near the plasma tube.
- The infrared filters can be used between the laser mirrors.

## Carbon dioxide ($CO_2$) Laser

- invented by Kumar Patel of Bell Labs in 1964.
- Highest-power continuous wave lasers.
- Quite efficient: $\frac{POWER_{output}}{POWER_{pump}} \approx 20\%$.
- CO2 laser produces a beam of IR light ($9.4\mu m$ & $10.6\mu m$)
- Active laser medium: Gas discharge with air- or water-cooling.
- Filling gas: Around 10–20% $CO_2$, 10–20% $N_2$, $H_2$, & $Xe$.
- The excitation energy is due to vibrations & rotations.
- The photons emitted due to these transition have comparatively lower energy, and longer wavelength, than visible and near-infrared light. The $9 - 12\ \mu m$ wavelength of $CO_2$ lasers.

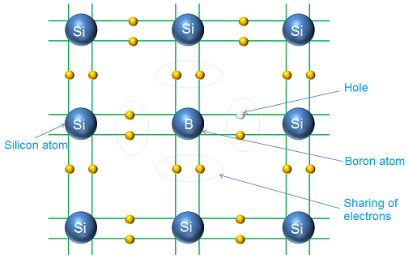
## Semiconductor Laser

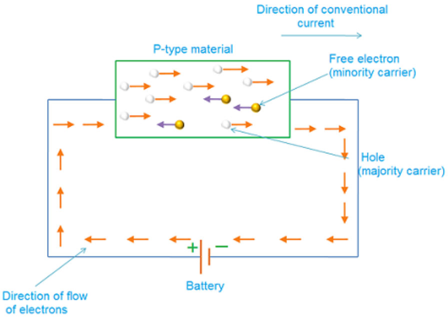
- Specially fabricated p-n junction device which emits coherent light when it is forward biased.
- R. N. Hall group: 1962 – First semiconductor laser made from Gallium arsenide (GaAs) operated at low temperatures and emitted light in the near IR region.
- Nowadays, p-n junction lasers are made to emit light almost anywhere in the spectrum from UV to IR.
- Diode lasers are remarkably small in size (0.1mm long). They have high efficiency of the order of 40%.
- Modulating the biasing current easily changes laser output.
- Operate at low powers & output power equivalent to that of He-Ne lasers.

## Semiconductor - Introduction
## p-type Semiconductor

Majority carriers: Holes

*Ex.: Solicon-14 with triavalent atom (Boron-5) doping!*

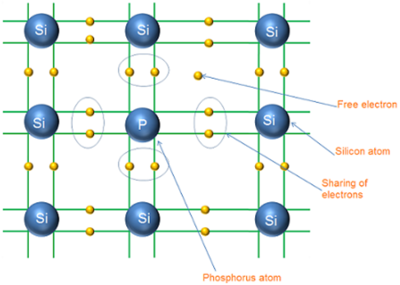


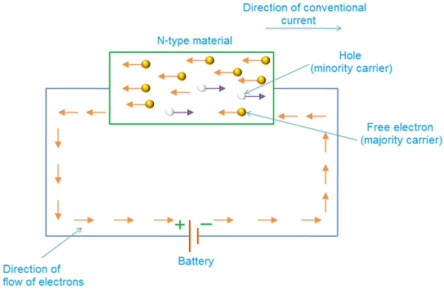



**n-type Semiconductor**

Majority carriers: Free electrons

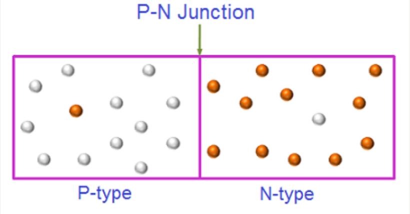
*Ex.: Solicon-14 with pentavalent atom (Phosphorus-15) doping!*



# p-n junction

* p-type material is joined/doped with a n-type material.
A fundamental building block of most semiconductor electronic devices such as transistors, solar cells, light emitting diodes, and integrated circuits.
* Discovered by Russel Ohi of Bell Laboratories.



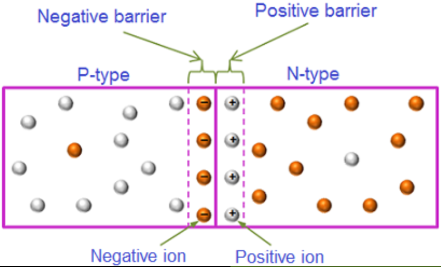

* Semiconductor devices are the fundamental building blocks of all the electronic devices such as computers, control systems, ATM, mobile phones, amplifiers, etc.
* Before the invention of semiconductor diode there was vacuum tubes which are large in size, takes more power, costly & noisy.

# pn Semiconductor

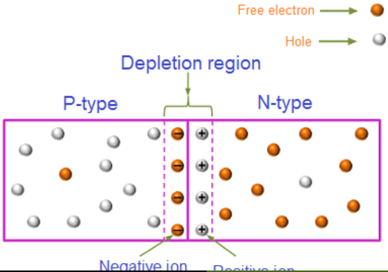
* In n-type region, large number of free electrons is present & get repelled from each other. So, move from a high concentration n-region to a low concentration p-region.

* Near pn-junction free electrons & holes are close to each other.

* Coulombs law: Free electrons from n-side attracted towards the holes at p-side. So, the free electrons move from n-side to p-side. Similarly, holes move from p-side to n-side

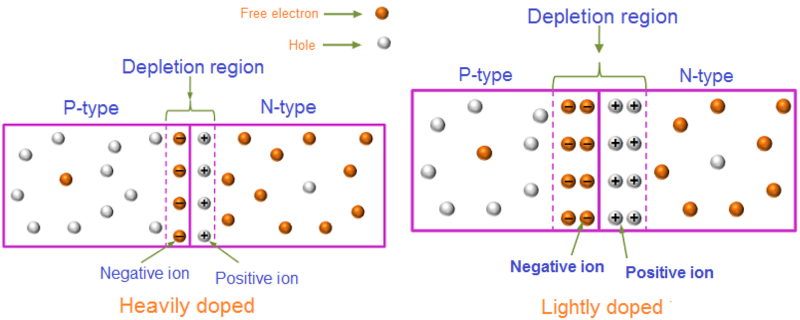


* Free electrons cross pn-junction & fill holes in p-side atoms.
* The p-atom/side turns with more electron than protons=> become a negative ion (charge).
* Each free electron that left the parent n-atom turns n-side as positive ion (charge).
* The net negative charge at p-side prevents further flow of free electrons crossing pn-junction (because the negative charge present at the p-side repels the free electrons).
* Similarly, the net positive charge at n-side prevents further flow of holes from p-side to n-side.
* Barrier: Depletion region or depletion zone or depletion layer!



**Width of depletion region inversely proportional to doping!**

If doping increase, width decreases! (more free electrons/holes)

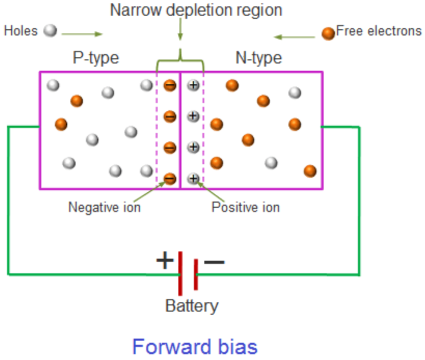



Forward biased: allows electric current/flow.

Reverse biased: blocks electric current/flow.

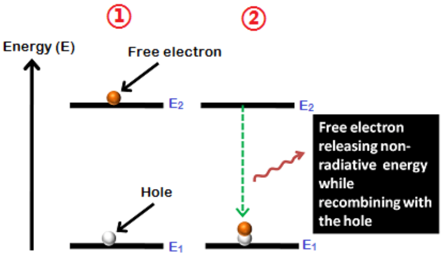
## LED or Laser Diode in forward bias

* Free electrons (negative to positive terminal) & holes (positive to negative terminal) of the battery.
* The electrons moving from n-type to p-type will recombines with the holes in the p-type semiconductor or junction.
* Holes moving from p-type to n-type will recombines with the electrons in the n-type semiconductor or junction.

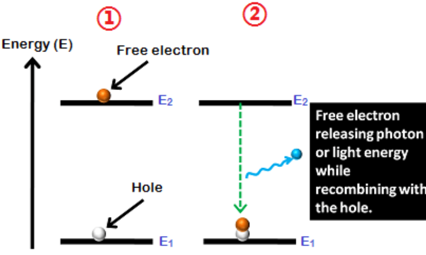


# LED or Laser Diode in forward bias

* We know that the energy level of free electrons in conduction band is high as compared to the holes in valence band.
* So, the free electrons will release their extra energy while recombining with the holes.




Electron transition in ordinary diode

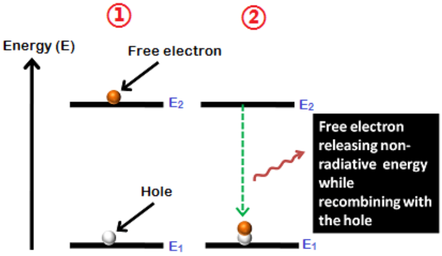



Electron transition in laser diode

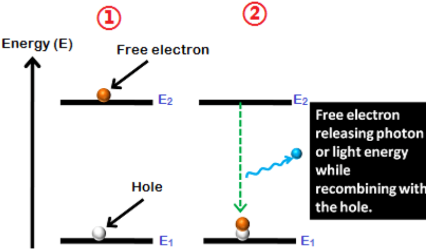
**During electron-hole recombination:**
**Excess energy is released in the form of light/photons ⇒ LEDs & Laser Diodes/Semiconductor lasers!**

## Laser Diode

* An optoelectronic device converting electrical energy into light energy to produce high-intensity coherent light.
* The p-n junction of the semiconductor diode acts as the laser medium or active medium.
* The working of the laser diode is almost similar to the LED.
* Main difference: LED emits incoherent light. But, Laser diode emits coherent light.




Electron transition in ordinary diode



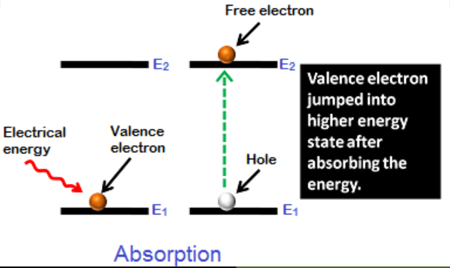

Electron transition in laser diode

## Laser Diode: Construction

- Made of two doped Gallium-Arsenide (GaAs) layers.
- One doped GaAs layer acts as n-type semiconductor!
  Second doped GaAs layer acts as p-type semiconductor.
- Doping agents: Selenium, Aluminum, and Silicon.
- **A p-n junction (lasing/active medium) is formed** by joining a p-type & n-type layers.
- GaAs diodes: Energy release in the form of light/photons.
  But, Si diodes energy release is not as light (mostly heat).
- Steps to produce a coherent beam of light:
  (i) Energy absorption
  (ii) Spontaneous emission
  (iii) Stimulated emission.

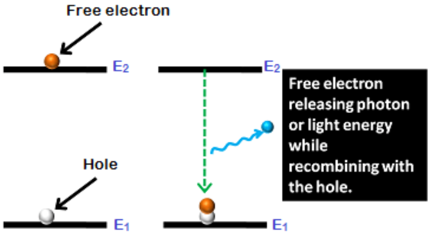
## Laser Diode: Working

- **Energy absorption from external sources**.
- Electrical energy or DC voltage – external energy source. It supplies enough energy to the valence electrons in parent atom for jumping into the higher-energy (conduction) level. These conduction band electrons – free electrons.
- When the electron leaves the valence shell it creates an empty space (hole) at the point.
- ∴ Both free electron-hole pairs are generated due to absorption of energy from the external DC source.



## Laser Diode: Working...

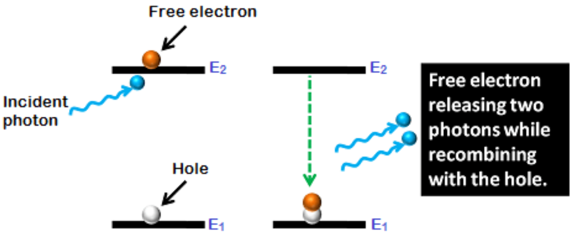
- **Spontaneous emission due to natural fall of electrons to the lower energy state.**
- Laser diodes: The valence band electrons (and so holes generated) are in the lower energy state.
- Conduction-band/free electrons are in the higher energy state. i.e. Free electrons have more energy than holes.
- The free electrons need to lose their extra energy by photons to recombine with the holes in the valence band.




Spontaneous emission

## Laser Diode: Working...

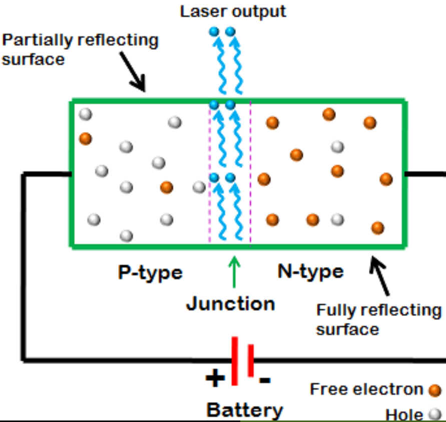
- **Stimulated emission**: Artificially inducing the free electrons by photon to fall into the lower energy state by releasing energy/photons.
- Free electrons need not wait for their whole lifetime.
- With external photons the free electrons are forced to recombine with holes releasing doubled-number of photons.
- All the stimulated photons travel in the same direction. $\Rightarrow$ Beam of high-intensity coherent light: diode-laser.




Stimulated emission

# Laser Diode: Working...

- Some electrons directly interact with the valence electrons. Some other electrons recombine with holes & releases photon.
- Photons generated due to stimulated emission moves parallel to the p-n junction.



## Diode Lasers: Advantages

- Simple construction, Small size & Light-weight.
- Very cheap, Longer operating life.
- Highly reliable compared to other types of lasers.
- Low power consumption & High efficiency.
- Mirrors are not required in the semiconductor lasers.

## Diode Lasers: Disadvantages

- Not suitable where high powers are required.
- Semiconductor lasers are highly dependent on temperature.

## Diode Lasers: Few Applications

- Laser pointers, fiber optic communications, barcode readers.
- Laser printing, scanning, range finders.
- Laser absorption spectrometry.

## Differences b/w LEDs & Diode Lasers

1. By spontaneous emission.
2. Polychromatic & Not directional.
3. Incoherent i.e. photons are in random phase.
4. Emitted power is relatively low (linearly proportional to drive current: 50-100 mA).
5. Requires small applied bias and operates under relatively low current densities.
6. Coupled power is Moderate.
7. Speed is Slower.

1. By stimulated emission.
2. highly monochromatic & Highly directional.
3. Coherent beam with identical phase.
4. Output power is high (few mW to GW). Proportional to current above the threshold: 5-40 mA.
5. Requires high driving power and high injected current density is needed.
6. Coupled power is High.
7. Speed is Faster.

## Differences b/w LEDs & Diode Lasers

1. Used in Multimode fibers only.
2. Easy to use.
3. Wider Spectral width 25 to 100 nm (10 to 50 THz).
4. Moderate Modulation Bandwidth.
5. Available Wavelength 0.66 to 1.65 mm.
6. Conversion Efficiency: 10 to 20%.
7. Eye Safety: Generally Yes.
8. Low Cost.

1. Used in both Singlemode & multimode fibers.
2. Harder to use.
3. Narrower Spectral width $< 10^{-5}$ to 5 nm $(< 1 - 2MHz)$.
4. High Modulation Bandwidth.
5. Available Wavelength 0.78 to 1.65 mm
6. Efficiency: 30 to 70%
7. Eye Safety: Not (specially $\lambda < 1400\ nm$).
8. Moderately Higher Cost.

## Simple Problems in Lasers

1. Population of electrons: $N_2/N_1 = e^{-\frac{E_2-E_1}{kT}}$.
2. Energy of emitted laser light $E$
3. Intensity - Power of laser: $P = IA$
4. Applications: Ranging

## Laser: Applications

- **Barcode Scanners**
  Supermarket scanners He-Ne lasers: Laser beam scans the code, send a modulated beam to a light detector and then to a computer which has the product information stored. Semiconductor lasers can also be used for this purpose.
- **Heat Treatment**
  Hardening or annealing is the main task in metallurgy. Lasers offer some new possibilities for *selective heat treatments* of metal parts. $CO_2$ laser
- **Garment Industry**
  Computer controlled/programmed laser garment cutters. The programmed cutter can cut dozens to hundreds of thicknesses of cloth and can cut out every piece of the garment in a single run.

## Laser: Applications...

- **Communication**

  Fiber optic cables are a major mode of communication, because multiple signals can be sent with high quality and low loss by light propagating along the fibers.

  The light signals can be modulated with the information to be sent by either light emitting diodes or lasers. The lasers have significant advantages because they are more nearly monochromatic and this allows the pulse shape to be maintained better over long distances. If a better pulse shape can be maintained, then the communication can be done at higher rates without overlap of the pulses.

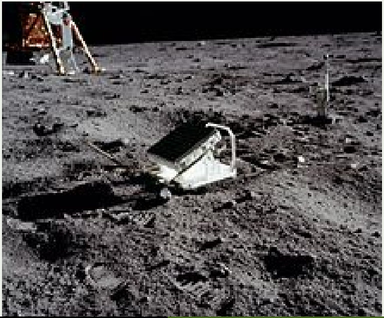
  Telephone fiber drivers are solid state lasers in the size of sand grain and consume a power of only half mW. Yet they can sent 50 million pulses per second into an attached fiber and encode over 600 simultaneous conversations.

## Laser: Applications

- **Surveying and Ranging**
  *Helium-neon and semiconductor lasers* have become standard parts of the field surveyor's equipment. A fast laser pulse is sent to a corner reflector at the point to be measured and the time of reflection is measured to get the distance.

## Laser: Applications

- **Earth-Moon distance**
  When the Apollo astronauts visited the moon, they planted retroreflector arrays to make possible the Lunar Laser Ranging Experiment. Laser beams are focused through large telescopes on Earth aimed toward the arrays, and the time taken for the beam to be reflected back to Earth measured to determine the distance between the Earth and Moon with high accuracy (385,000.6 km).



## Laser: Applications

- **Welding and Cutting**

  The highly collimated beam of a laser can be further focused to a microscopic dot of extremely high energy density for welding and cutting.

  The automobile industry makes extensive use of $CO_2$ lasers with powers up to several kilowatts for computer controlled welding on auto assembly lines.

  $CO_2$ lasers to weld stainless steel handles on copper cooking pots. A nearly impossible task for conventional welding because of the great difference in thermal conductivities between stainless steel and copper, it is done so quickly by the laser that the thermal conductivities are irrelevant.

## Laser: Applications

- **Medical Uses of Lasers**

  * Highly collimated beam of a laser can be further focused to a microscopic dot of extremely high energy density for cutting and cauterizing instrument.
  * Lasers are used for photocoagulation of the retina to halt retinal hemorrhaging and for the tacking of retinal tears.
  * Higher power lasers are used after cataract surgery.
  * A focused laser can act as an extremely sharp scalpel for delicate surgery, cauterizing as it cuts blood-rich tissue such as the liver.
  * Lasers have been used to make incisions (cut/hole) half a micron wide, compared to about 80 microns for the diameter of a human hair.
  * Many more...

## Laser: Applications

- **Laser Printers**
  The laser printer become the dominant mode of printing in offices with semiconductor lasers. The laser is focused and scanned across a photoactive selenium coated drum where it produces a charge pattern which mirrors the material to be printed. This drum then holds the particles of the toner to transfer to paper which is rolled over the drum in the presence of heat. Typically Aluminum-Gallium-Arsenide (AlGaAs) laser at 760 nm wavelength used.
- **Laser for Compact Discs**
  The detection of the binary data stored in the form of pits on the compact disc is done with the use of a semiconductor laser. The laser is focused to a diameter of about 0.8 mm at the bottom of the disc, but is further focused to about 1.7 micrometers as it passes through the clear plastic substrate to strike the reflective layer.

## Laser: Applications

- **Polarizing Prism**
  A polarizing prism is made up of two prisms of a birefringent material joined along a diagonal. The angle of cut is such that the plane of polarization parallel to the surface undergoes total internal reflection whereas the plane perpendicular to the surface passes through. Because of the action of the quarter-wave plate, the beam returning from the disc will be polarized parallel to the surface and will be reflected 90°, toward the photodiode detector.
- **Photodiode Detection**
  Laser light from the reflective layer of the disc returns through the quarter-wave plate. This reflects to the beam-splitter so that it reaches the photodiode for detection. This produces enough change in light level to be detected by the photodiode, and to be coded as the 0's and 1's of binary data.

## Laser: Applications

- **Laser Beam Positioning**
  In order to be reliably decoded, the laser beam must be focused within about 0.5 micrometers of the reflective surface, but the location of the bottom of the disc may be uncertain by about 0.5 mm during rotation. To keep the beam focused, a positioning coil drives the focusing lens up or down in response to an error voltage from the detector. One scheme uses a cylindrical lens arrangement to focus light on the detector. When the beam is properly focused, it projects a round beam and a zero error voltage results.
- **Weather Manipulation**
  Research shows that scientists may one day be able to induce rain and lightning storms (also micro-manipulating some other weather phenomena) using high energy lasers. Such a breakthrough could potentially eradicate droughts, help alleviate weather related catastrophes, and allocate weather resources to areas in need.

## Laser: Applications

- **Laser cooling**
  A technique that has recent success is laser cooling.

  This involves atom trapping, a method where a number of atoms are confined in a specially shaped arrangement of electric and magnetic fields.

  Shining particular wavelengths of light at the ions or atoms slows them down, thus cooling them.

  This process is continued, they all are slowed and have the same energy level, to form an unusual arrangement of matter known as a Bose–Einstein condensate.

## Laser: Applications

- **Nuclear fusion**
  Some of the world's most powerful and complex arrangements of multiple lasers and optical amplifiers are used to produce extremely high intensity pulses of light of extremely short duration.
  Ex. laboratory for laser energetics, National Ignition Facility, GEKKO XII, Nike laser, Laser Mégajoule, HiPER.

  These pulses are arranged such that they impact pellets of tritium–deuterium simultaneously from all directions, hoping that the squeezing effect of the impacts will induce atomic fusion in the pellets: called "inertial confinement fusion".

  So far has not been able to achieve "breakeven" (the fusion reaction generates less power than is used to power the lasers) but research continues.

## Laser: Applications

- **Microscopy**
  Confocal laser scanning microscopy and Two-photon excitation microscopy make use of lasers to obtain blur-free images of thick specimens at various depths.
  Additional laser microscopy techniques include harmonic microscopy, four-wave mixing microscopy and interferometric microscopy
- **Entertainment and recreation**
  * Laser lighting displays accompany many music concerts.
  * Laser source for digital cinema projectors
- **Bird deterrent**
  Laser beams are used to disperse birds from agricultural land, industrial sites, rooftops and from airport runways. Birds tend to perceive the laser beam as a physical stick. Both manual and automated laser torches are available.

## Laser: Applications...

- **Military**: Lasers applications such as target designation and ranging, defensive countermeasures, communications and directed energy weapons.

  * Directly as an energy weapon: Directed energy weapons are being developed, such as Boeing's Airborne Laser which was constructed inside a Boeing 747. Designated the YAL-1, it was intended to kill short- and intermediate-range ballistic missiles in their boost phase.

  * Laser Guidance: A technique of guiding a missile or other projectile or vehicle to a target by means of a laser beam.

  * Target designator: Another military use as a laser target designator. This is a low-power laser pointer used to indicate a target for a high precision-guided munition, typically launched from an aircraft.

## Laser: Applications...

- **Spectroscopy**
  Most types of laser are an inherently pure source of light (near-monochromatic light with well defined range of wavelengths). By careful design of the laser components, the purity of the laser light can be improved more than the purity of any other light source.

  The high intensity of light beam can also be used to induce a nonlinear optical effect in a sample, which makes techniques such as Raman spectroscopy possible.

  Lasers can be used to make extremely sensitive detectors of various molecules, able to measure molecular concentrations in the parts-per-1012 (ppt) level. Due to the high power densities achievable by lasers, beam-induced atomic emission is possible: called Laser induced breakdown spectroscopy (LIBS).