Lecture 7-9: Optics – Lasers

27. Lasers: An Introduction

27.1 Introduction

27.1.1 Spontaneous and Stimulated Emission

27.1.2 Main components of lasers

27.4 The He-Ne laser

Applications of lasers

Light Amplification by Stimulated Emission of Radiation

Special characteristics of lasers:

1. Directionality
2. High Power
3. Tight Focusing
4. Spectral Purity

Directionality

laser beam can travel to long distances without much spreading

High power

Laser light has greater intensity when compared to the ordinary light

Pulsed laser can have ~ 50,000 Joules of energy

$$intensity = \frac{energy/time}{area} = \frac{power}{area}$$

Tight focusing

Because of highly
directional properties,

laser beams can be
focused to very small area

(micrometer^2)

Spectral purity

quantification of the monochromaticity

Spectrum of various light source

How laser works?

Basic phenomenon:

Stimulated emission

-predicted by Einstein in 1917

Main components:

- Active medium
- Pumping source
- Optical resonator

He-Ne laser

According to Einstein,

Atom interact with electromagnetic radiation in <u>three different ways</u>

Stimulated absorption | Spontaneous emission | Stimulated emission

External radiation pumps the atoms to its excited state

Rate of absorption depends on:

- Intensity of the external field
- Number of atoms in the lower state

Atoms in excited state make a transition to lower state and emit radiation

External field is not required

Rate of emission depends on:

- Number of atoms in excited state

Atoms in excited state make a transition to lower state and emit radiation

External field of appropriate frequency triggers an atom in excited state: <u>Results in amplification of beam</u>

Rate of emission depends on

- Intensity of external field
- Number of atoms in excited state

Stimulated emission can do light amplification!

So, how to achieve stimulated emission?

Einstein showed:

Probability of Stimulated Emission = Probability of Stimulated Absorption

When atoms are in thermodynamic equilibrium,

Number of atoms in the lower state > Number of atoms in the higher state

Therefore,

Number of stimulated absorbtions > Number of stimulated emission

…results in beam attenuation

When atoms are in population inversion,

Number of atoms in the lower state < Number of atoms in the higher state

Therefore,

Number of stimulated absorbtions < Number of stimulated emission

…results in beam amplification

Amplification process due to stimulated transition is **phase coherent**!

Main components of the Lasers

- Active medium
- Pumping source
- Optical resonator

Active Medium:

It consists of a collection of atoms, molecules or ions (in solid, liquid or gaseous form) in a state of polulation inversion

…required for stimulated emission

…to perform optical amplification

Pumping source

It required to obtain and maintain population inversion between a pair of energy levels of the atomic system

Optical resonator

A medium with population inversion capable of amplification

Part of output energy is fed back to system to act as oscillator.

Active medium is placed in a resonator

Resonator could be a pair of mirrors

Helium-Neon laser

First gas Laser developed by Ali Javan and his co-workers in1961

- Short name: He-Ne laser
- Type: gas laser
- Four-level laser that uses helium atoms to excite neon atoms
- Continuous wave (CW) laser
- Most widely used gas lasers

He-Ne laser

Main components of a laser:

- Active medium
- Pumping source
- Optical resonator

For He Ne laser:

Active medium:

- Gas system placed in a long narrow discharge tube
- consisting of mixture of He and Ne (ratio 10:1)

Pumping source:

- Electrical discharge (high DC voltage power supply)

Optical resonator:

- Gas system in enclosed between pair of plane or concave mirrors

Electrical discharge

Electrical discharge is the release and transmission of electricity in an applied electric field through a medium such as a gas.

Why Helium and Neon?

Neon atoms have energy levels suitable for laser transition.

Direct excitation of Neon gas is inefficient.

So, Helium is used to increase the efficiency of the lasing process.

Helium atoms help in exciting Neon atoms.

The gas mixture is mostly Helium gas.
Ratio of He & Ne: 10:1

Energy level diagram for He-Ne laser:

- He atom in ground state (F1)
- Electric discharge is passed through gas
- Electrons collide and excite Helium atoms (F2 & F3)
- F2 and F3 are Metastable states: excited atoms stay longer time
- He atoms collide and excite Ne atoms (E4 & E6)

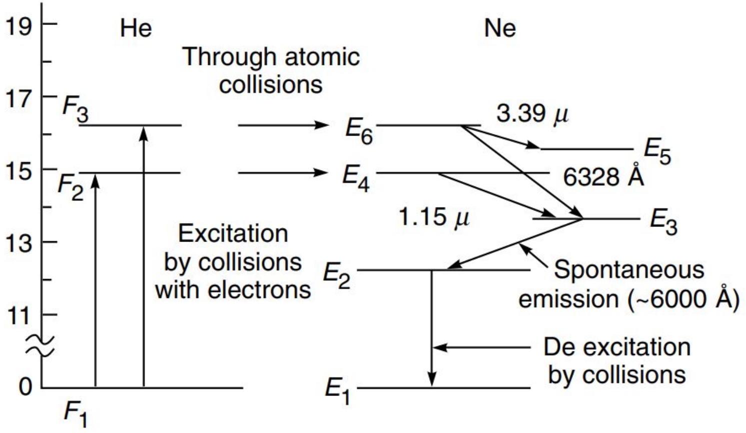
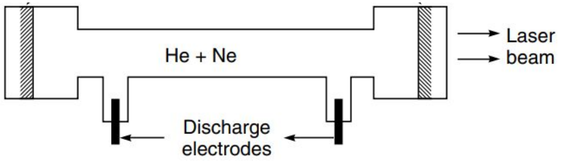


Fig. 27.23 Relevant energy levels of helium and neon.



- Population of the level E4 & E6 increases than its lower levels

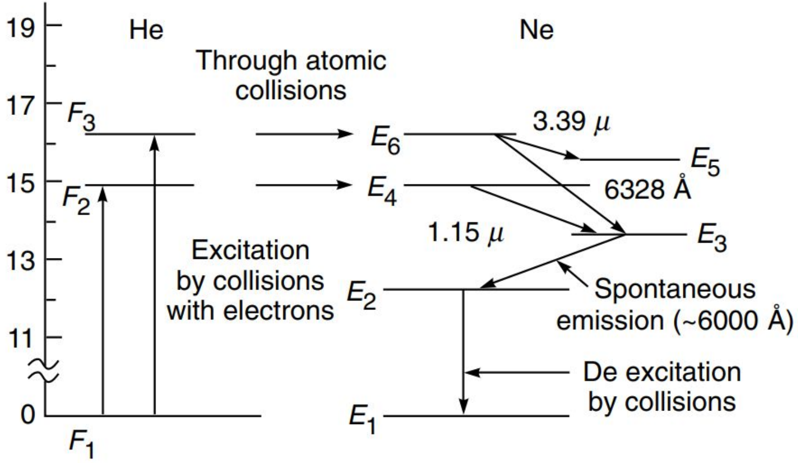
  Population inversion achieved!

- Any spontaneous emitted photon triggers laser action

- E6 => E5, λ = 3390 nm
- E4 => E3 , λ = 1150 nm
- E6 => E3 , λ = 632.8 nm

- Wavelength selection by mirror reflectivity

- Neon atoms drop down to lower levels (E2)



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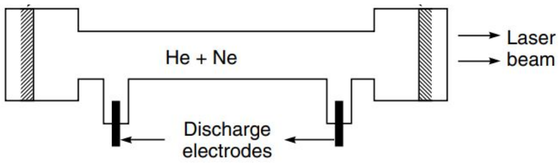


- Level E2 is metastable
- So, electrons in E2 may collide and excite atoms to E3
- It will decrease population inversion!
- So, tube is kept narrow, such that,
- atoms in E2 gets de-excited by collision with walls of tube.

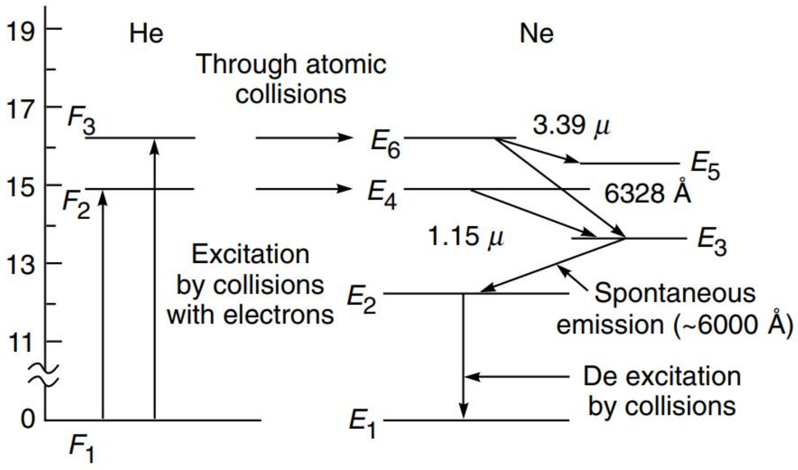
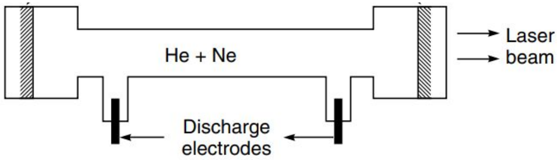


Fig. 27.23 Relevant energy levels of helium and neon.

In general, Gas lasers are
- directional
- monochromatic

Reason: Absence of crystalline imperfections, thermal distortion, and scattering.



Different commercially available lasers

Wavelengths of commercially available lasers.