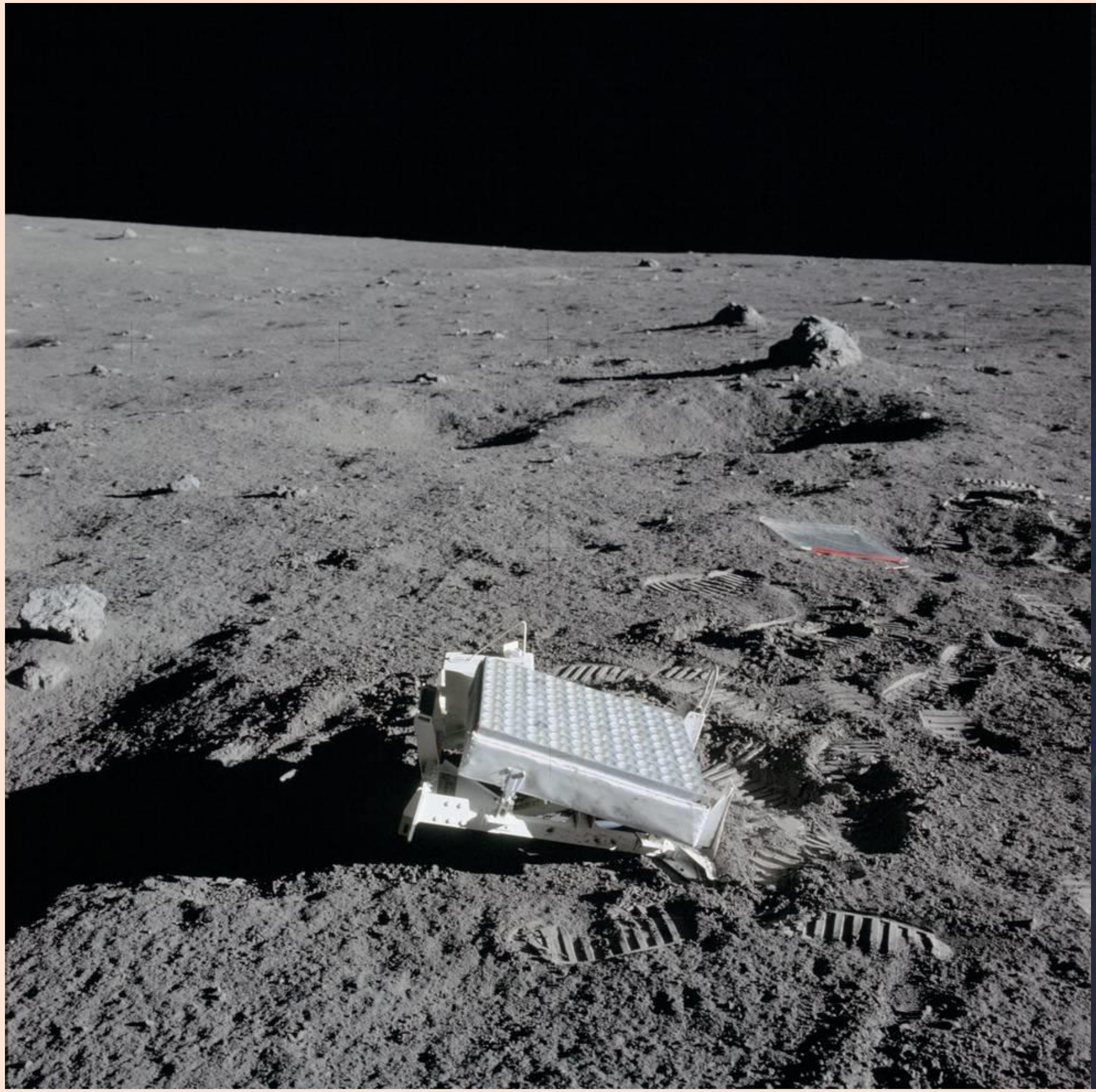
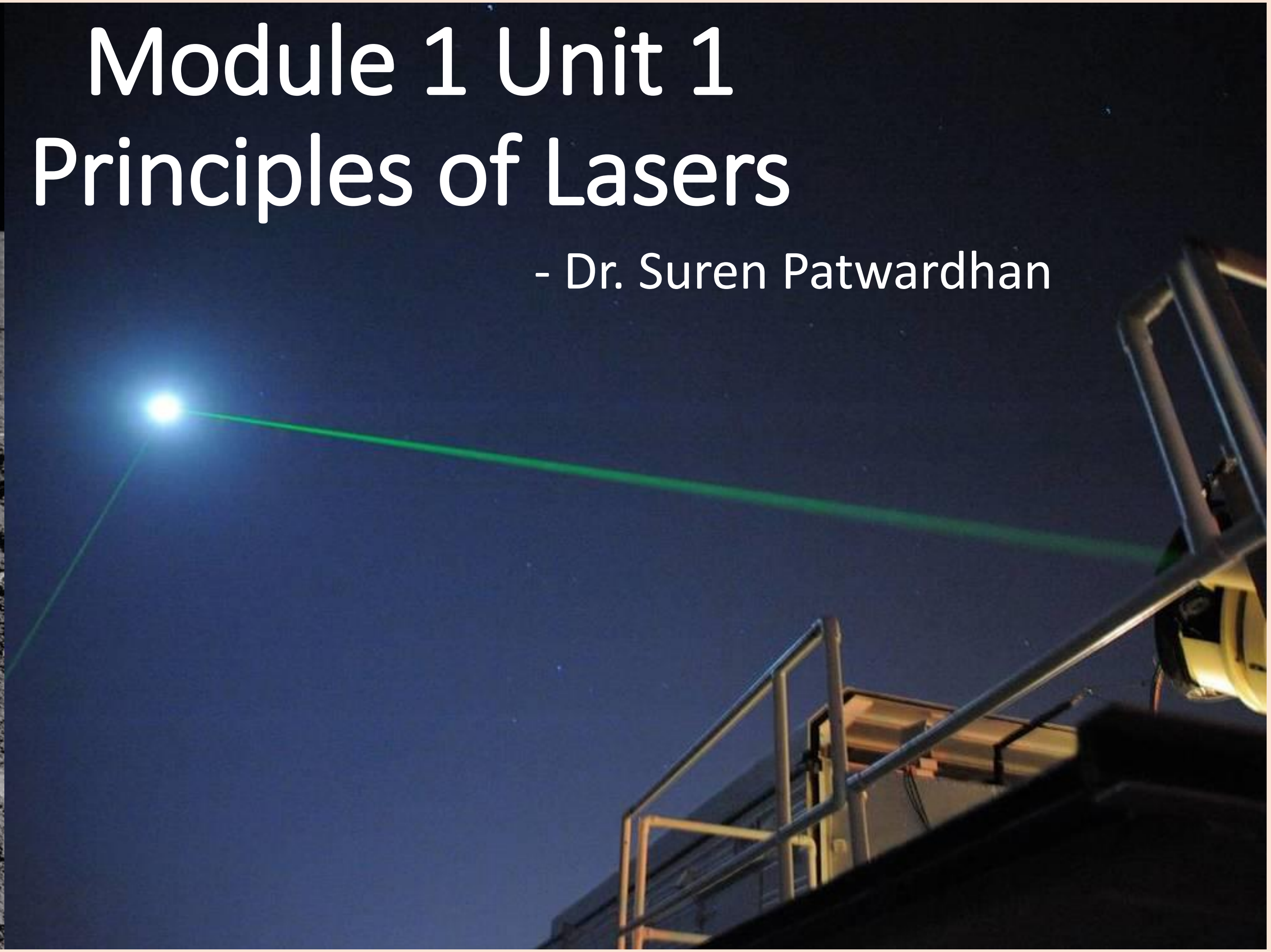
Module 1 Unit 1
Principles of Lasers

- Dr. Suren Patwardhan



Lunar surface and reflector by Apollo Astronauts



Geophysical and Astronomical Observatory at NASA's Goddard Space Flight Center in Greenbelt, Md., USA

Image Courtesy: https://www.nasa.gov/multimedia/imagegallery

Ordinary Light v/s LASER Light

- Examples of ordinary Light
  - Bulbs (Incandescent, CFL, LED), Tube lights, Decorative lights
  - Halogen lamps, Flood Lights
  - Photographic Light, Xenon Lamp
  - Neon Lamp, Street Lamps (yellow)
  - Burner flame
  - Petromax Light, Kerosene Lamp
  - Candle, Matchstick
  - Sunlight

- Laser Light?
  - Laser Pointer (semiconductor Laser)

Properties of LASER

Light Amplification by Stimulated Emission of Radiation

- Monochromatic - Unique wavelength
- Coherent - All waves are In phase
- Directional - Light emitted along same path
- Focused - Low spreading
- Bright - High intensity
- Polarized (optional) - E-M vibrations in same plane

- Most of the lasers are in the IR to Visible range
- Radio and microwave frequency lasers are called MASERS
- Difficult to get Ultraviolet lasers
- May not be possible to get X-ray and γ-ray lasers

Laser Beam Parameters

- Monochromaticity - Linewidth of radiation
- Coherence length - Distance up to which waves are in phase
- Directionality - Unique direction of emission
- Divergence - Amount of spread
- Intensity - Optical power emitted per unit area

Parameter	Ordinary sources	Laser sources
Monochromaticity	10^{5} nm	10^{-4} nm
Coherence length	mm to cm	m to km
Directionality	30-360°	< 2°
Divergence	> 10^{-2} strad	< 10^{-4} strad
Intensity	mW to W	mW to kW

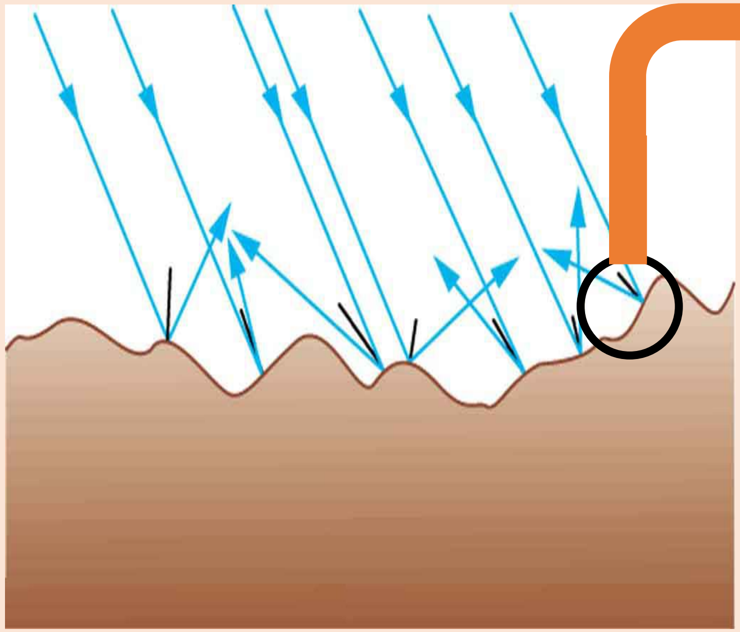
LASER are Everywhere

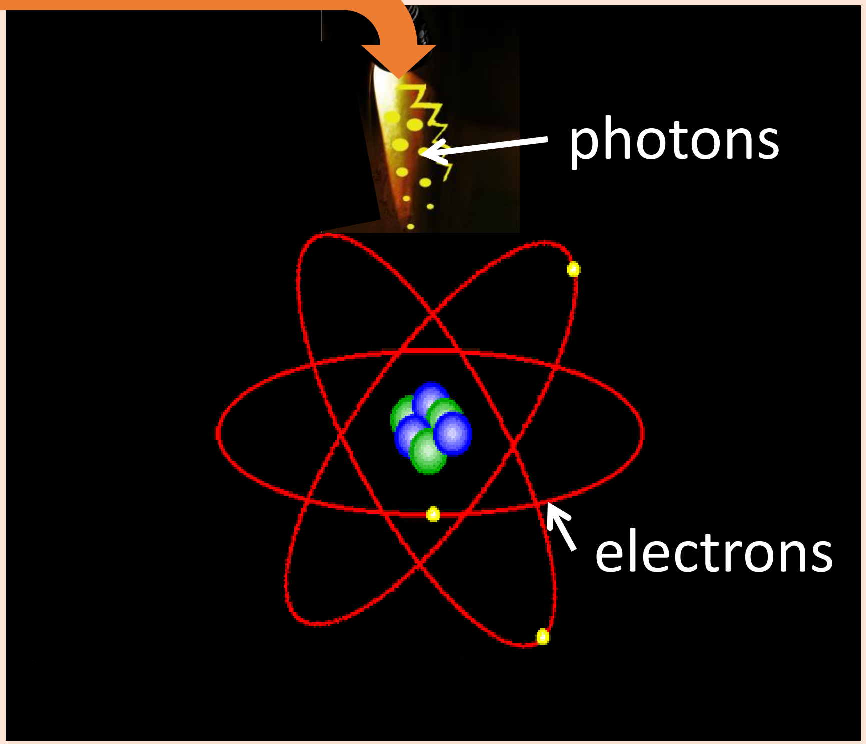
- First discovered by Maiman 1960 (kind of MASER – M for Microwaves)
- Once teased as discovery in search of applications, today has hundreds of applications

Name of laser source	Emission wavelength	Applications
He-Ne laser	Red, green	Laboratory purpose
Ar laser	Blue-green	Eye surgery
Nd:YAG laser	Invisible (IR)	Machining, surgery
Ruby laser	Extreme Red	High speed photography
GaAs/GaN lasers	Red to Blue	Fibre optic communications
CO_2 laser	Invisible (IR)	Dermatology
Dye lasers	Visible to IR	Spectroscopy
Nd:Glass	Invisible (IR)	Nuclear reactors

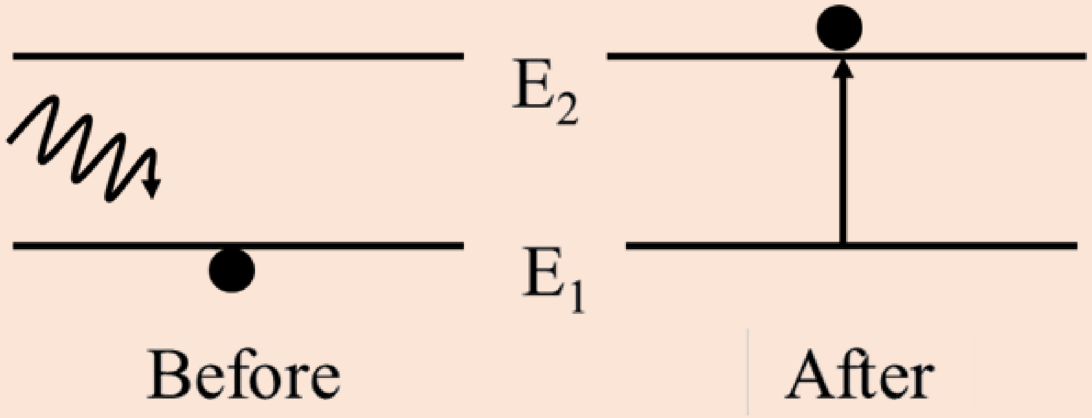
Interaction of Radiation with Matter

1. Absorption - Energy supplied
2. Emission - Energy emitted
   - Spontaneous emission
   - Stimulated emission





Stimulated Absorption (or just Absorption)



Rate of transition

$$\left.\frac{dN}{dt}\right|_{ab} = B_{12}N_1Q$$

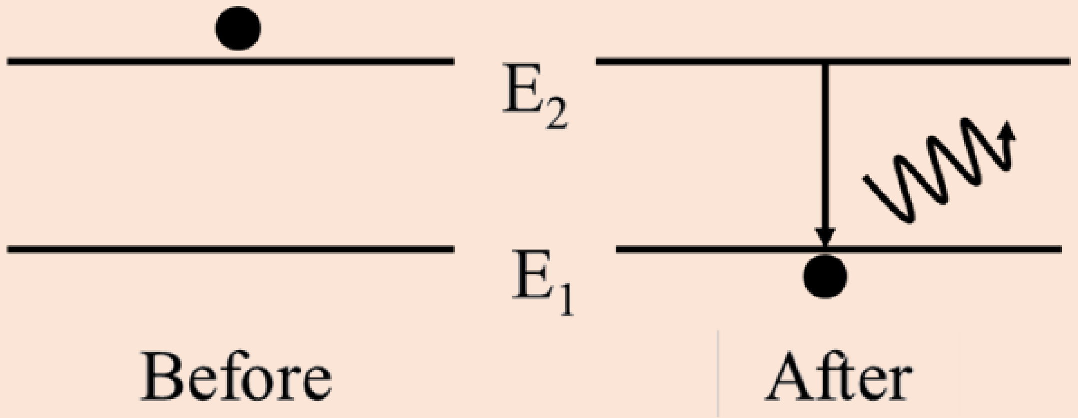
Where,

B_{12}: probability of absorption process

N_1: number of atoms in lower energy level E_1

Q: energy density of incident radiation per unit frequency (J-s/m^3)

Spontaneous Emission (i.e. Natural Emission)



Rate of transition

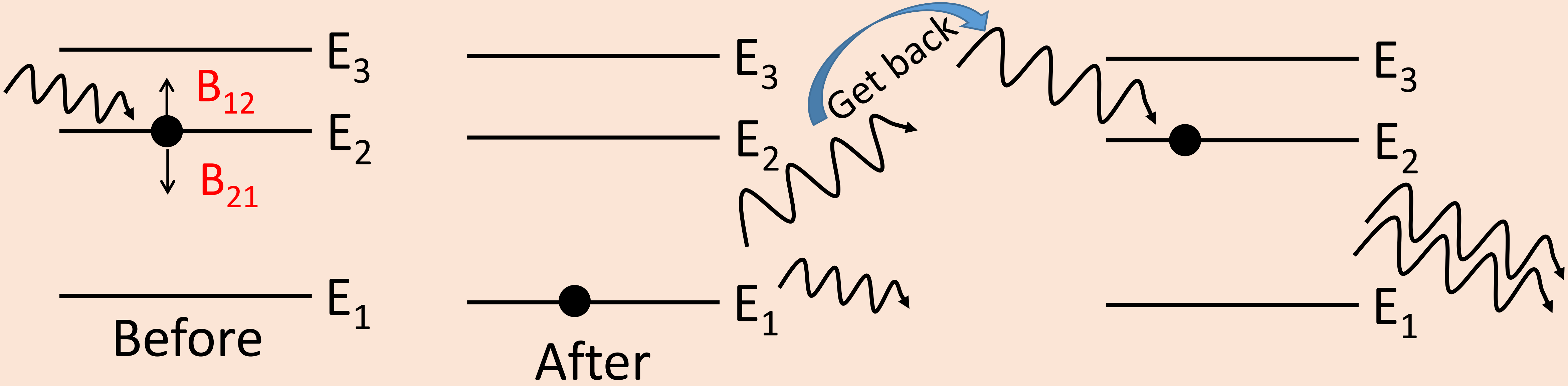
$$\left.\frac{dN}{dt}\right|_{sp} = A_{21}N_2$$

Where,

A_{21}: probability of spontaneous emission process

N_2: number of atoms in higher energy level

Stimulated Emission (i.e. Triggered Emission)



Einstein showed $B_{12} = B_{21}$

Rate of transition $\left.\frac{dN}{dt}\right|_{st} = B_{21} N_2 Q$

Where,

B_{21}: probability of stimulated emission process

N_2: number of atoms in higher energy level E_2

Q: energy density of incident radiation per unit frequency

Advantages

Emitted radiation has:

Same wavelength

Same direction

Same phase

Laser Emission is Not Possible in Ordinary Conditions

Reason:

Spontaneous emission dominates at normal temperatures

Rate of absorption: $$\left.\frac{dN}{dt}\right|_{ab} = B_{12}N_1Q$$

Rate of spontaneous emission: $$\left.\frac{dN}{dt}\right|_{sp} = A_{21}N_2$$

Rate of stimulated emission: $$\left.\frac{dN}{dt}\right|_{st} = B_{21}N_2Q$$

How to Lase?

Answer: Break the laws

Laws:

1. “Equilibrium” condition – more atoms in lower states than upper states

- At equilibrium, $N_1 >> N_2$

2. Any medium is “Lossy” – on passage, optical intensity decreases

- For lossy medium, loss (α) > gain (γ)

How to break them?

1. Make $N_2 > N_1$ i.e. populate upper states E_2 as compared to Lower states E_1 (population invasion)
2. so make $\gamma > \alpha$ i. e. trap light to achieve optical gain in a region (light amplification)

Agents to Break the Laws

Achieved by two important concepts:

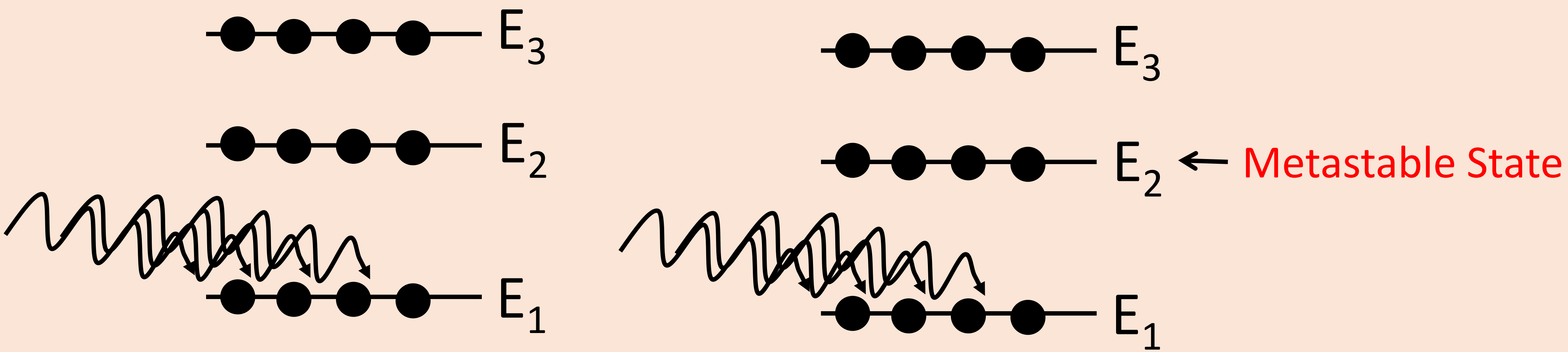
1. Metastable states – ensures $N_2 > N_1$
   - ➢ Achieves population inversion along with pumping
2. Optical Resonator – ensures $\gamma > \alpha$
   - ➢ Achieves light amplification*

- 1 and 2 together ensure stimulated emission is promoted for laser emission

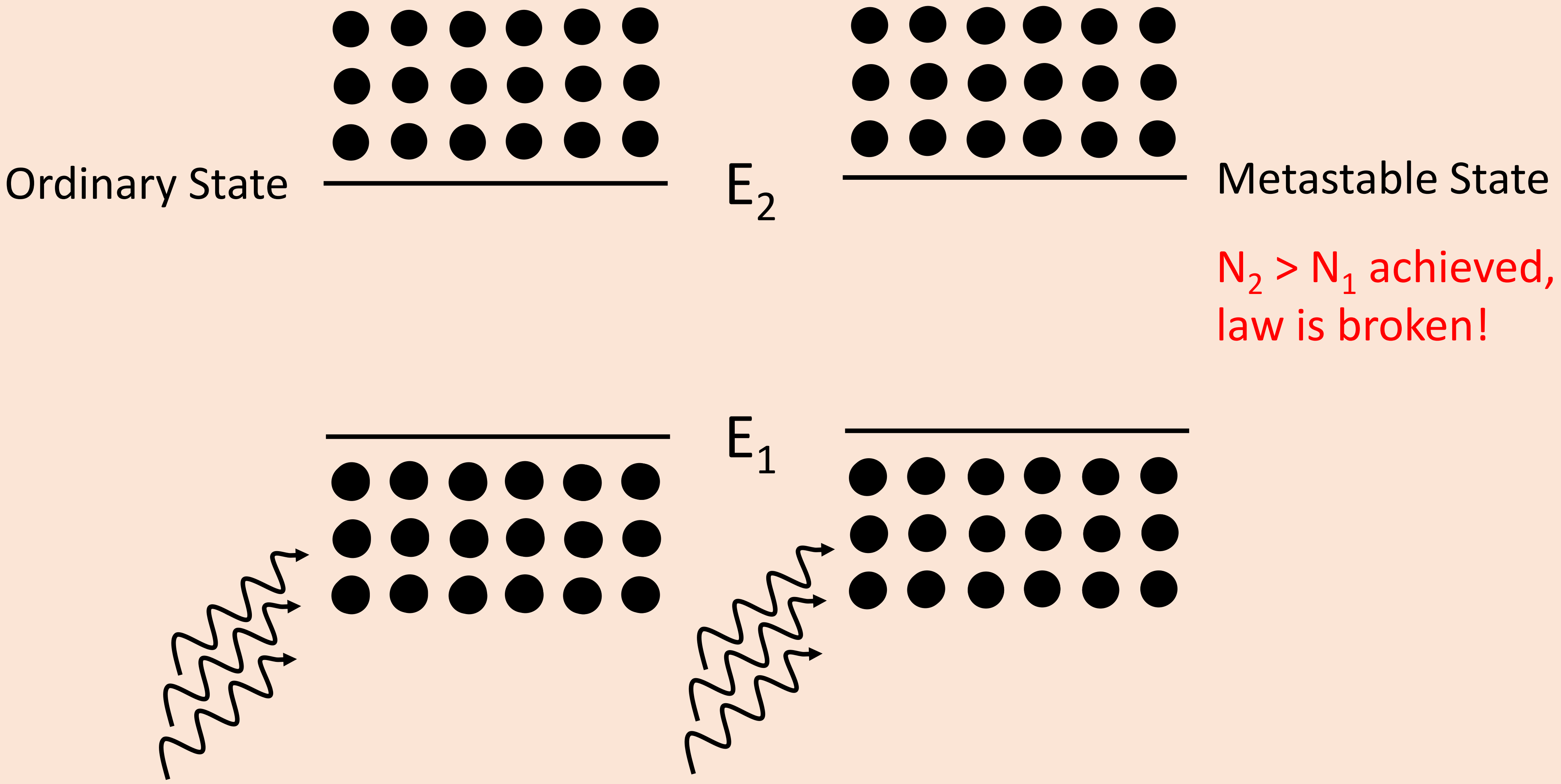
*Does it violate laws of thermodynamics?

Metastable State

- Typical lifetime of an excited state in any atom is ≈ 10 ns (10^{-8} s)
- But there are certain special excited state in some atoms
- For these states, the lifetime is ≈ 1 ms (10^{-3} s); 100000 times longer!
- Such states are called metastable states
- Materials having metastable states is necessary condition for laser

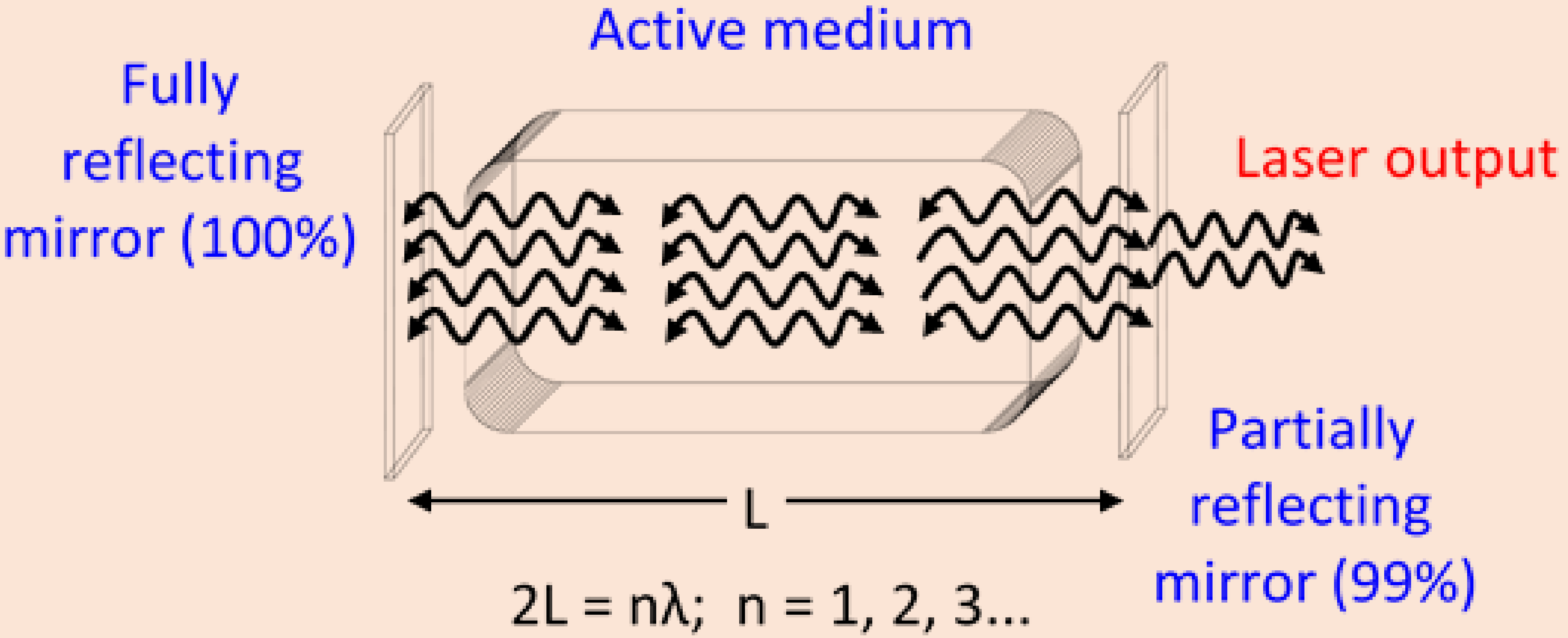


Action of Metastable State

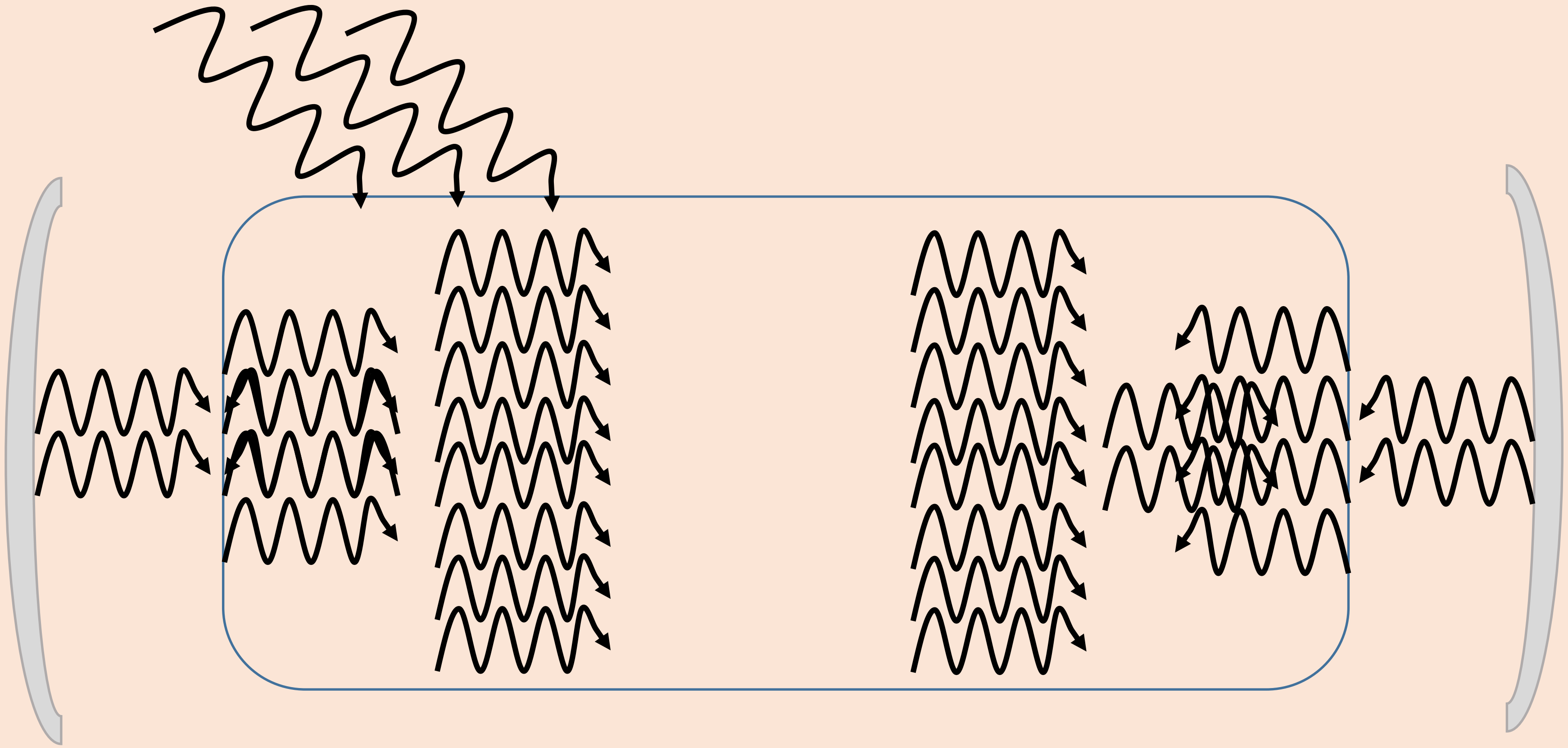


Optical Resonator/Active Medium

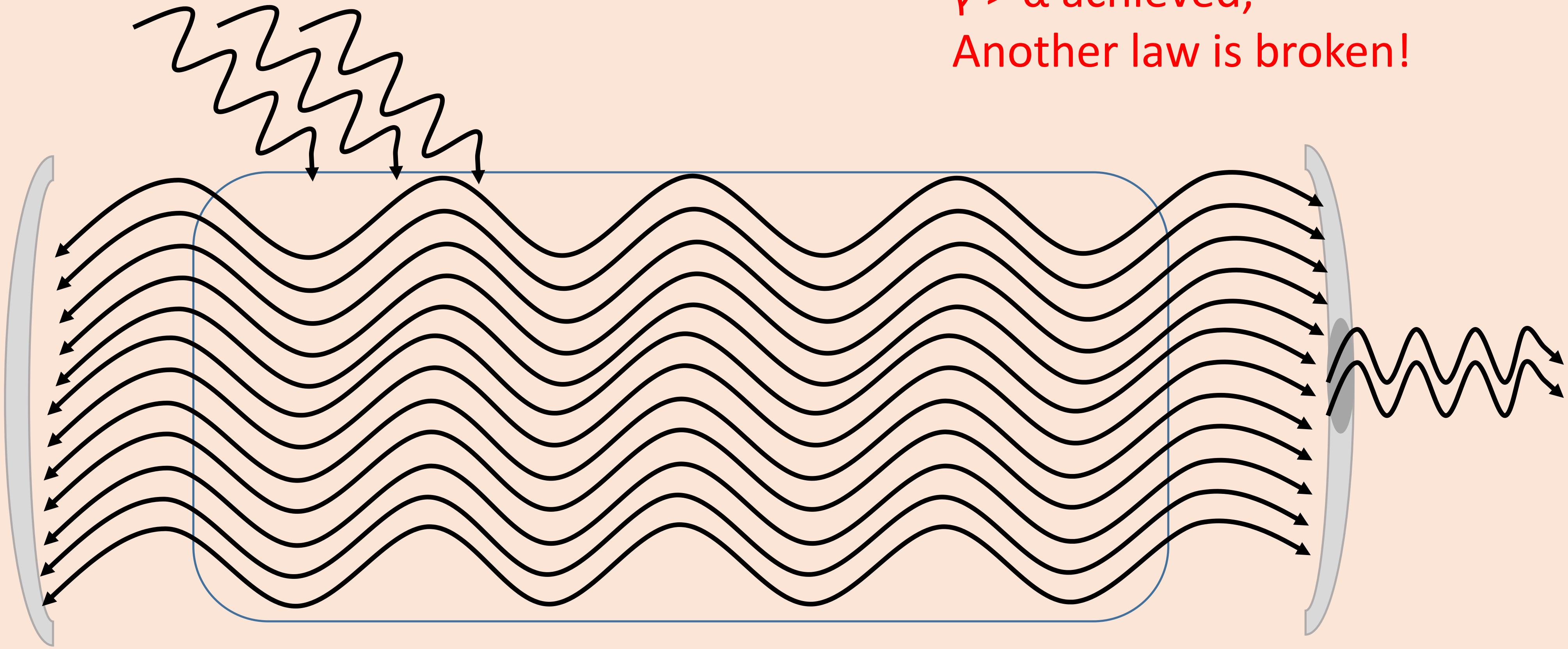
Active medium: *Region of the laser source where optical gain takes place*



Action of Optical Resonator

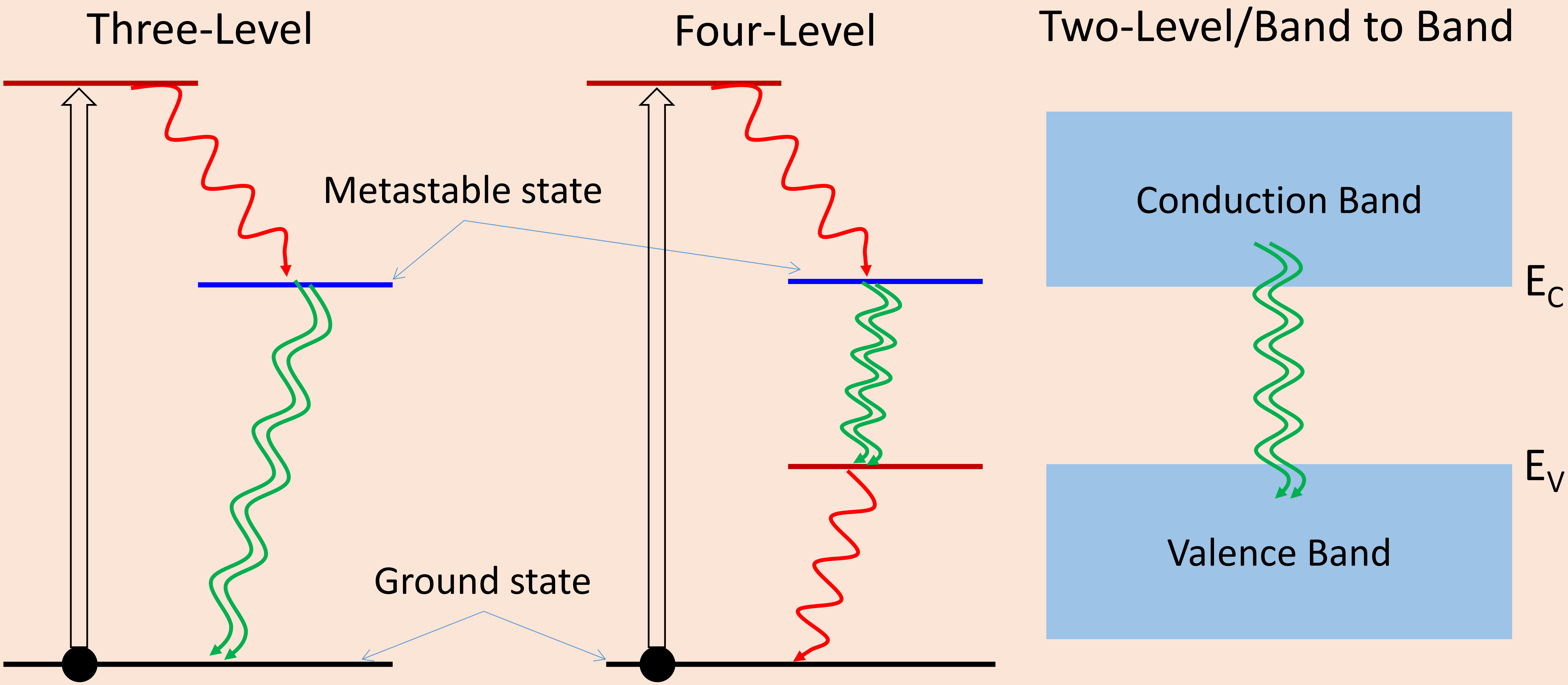


Action of Optical Resonator



$\gamma > \alpha$ achieved,
Another law is broken!

Pumping Schemes



Quick Poll

Types of Pumping

Pumping: *Process of supplying energy to trigger population inversion*

- **Optical pumping**

  A broad and bright source of light (photons) is used to supply energy

  Example: Xenon flash lamp in Ruby laser, Nd:YAG laser, Dye lasers

- **Electrical Pumping**

  High electric field is set up by a pair of electrodes

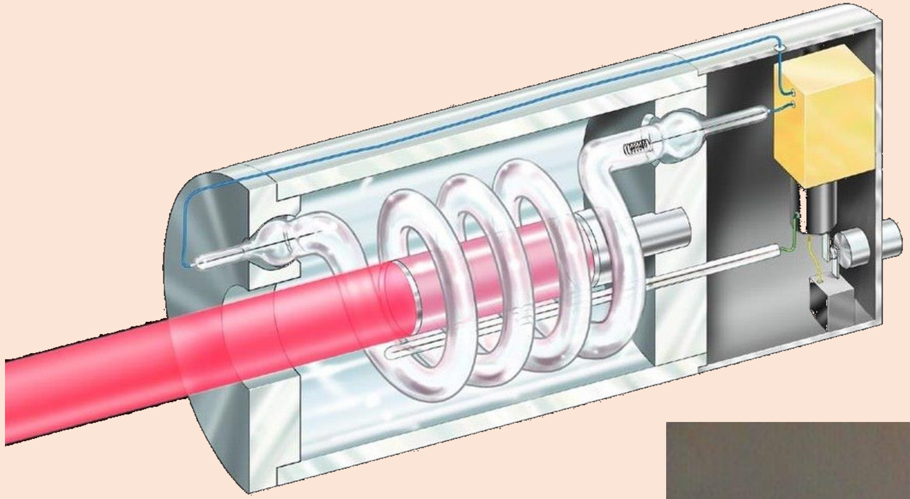
  Example: He-Ne laser, CO_2 laser, Ar laser

- **Direct conversion**

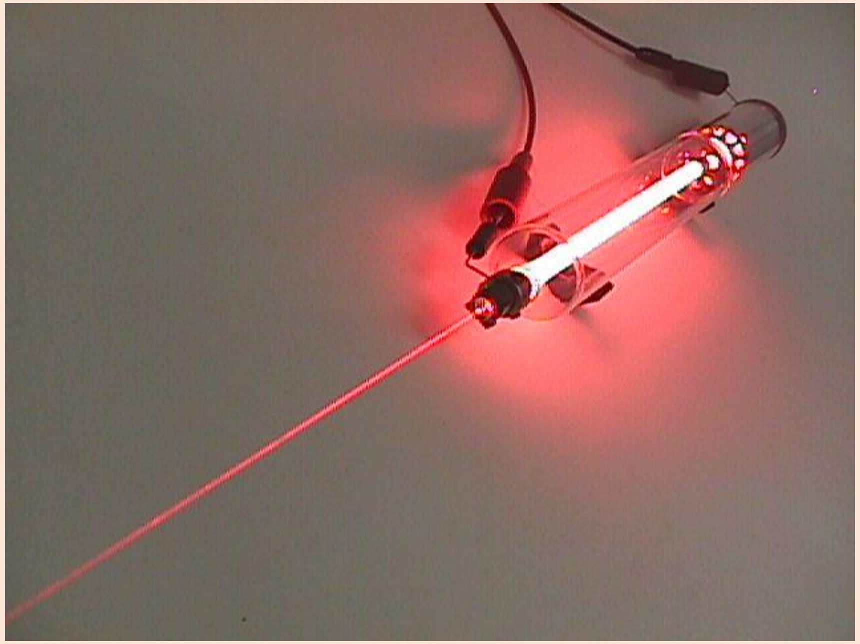
  By passing an electric current

  Example: Semiconductor diode lasers

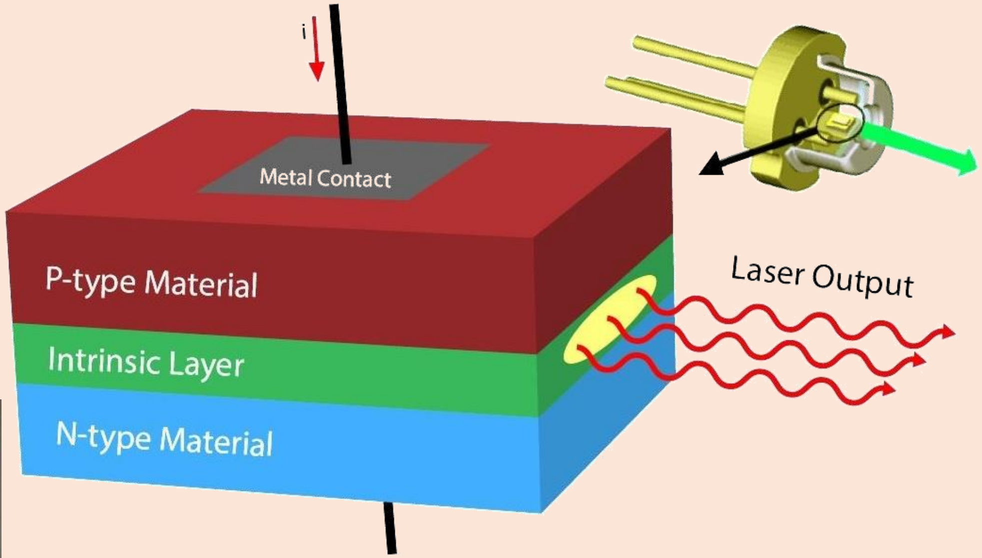
Types of Pumping - Schematics



Optical



Electrical



Direct conversion

Important Laser Physics Terms

- Population

  The number of active atoms occupying a particular energy state

- Population Inversion

  Creating a non-equilibrium state with more atoms in excited states

- Pumping

  Process of supplying energy to achieve population inversion

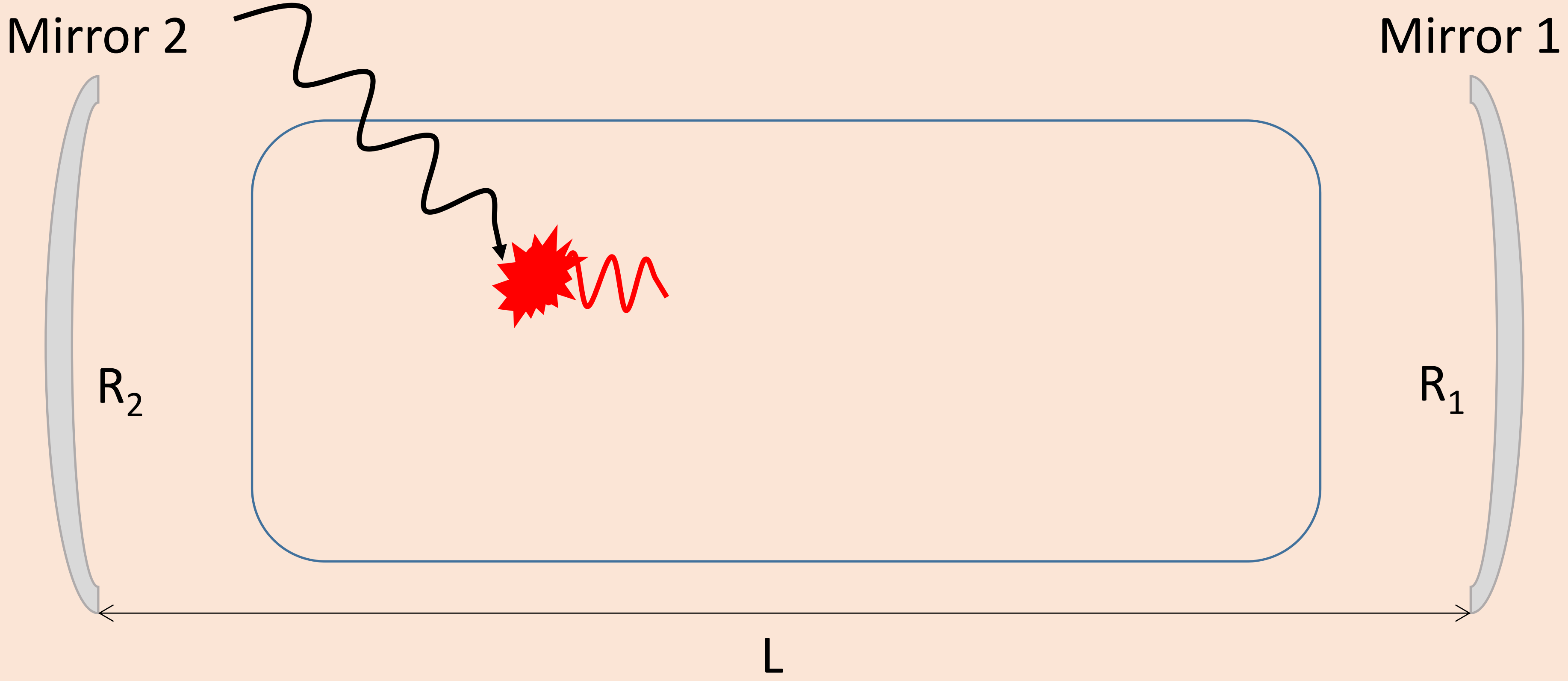
- Metastable State

  Special energy levels having unusually high lifetime that normal excited states

- Active medium

  Region of the laser source where optical gain takes place

Condition for Lasing



$$I(x) = I_0 e^{(\gamma-\alpha)x}$$

Thanks!