LASER

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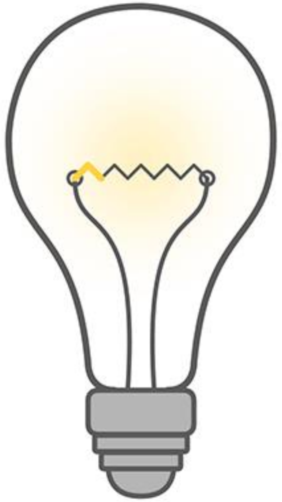
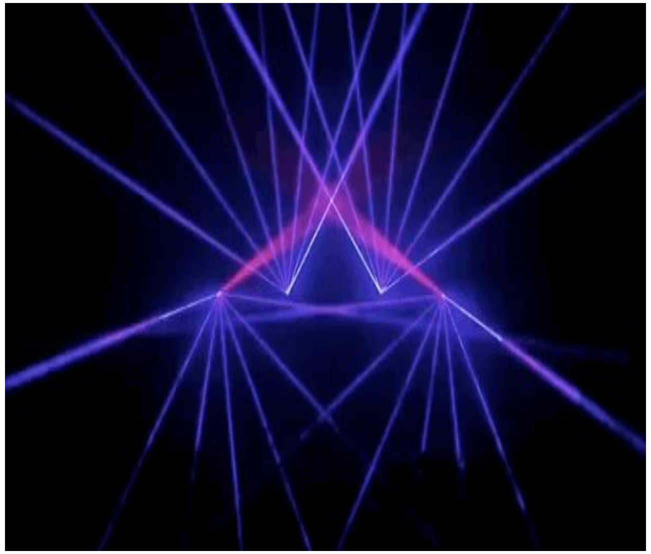
Introduction of LASER

Light ***A***mplification by ***S***timulated

Emission of ***R***adiation

Ordinary vs. Laser Light



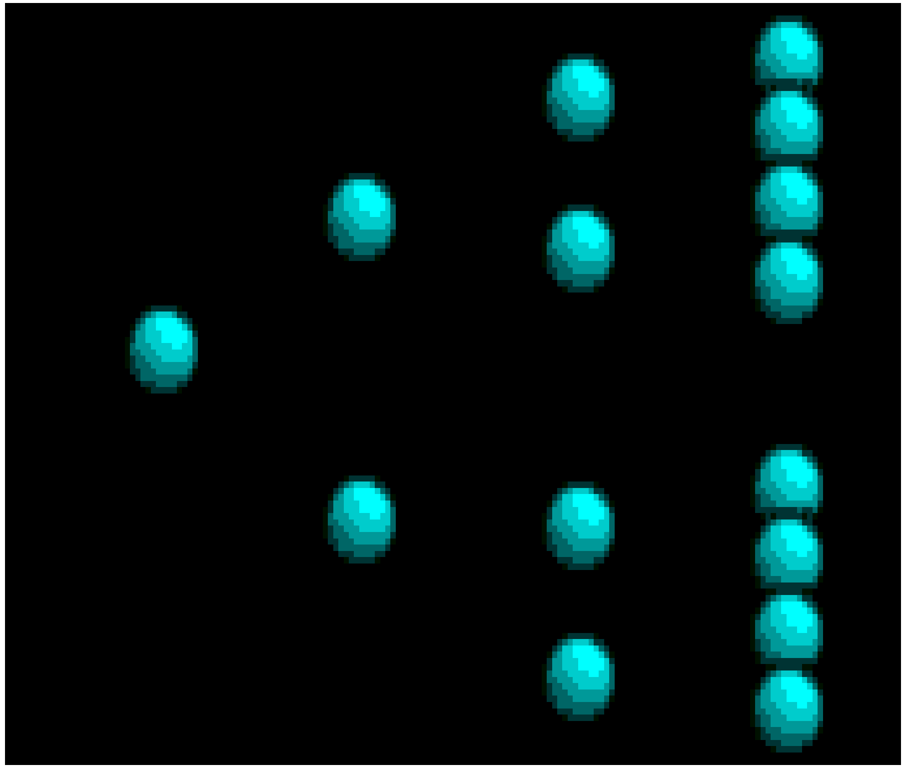


1. Many wavelengths
2. Multidirectional
3. Incoherent

1. Monochromatic
2. Directional
3. Coherent

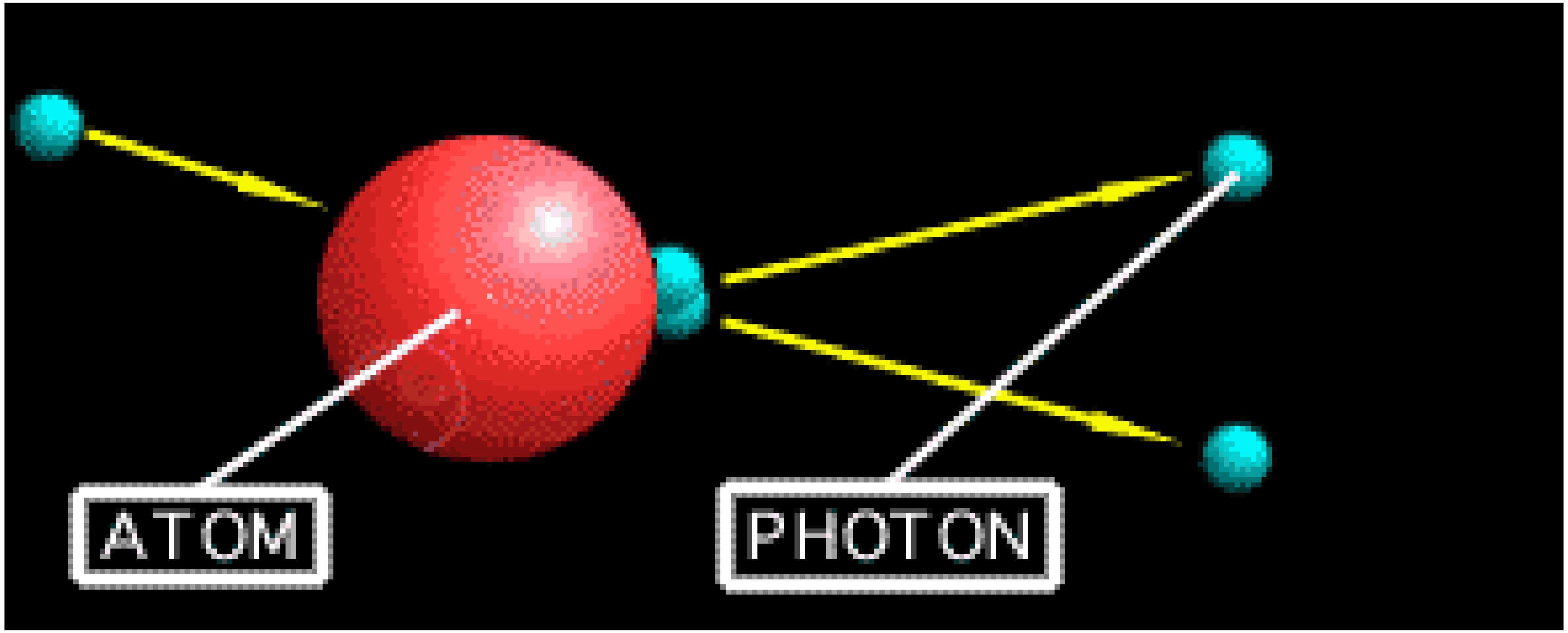
‘A’ stands for AMPLIFICATION

The laser may be activated by a few photons, but then many, many more are generated. The initial light is ***amplified*** to make a very bright compact beam.

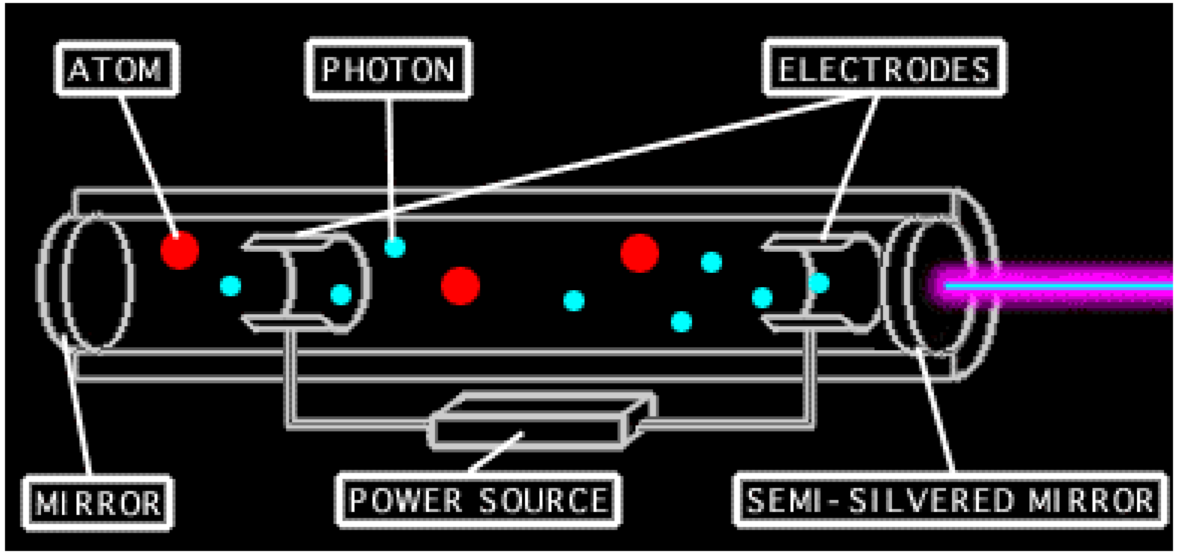


‘S’ stands for STIMULATED

- the photons are amplified by stimulating an atom to release more photons.



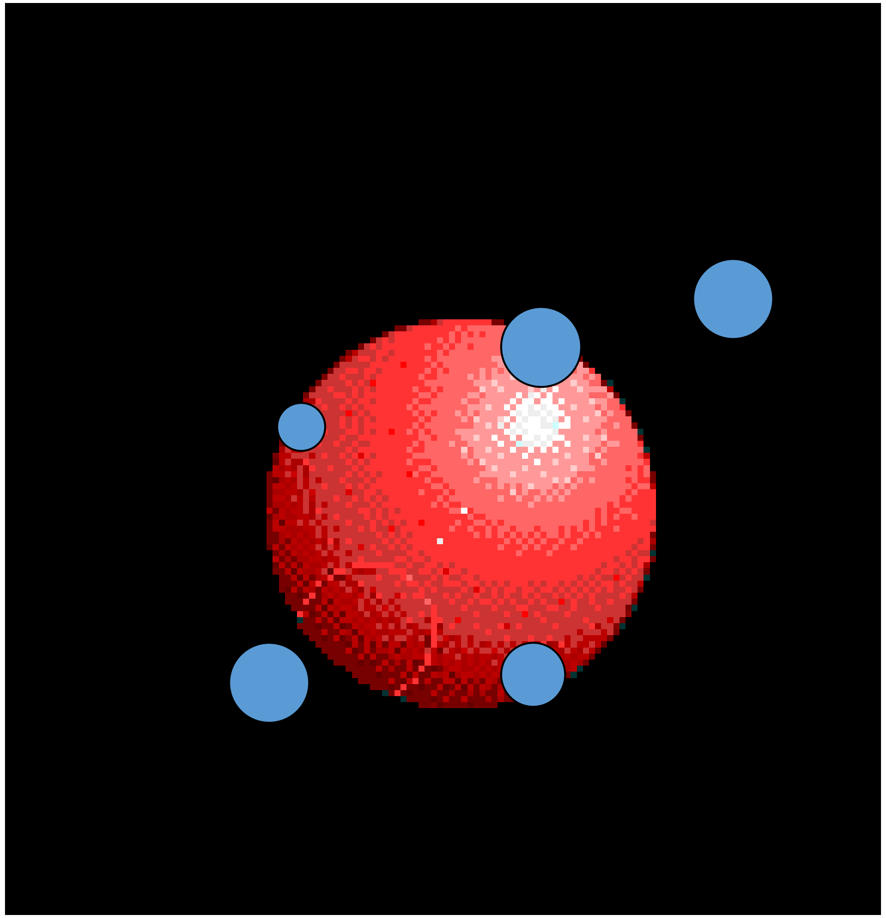
‘E’ stands for EMISSION



- The excited atom ***emits*** a photon when another photon comes by
- The photons bounce between the two mirrors until enough photons have been emitted that some pass through the semi-silvered mirror on one end. These are the photons which are seen as the laser beam.

‘R’ stands for RADIATION

- Radiation refers to the photons which are being emitted.



GENERAL OBSERVATION ABOUT LASERS

- They produce narrow beams of intense light
- They often have pure colors
- They are dangerous to eyes

PROPERTIES OF LASER

- ***Monochromatic***

  Concentrate in a narrow range of wavelengths (one specific colour).

- ***Coherent***

  All the emitted photons bear a constant phase relationship with each other in both time and phase

- ***Directional***

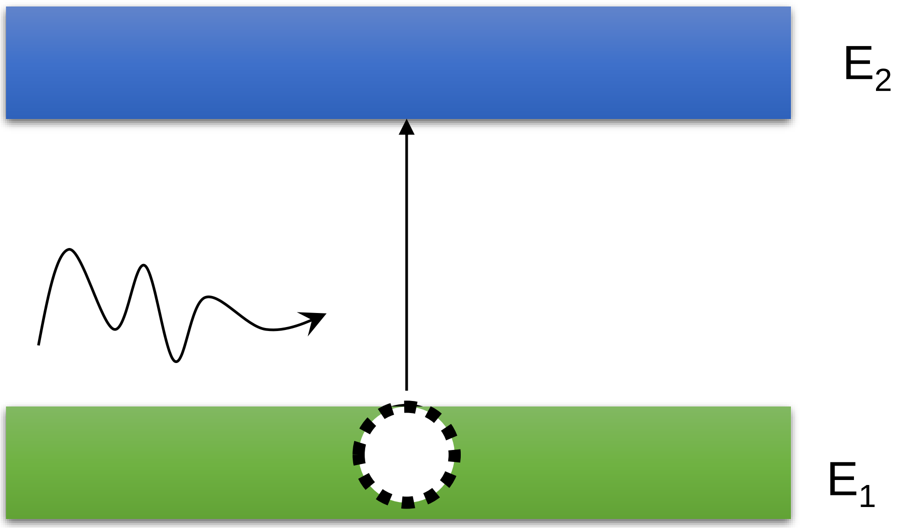
  A very tight beam which is very strong and concentrated.

Basic Concepts of A Laser

BASIC CONCEPTS OF A LASER

- Absorption
- Spontaneous emission
- Stimulated emission
- Population inversion

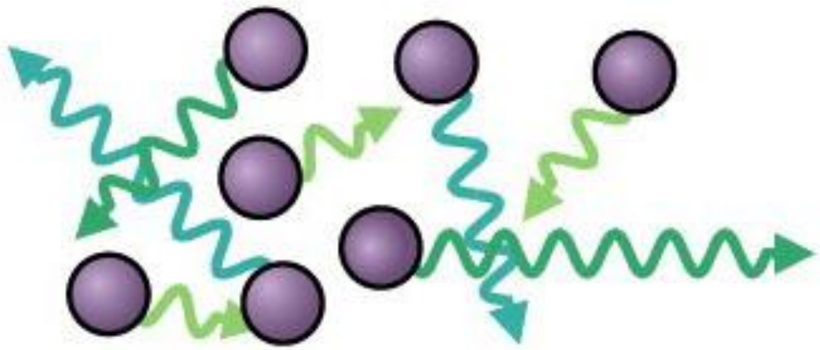
ABSORPTION



➢ Energy is absorbed by an atom, the electrons are excited into higher energy state.

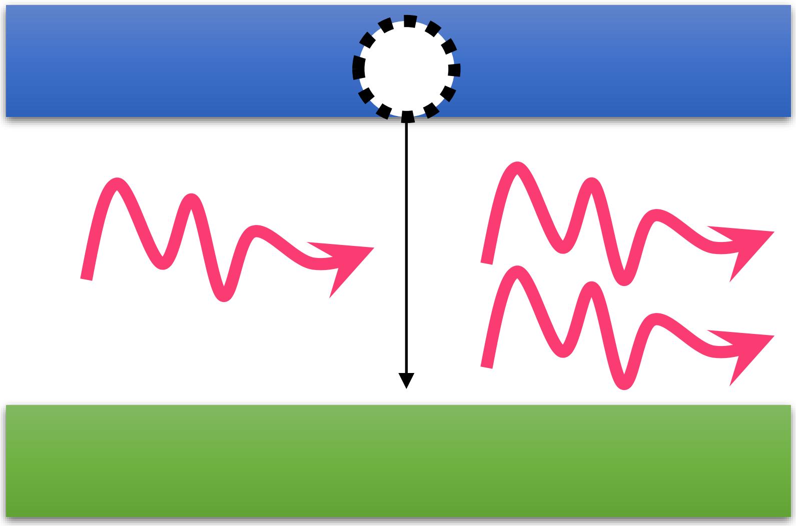
SPONTANEOUS EMISSION

- Excited atoms normally emit light spontaneously
- Photons are uncorrelated and independent
- Incoherent light



Incoherent radiation from excited atoms

STIMULATED EMISSION



- Atoms in an upper energy level can be triggered or stimulated in phase by an incoming photon of a specific energy.

The ***stimulated photons*** have unique properties:

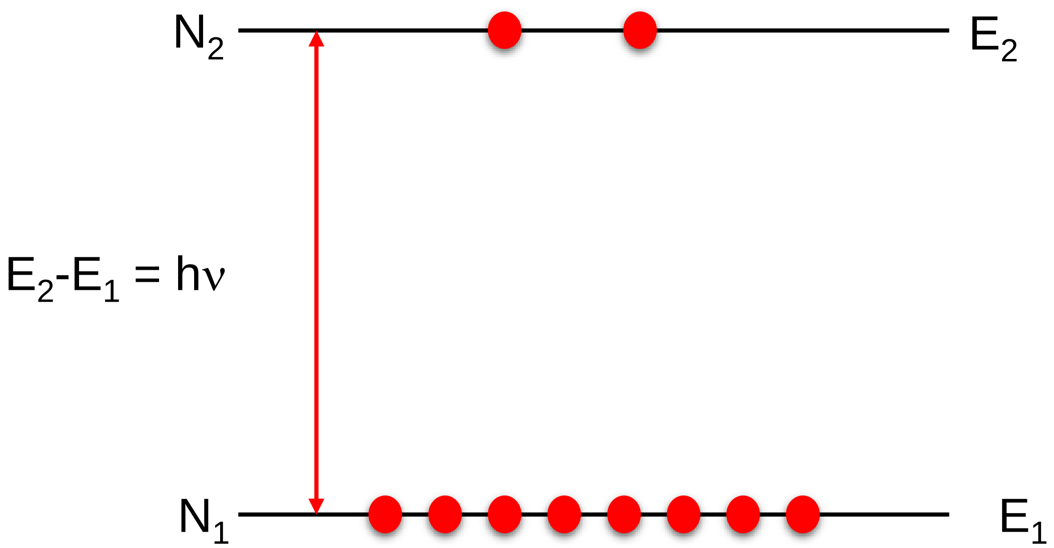
- ***In phase*** with the incident photon
- ***Same wavelength*** as the incident photon
- Travel in ***same direction*** as incident photon

POPULATION INVERSION

- A state in which a substance has been energized, or excited to specific energy levels.
- More atoms or molecules are in a higher excited state.
- The process of producing a population inversion is called ***pumping***.
- Examples:
  - by lamps of appropriate intensity
  - by electrical discharge

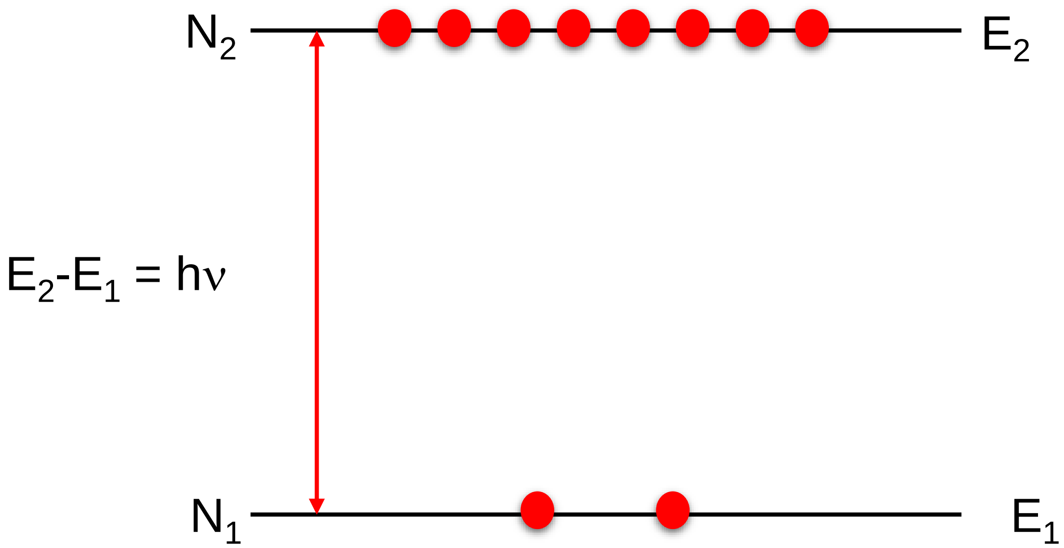
Population Inversion

In thermodynamically equilibrium



$$N_1 > N_2$$

-electron



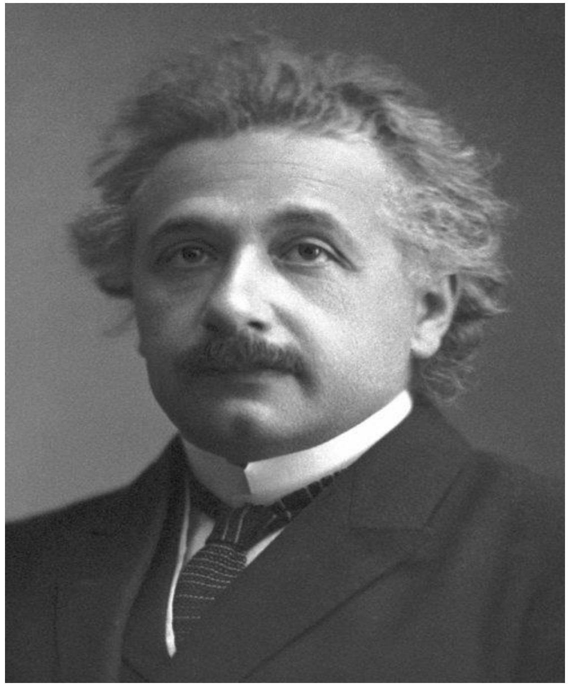
$$\boxed{N_2 > N_1}$$

Required for LASER Action

Einstein's Coefficients

In ***1916***, According to Einstein,

Electromagnetic radiations such as light, interact with matter through three processes.



- ***Stimulated absorption,***
- ***Spontaneous emission***
- ***Stimulated emission***

Einstein's Coefficients

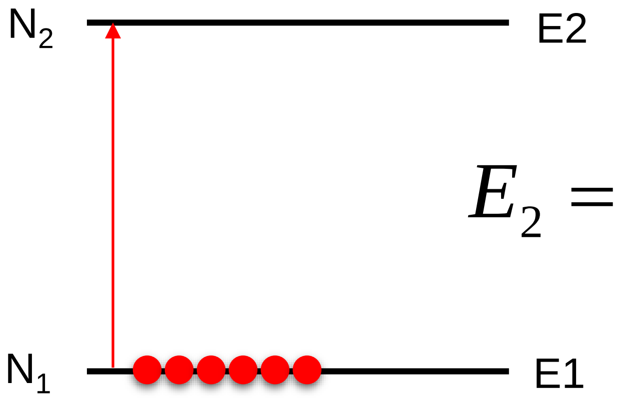
There are three Einstein's Coefficient

- B_{12}: Einstein's Coefficient for ***Stimulated*** absorption,
- A_{21}: Einstein's Coefficient for ***Spontaneous*** emission
- B_{21}: Einstein's Coefficient for ***Stimulated*** emission

Stimulated absorption

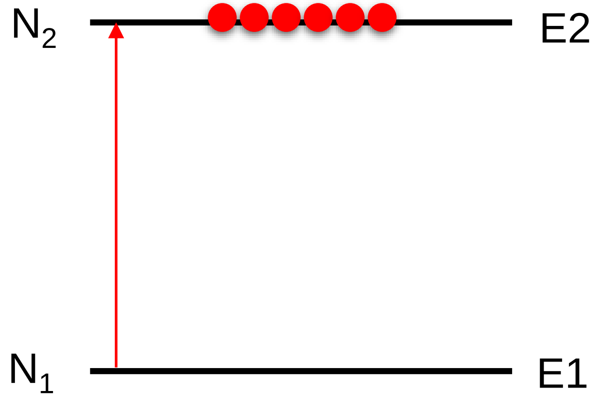
Energy is absorbed by an atom, the electrons are excited into higher energy state.

Before Absorption



$$E_2 = E_1 + h\upsilon$$

After Absorption

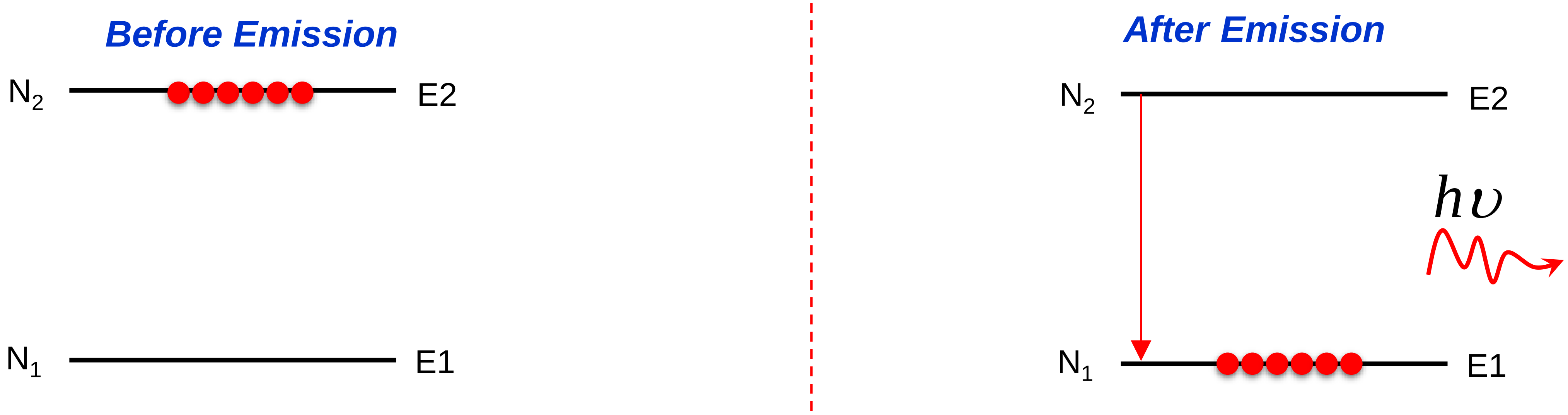


The probability of this absorption from state 1 to state 2 is proportional to the energy density u(ν) of the radiation

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

where the proportionality constant **B_{12}** **is known as the Einstein's coefficient of absorption of radiation** and depends on the properties of states 1&2.

Spontaneous Emission



The atom decays from level 2 to level 1 through the emission of a photon with the energy *hv*. It is a completely **random** process.

$$E_2 - E_1 = h\upsilon$$

An atom is in excited state and it remains in it for only 10^{-8} sec. Then it (of its own record) jumps to the lower energy state emitting a radiation.

Spontaneous Emission

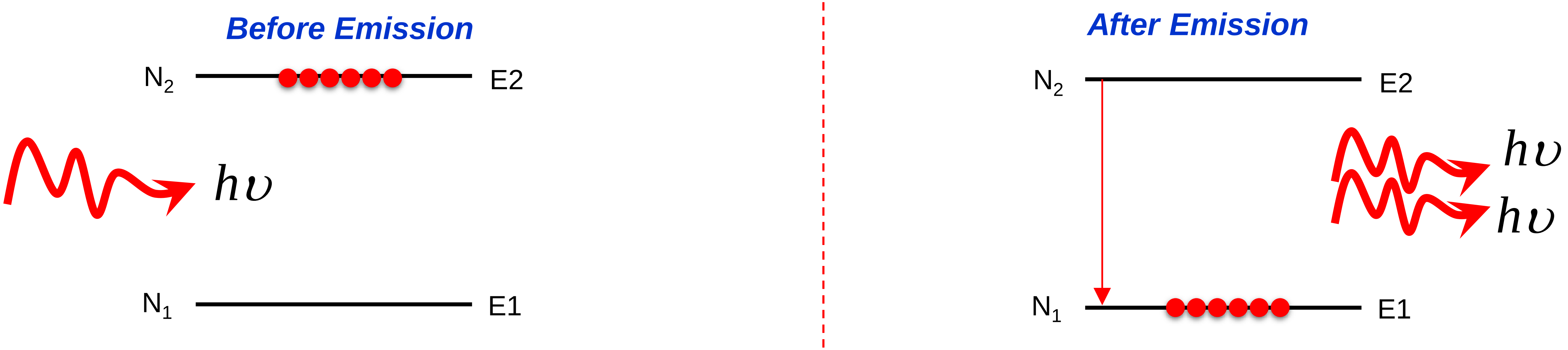
If there are large number of atoms in excited states then the photons emitted by different atoms have a random phase and hence they are incoherent.

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

$$(P_{21})_{sp} = A_{21} N_2$$

where the proportionality constant A_{21} **is known as the Einstein's coefficient of spontaneous emission**.

Stimulated or induced Emission



- If an atom is in excited state, then an incident photon of correct frequency (or energy) may cause the atom to jump to the lower energy state emitting an additional photon of same frequency. Thus now, two photons of same frequency are present.
- This phenomenon is called stimulated emission. These two photons are coherent and travel in the same direction

Stimulated or induced Emission

If the photon of frequency ν is made incident on it, then the atom jumps to the lower energy state emitting an additional photon of same frequency ν.

The probability of this emission from state 2 to state 1 is proportional to the energy density u(v) of the radiation and depends on the properties of states 1 & 2.

$$(P_{21})_{st} = \boldsymbol{B_{21}} N_2 u(\nu)$$

where the proportionality constant **B$_{21}$ is known as the Einstein's coefficient of stimulated emission of radiation**

So the total probability of emission from energy state 2 to 1 is the sum of spontaneous and stimulated probabilities.

$$P_{21} = (P_{21})_{sp} + (P_{21})_{st} = [\boldsymbol{A_{21}} + \boldsymbol{B_{21}} u(\nu)] N_2$$

Relation between Einstein's *Coefficients*

Consider an assembly of atoms in thermal equilibrium T with radiations of frequency ν and the energy density u(ν).

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 transition for atoms from state 1 to 2 per unit time is

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

The probability of transition of atoms from state 2 to 1,either by spontaneously or by stimulated emission per unit time is

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

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

$$P_{12} = P_{21}$$

The Derivation

$$P_{12} = \boldsymbol{B_{12}} N_1 u(\nu) \qquad (1)$$

$$P_{21} = (P_{21})_{sp} + (P_{21})_{st} = [\boldsymbol{A_{21}} + \boldsymbol{B_{21}} u(\nu)] N_2 \qquad (2)$$

$$\boxed{P_{12} = P_{21}} \qquad (3)$$

$$\boldsymbol{B_{12}} N_1 u(\nu) = [\boldsymbol{A_{21}} + \boldsymbol{B_{21}} u(\nu)] N_2$$

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

$$u(\nu) = \frac{\boldsymbol{A_{21}}}{\boldsymbol{B_{21}}} \cdot \frac{1}{\left[\frac{N_1}{N_2} \cdot \frac{\boldsymbol{B_{12}}}{\boldsymbol{B_{21}}} - 1\right]} \qquad (4)$$

The Derivation

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

$$\frac{N_1}{N_2} = \frac{N_0 e^{-E_1/kT}}{N_0 e^{-E_2/kT}} = e^{(E_2-E_1)/kT} \qquad \text{or,} \qquad \frac{N_1}{N_2} = e^{h\nu/kT}$$

where N_0 is the total number of atoms present and ***k*** is the Boltzmann constant

or, $$u(\nu) = \frac{A_{21}}{B_{21}} \cdot \frac{1}{\left[e^{h\nu/kT} \cdot \frac{B_{12}}{B_{21}} - 1\right]} \qquad (5)$$

Planck's radiation formula gives the energy density of radiation u(ν) as

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{h\nu/kT} - 1} \qquad (6)$$

Compare equation number 5 and 6

$$u(\nu) = \boxed{\frac{A_{21}}{B_{21}}} \cdot \frac{1}{\left[e^{h\nu/kT} \cdot \frac{B_{12}}{B_{21}} - 1\right]}$$

$$u(\nu) = \boxed{\frac{8\pi h\nu^3}{c^3}} \cdot \frac{1}{[e^{h\nu/kT} \cdot 1 - 1]}$$

from equation (1) and (2)

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

and

$$\frac{B_{12}}{B_{21}} = 1$$

This equation gives the relation between the probabilities of spontaneous and stimulated emission. "The ratio of spontaneous emission to the stimulated emission is proportional to ν^3".

ie., probability of spontaneous emission dominates over stimulated emission more as energy difference b/w two states increases

THANK YOU