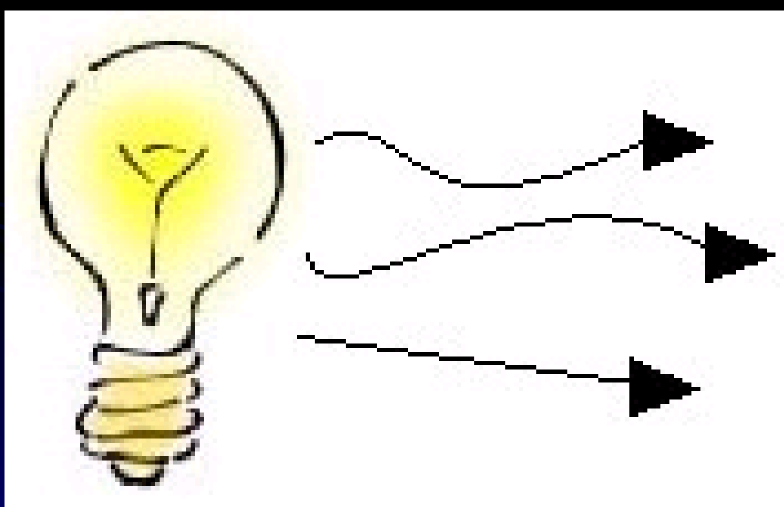
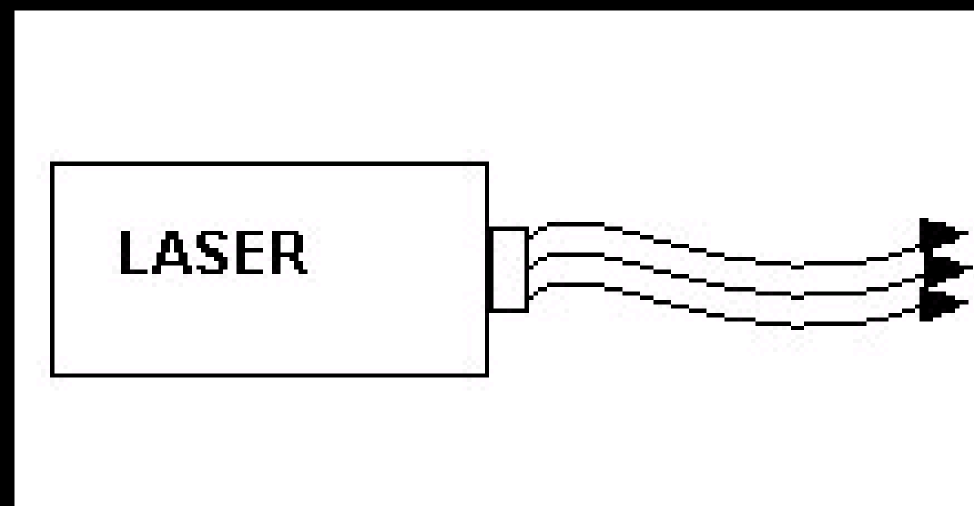
LASER

- LIGHT AMPLIFICATION by STIMULATED EMISSION of RADIATION
- Characteristics
  - Monochromaticity

Incandescent vs. Laser Light

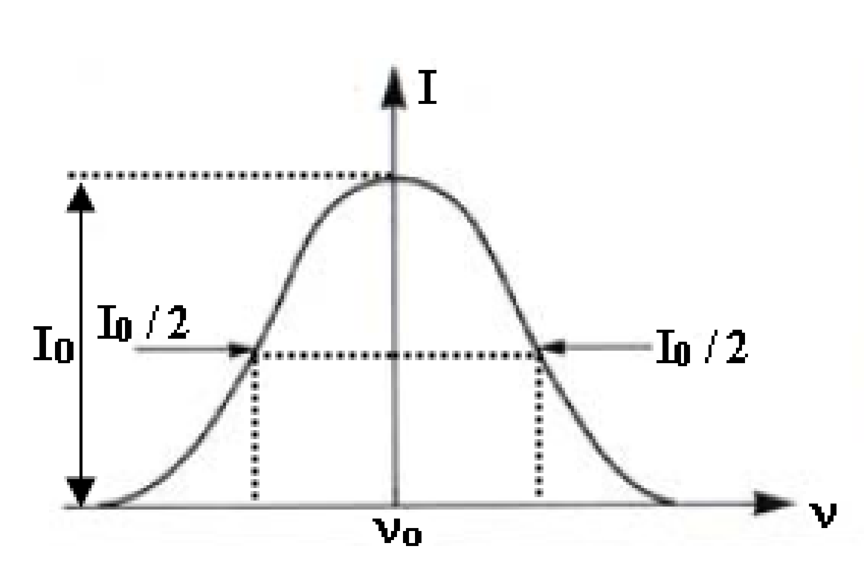


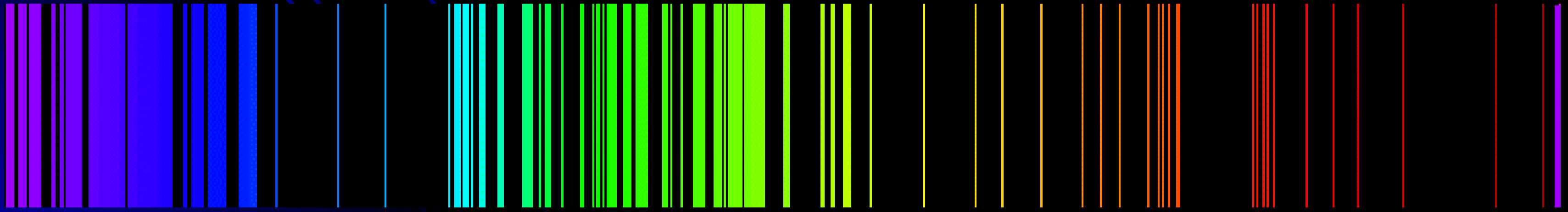


1. Many wavelengths
2. Multidirectional
3. Incoherent

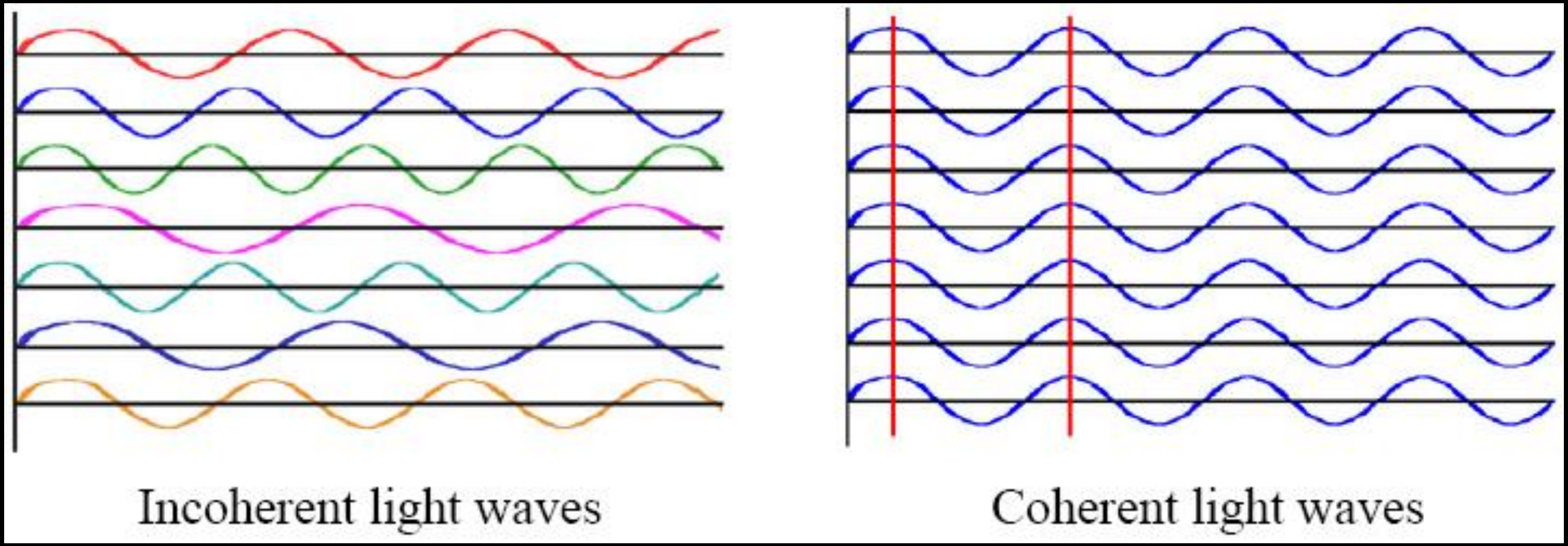
1. Monochromatic
2. Directional
3. Coherent

- Monochromatic light – having one frequency of oscillation
- Practically not possible
- Consist a band of frequencies closely spaced around a central frequency ν_0
- Band frequency $\Delta\nu$ is called line width or band width
- Light from conventional source – line width 10^{10} Hz or higher
- Laser source has a line width of 100 Hz.





- Higher degree of coherence



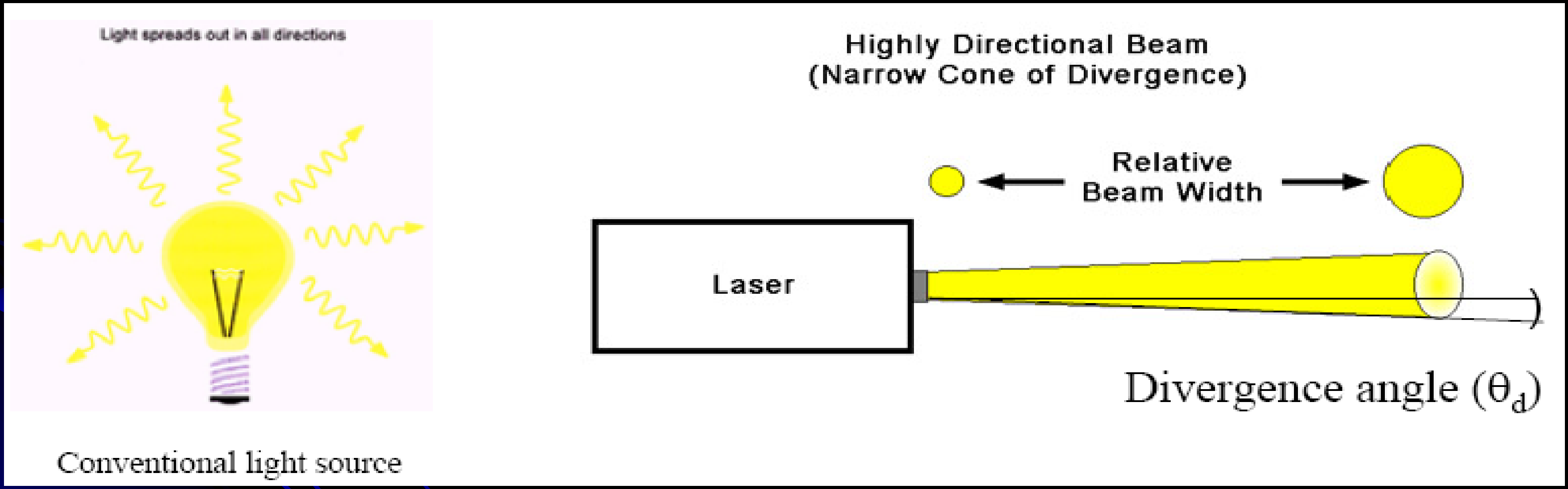
- Coherent if in phase – maintain crest to crest and trough to trough correspondence
- Things necessary for light waves to be coherent
  - Start at same point with same phase
  - Wavelengths must be the same
- Laser light is a resultant of number if identical photons which are in phase, hence exhibiting higher degree of coherence

- High intensity
  - Power o/p varies from few mW to few kW.
  - This o/p power is concentrated by a very small CS
  - Intensity of laser beam is given by

$$I = (10 / \lambda)^2 P$$

P is the power radiated by the laser

- Directionality

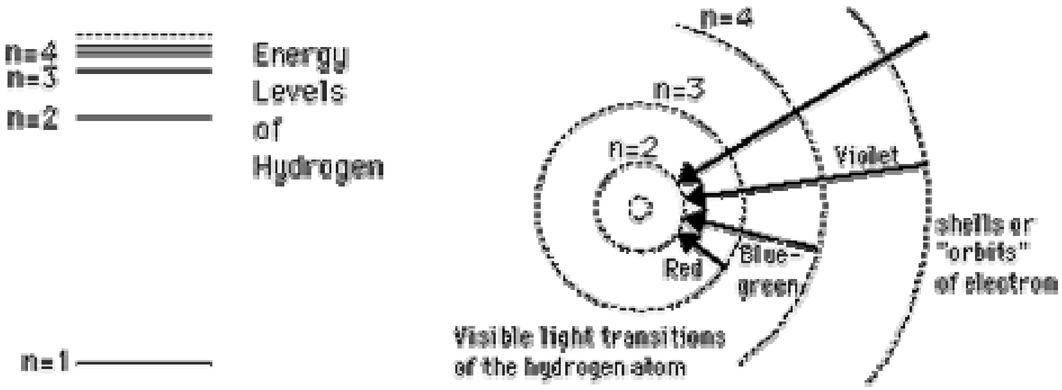


- Light from laser diverges very little
- Light beam can travel as a parallel beam up to a distance of d^2 / λ

d – diameter of the aperture, λ wavelength of light

- After the distance d^2 / λ light beam spreads radially
- Ordinary light beam angular spread is given by $\Delta\theta = \lambda / d$
- For laser angular spread is 1mm / m (ordinary light 1m / m)

Einstein's Prediction



frequency of radiation, sometimes written as f giving expression E = hf.

$$E = h\nu$$

Quantum energy of a photon.

h = Planck's constant = 6.626×10^{-34} Joule-sec = 4.136×10^{-15} eV·s

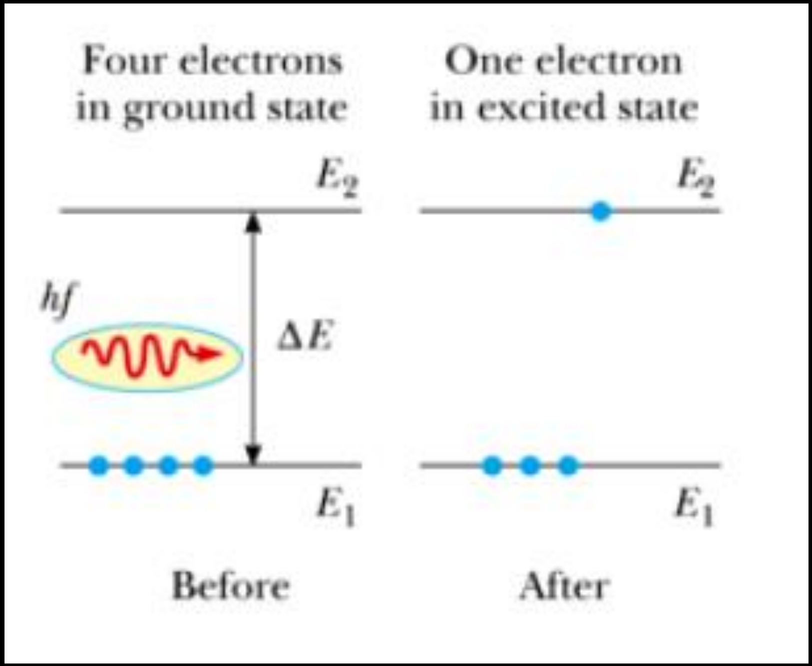
•To raise an electron from one energy level to another, „input" energy is required

•When falling from one energy level to another, there will be an energy output given by the Planck's law

- An excited atom tend to return randomly to ground state.
- As gnd. State population is high, more atoms are excited and a state will reach where all the electrons from the gnd. state are excited – violation of thermal equilibrium.
- Hence Einstein suggested there could be some emission mechanism by which the excited atom comes to the gnd. State.
- He predicted that photons in the light field induce the excited atom to fall to lower state and give up their excess energy in the form of photons. He called this type of second emission as stimulated emission.

- Almost all electronic transitions that occur in atoms that involve photons fall into one of three categories:
- Stimulated absorption or absorption
  - Transition from E_1 to E_2 due to the absorption of energy from the incident photon is called as stimulated absorption.
  - The process can be represented as

    atom + Photon → atom*



No. of absorption transition occurring in the Material will be α to the population in the lower level and number of photons / unit Volume in the incident beam.

- The rate of absorption may be expressed as

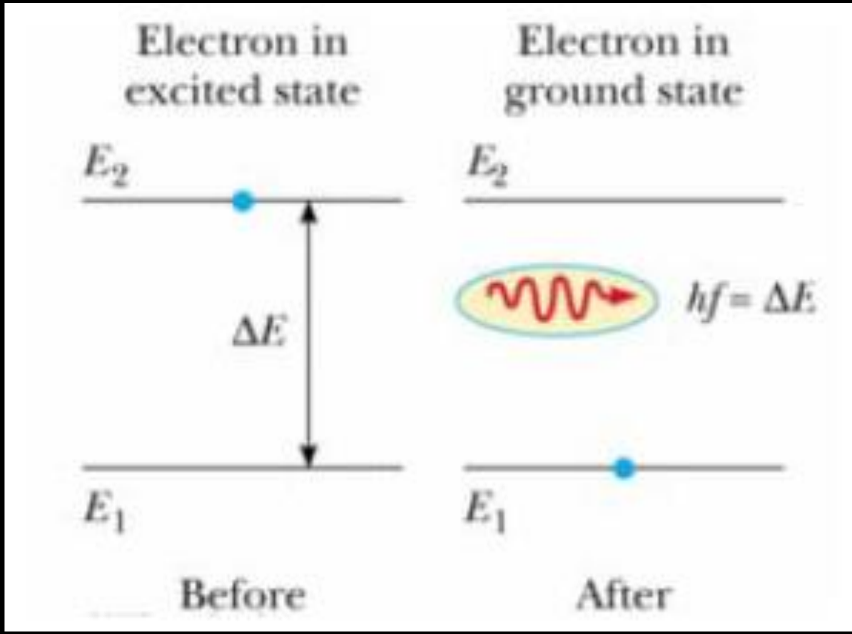
$$R_{abs} = B_{12}\, \rho(\nu)\, N_1 = B_{12}\, Q\, N_1 \quad \text{where } Q = \rho(\nu)$$

$\rho(\nu)$ – energy density of incident light

B_{12} – Einstein's coefficient for absorption

- Spontaneous emission
  - Excited atom stays in the excited state for a period of 10^{-8} s.
  - If not stimulated undergoes transition to gnd. State of its own emitting energy in the form of photons
  - Known as spontaneous emission
  - The process is represented as

    $atom^{*} \rightarrow atom + photon$



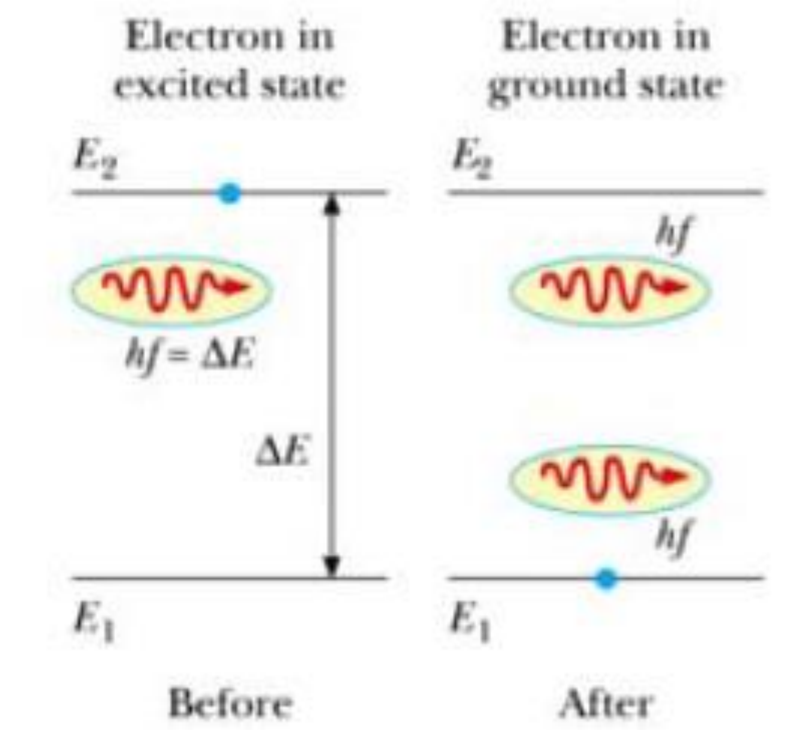
No. of photons generated is α to population in the excited level

$$R_{SP} = A_{21}\, N_2$$

A_{21} – Einstein co efficient for spontaneous emission

Thus spontaneous emission is independent of energy density

- Stimulated emission
  - Atoms in the excited state is stimulated by the photon with appropriate energy then transition to gnd. Level occurs with emission of additional photon.
  - Hence this is called as stimulated emission.



- The process may be expressed as

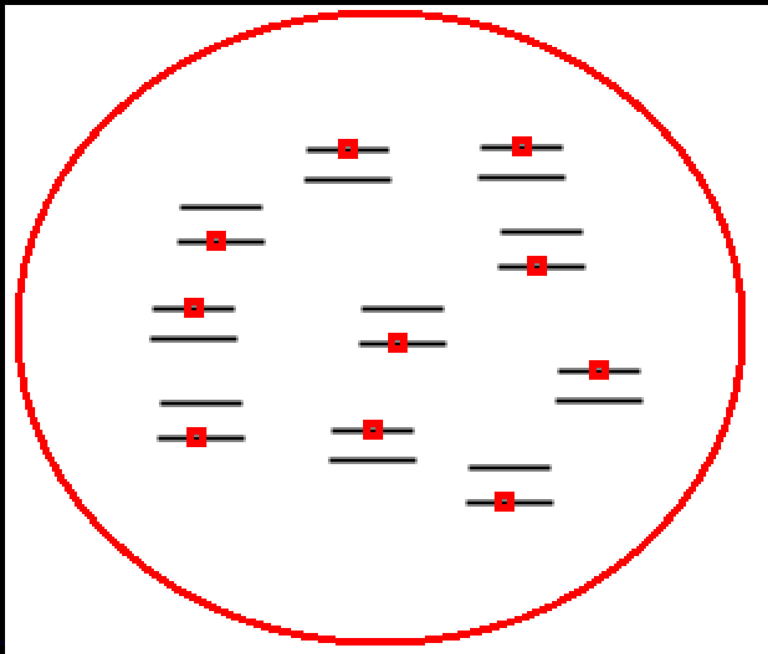
  atom* + Photon = atom + 2 Photons

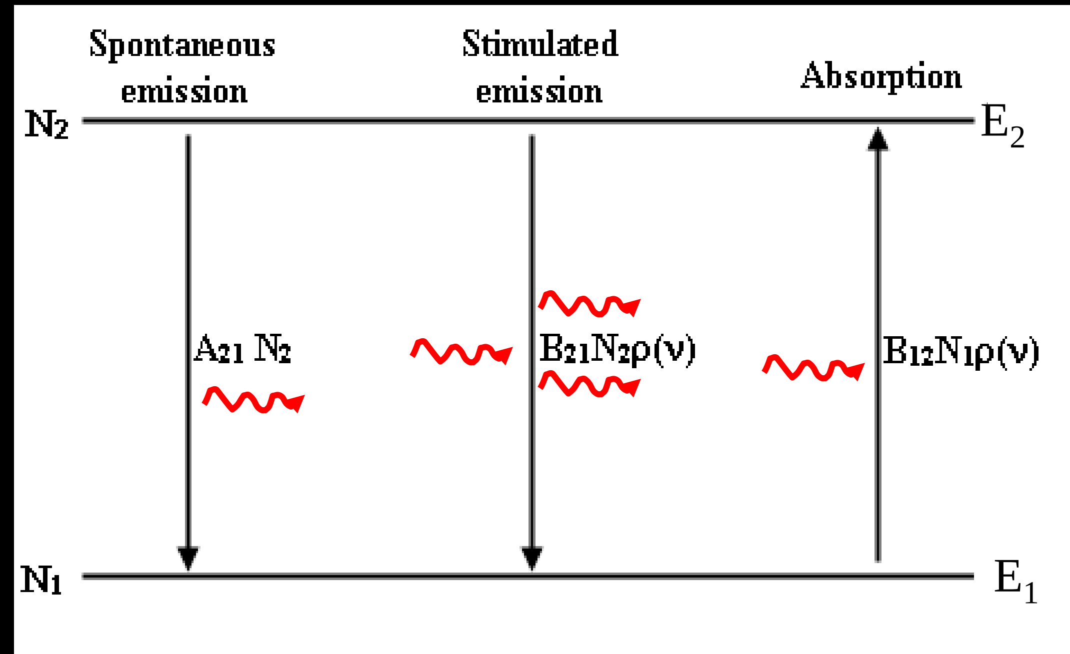
The rate of stimulated emission of photons is given by

$$R_{St} = B_{21}\,\rho\,(\nu)\,N_2 = B_{21}\,Q\,N_2 \quad \text{where} \quad Q = \rho\,(\nu)$$

B_{21} – Einstein coefficient of stimulated emission

- Einstein's A and B coefficients





- Under thermal equilibrium transitions from E_1 to E_2 should be equal to transitions from E_2 to E_1

No. of atoms absorbing photons per unit volume = the number of atoms emitting photons per second

$$B_{12}\rho(\nu)N_1 = A_{21}N_2 + B_{21}\rho(\nu)N_2$$

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

$$\rho(\nu)[B_{12}N_1 - B_{21}N_2] = A_{21}N_2$$

$$\rho(\nu) = A_{21}N_2 / [B_{12}N_1 - B_{21}N_2]$$

Taking $B_{21}N_2$ in the denominator as common

$$\rho(\nu) = A_{21}N_2 / B_{21}N_2 \{ 1 / [(B_{12}N_1 / B_{21}N_2) - 1] \}$$

$$\rho(\nu) = (A_{21} / B_{21}) \{ 1 / [(B_{12}N_1 / B_{21}N_2) - 1]\}$$

It was proved thermodynamically that $B_{12} = B_{21}$

Then

$$\rho(\nu) = (A_{21} / B_{21}) \{ 1 / [(N_1 / N_2) - 1]\}$$

Distribution of atoms under equilibrium among diff. states is given by Boltzmann's law according to which

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

Therefore

$$\rho(\nu) = (A_{21}/B_{21}) \left[1 / (e^{h\nu/kT} - 1) \right]$$

The above equation is the energy density of photon of frequency ν in equilibrium with atoms in energy states 1 and 2 at temperature T

comparing with Plank's radiation formula

$$\rho(\nu) = (8\pi h\nu^3/c^3) \left[1 / (e^{h\nu/kT} - 1) \right]$$

We get

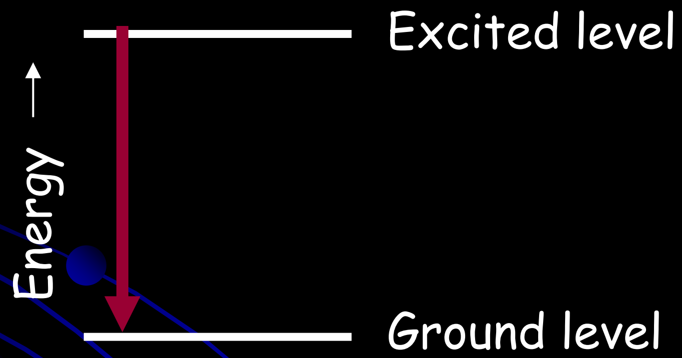
$$A_{21}/B_{21} = 8\pi h\nu^3/c^3$$

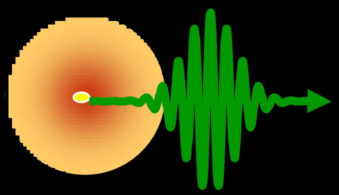
The above equation gives the relation between Einstein's A and B coefficients

- Significance of Einstein's coefficients
  - Coefficients A_{21}, B_{21} and B_{12} are interrelated and can be calculated if one is known
  - Stimulated emission and absorption coefficients are equal at least for non-degenerate energy states
  - Since B_{21}/A_{21} is proportional to reciprocal of cube of ν, higher the frequency smaller the B_{21}

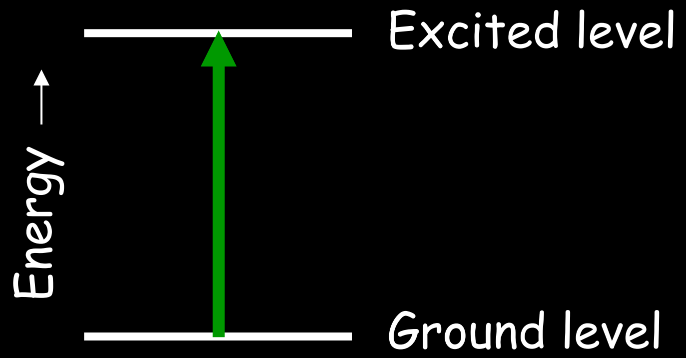
Excited atoms emit photons spontaneously.

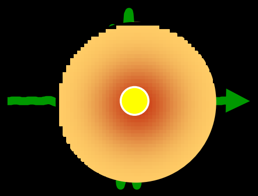
When an atom in an excited state falls to a lower energy level, it emits a photon of light.



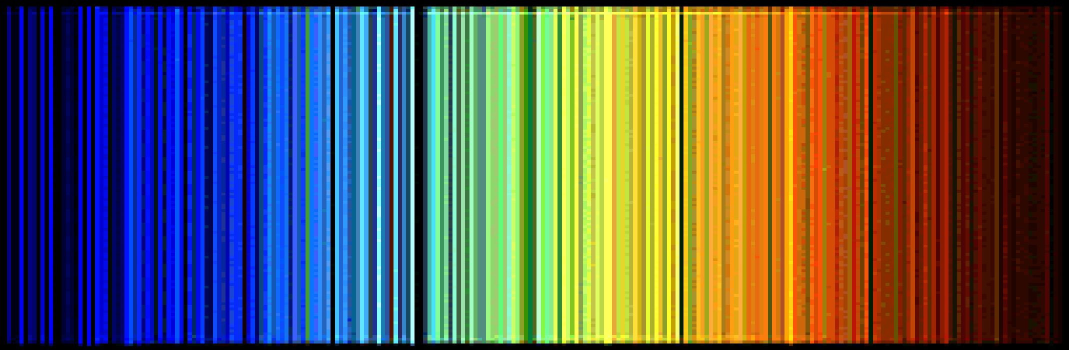


Atoms and molecules can also absorb photons, making a transition from a lower level to a more excited one.





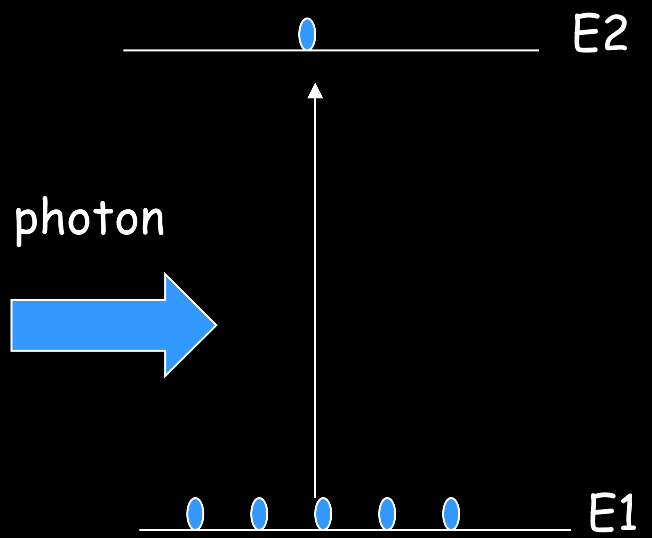
This is, of course, absorption.



Absorption lines in an otherwise continuous light spectrum due to a cold atomic gas in front of a hot source.

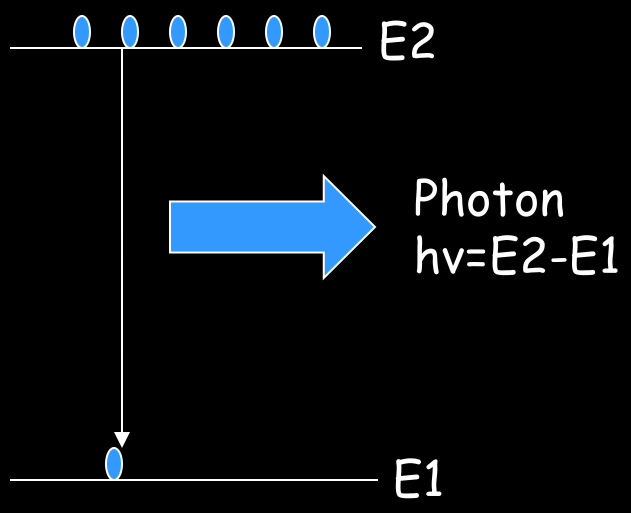
Spontaneous absorption

- Let us consider two energy level having energy E1 & E2 resp.
- The atom will remain in ground state unless some external stimulant is applied to it.
- When an EM wave i.e photon of particular freq fall on it , there is finite probability that atom will jump form energy state E1 to E2.



Spontaneous emission

- Consider an atom in higher state (E_2).
- It can decay to lower energy level by emitting photon.
- Emitted photon have energy $hv=E_2-E_1$.
- Life time of excited state is 10^{-9}sec.



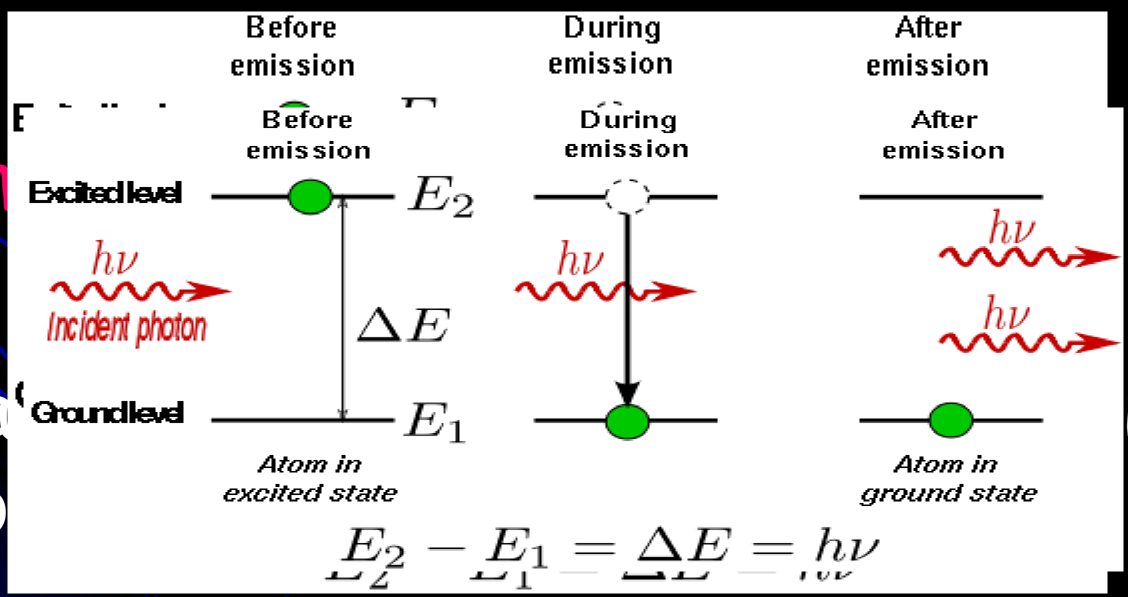
Stimulated Emission

The stimulated photons have unique properties:

- In phase with the incident photon

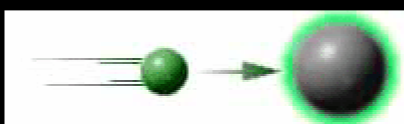
- San ... photon

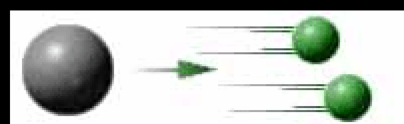
- Tra ... nt pho...



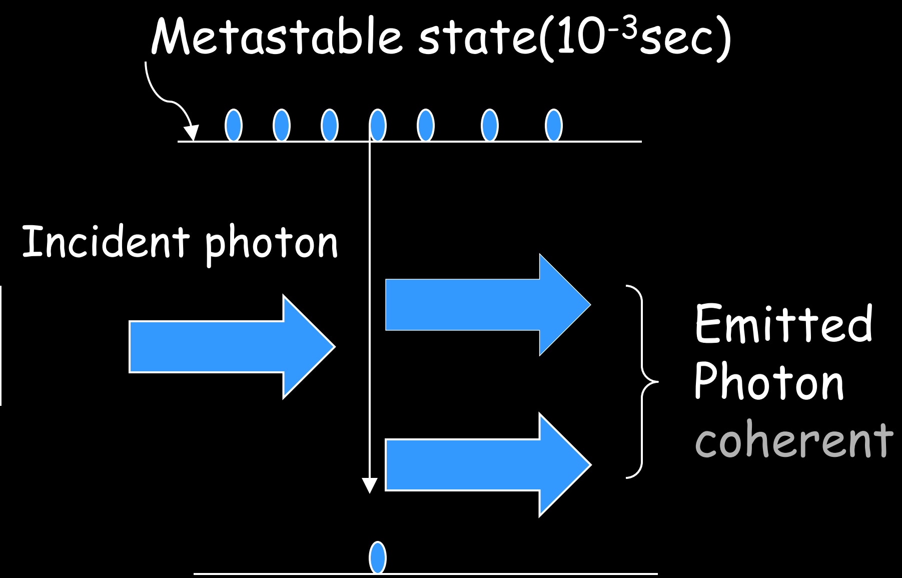
Stimulated emission

- There are metastable state i.e. transition from this state is not allowed acc to selection rule.
- There life time is 10^{-3} sec.





- ... state ... lower state at there own.
- When an photon of suitable freq arrive it make the atom in metastable unstable.
- The emitted photon is in coherence with incident photon.



Stimulated vs Spontaneous Emission

Stimulated emission requires the presence of a photon. An "incoming" photon stimulates a molecule in an excited state to decay to the ground state by emitting a photon. The stimulated photons travel in the same direction as the incoming photon.

Spontaneous emission does not require the presence of a photon. Instead a molecule in the excited state can relax to the ground state by spontaneously emitting a photon. Spontaneously emitted photons are emitted in all directions.