Laser Physics 168
Chapter 1
Introductory concepts

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Material to be covered

- Introduction to many concepts that will be covered
- Three major elements of a laser
    1. An active material
    2. A pumping scheme
    3. A resonator
- CW and transient laser behavior
- Properties of different kinds of lasers
- Properties of the laser light
- Transformation of laser light or different applications
- Appendixes for selected subjects.

In this lecture

1. Spontaneous and Stimulated Emission, Absorption
2. The Laser Idea
3. Pumping Schemes
4. Properties of Laser Beams
    1. Monochromaticity
    2. Coherence
    3. Directionality
    4. Brightness
    5. Short Time Duration
5. Types of Lasers

Quantization of the Electromagnetic Radiation

Energy of EM radiation is quantized in units of $h\nu$

$$E_{photon} = h\nu,$$

$h = 6.63\times 10^{-34}\, J.s$ is the Plank's constant

ν is the frequency of the EM radiation

Total energy stored in an EM field of frequency ν is:

$$E_n^{EM} = \frac{h\nu}{2} + nh\nu$$

$n = 0,1,2,...$ is number of photons in the EM radiation.

$\frac{h\nu}{2}$ is the energy associated with electromagnetic vacuum.

In absence of photons there is some energy stored in vacuum.

Energy Quantization in Matter

Atoms are composed of charged particles.

Atoms interact with EM fields.

Atoms have quantized energy levels.

Energy levels of hydrogen atom: $E_n = -\frac{13.6eV}{n^2}$ where $n = 1,2,4,...$

A strong interaction between the EM field and atom can occur if some constituents of the matter have allowed energy levels that is in resonance with the energy of the photons in EM radiation or:

$$\underbrace{E_n - E_m}_{\text{Energy of an atomic or molecular transition}} = \underbrace{E_{n+1}^{EM} - E_n^{EM}}_{\text{Energy of a photon}} = h\nu_0$$

States of an Atom

<u>Ground state of an atom</u>: is the most stable state of it which corresponds to the lowest energy level of the atom.

<u>Excited states of an atom</u>: are states above the ground state and less stable and correspond to higher energy levels.

Boud electrons absorb energies in **packets** that **matches** the <u>quantized energy levels available</u> to them.

<u>Free the electrons</u> can interact with photons of any energy because their energy is not quantized.

Spontaneous emission

Atom decays from E_2 to E_1

Result is emission of a photon

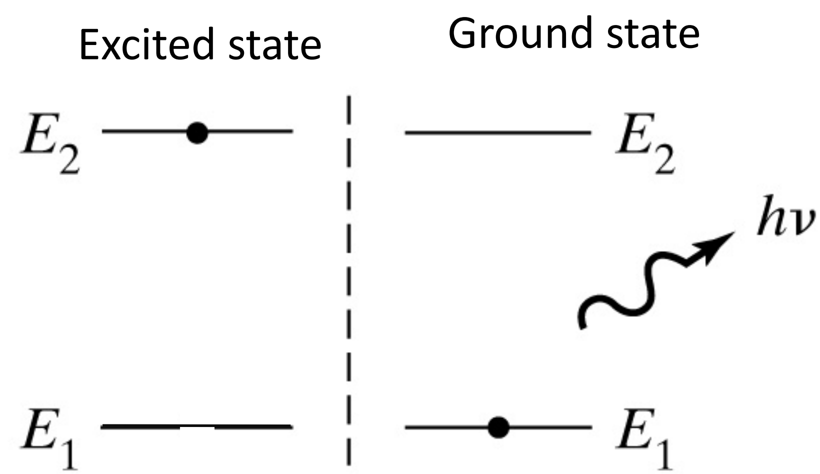
in case of **radiative decay**

Energy of the Photon:

$$h\nu_0 = E_2 - E_1$$

or

Increasing internal energy of the atoms surrounding the decayed atom in case of **non - radiative decay**.



(c) Spontaneous emission

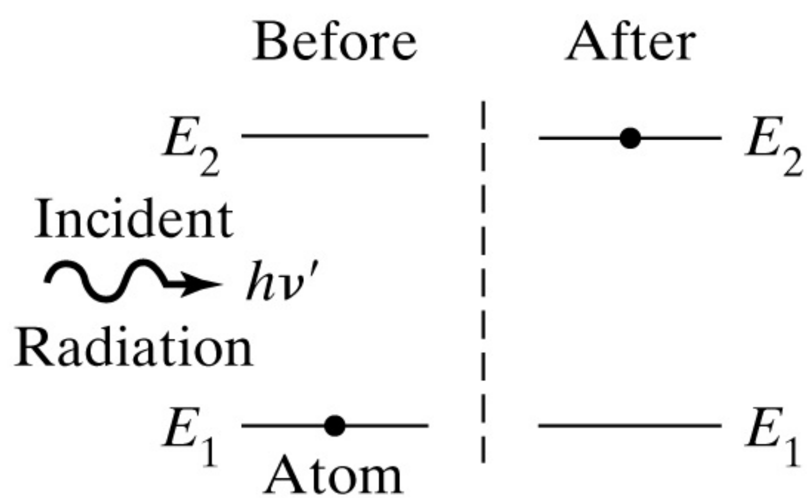
Absorption

Atom is in E_1 and is raised to E_2 by incidence of an EM radiation of **frequency** ν **that matches** ν_0

$$\nu_0 = \frac{E_2 - E_1}{h}$$

Energy of the radiation is **absorbed** to excite the atom from E_1 to E_2 wher

$$E_2 > E_1$$



(a) Stimulated absorption

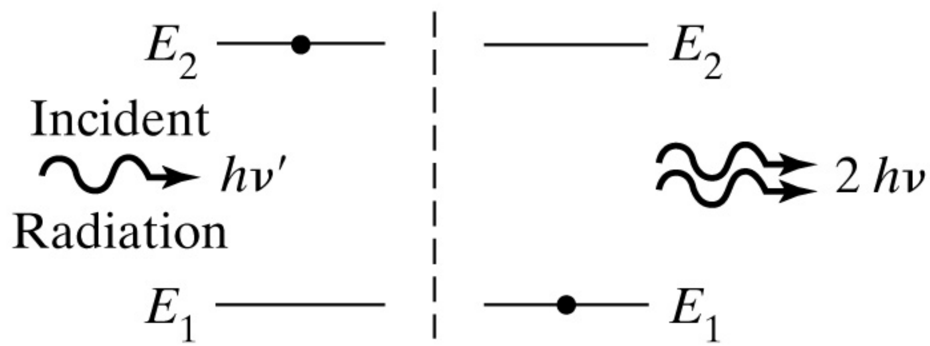
Stimulated emission

Atom **forced** to decay from E_2 to E_1 by a radiation that its frequency matches that of the $\nu_0 = \frac{E_2 - E_1}{h}$

Result is emission of two photons

In stimulated emission direction and phase of the emitted photon matches that of the incident photon.

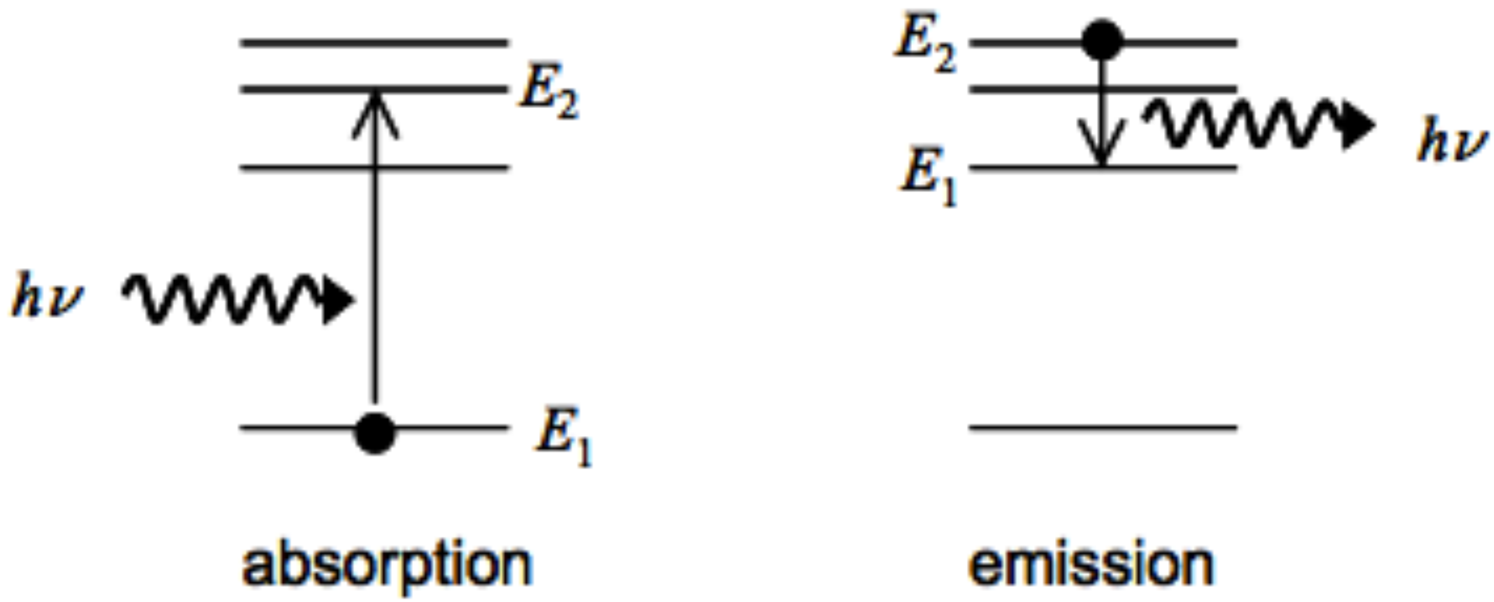
While there is no phase or direction relationship between the spontaneousely emitted photones.



(b) Stimulated emission

Transitions may not be between the consecutive levels

- There are specific rules for allowed transitions. You may already know them from Modern physics.
- Transition rules are dictated by some fundamental physical law such as conservation laws.



Probability of emission and absorption phenomena: Spontaneous emission

N : number of atoms or molecules per unit volume at time t that are at a given energy level.

N_1 & N_2 : population of levels 1 and 2 at t

Probability of spontaneous emission:

$$\left(\frac{dN_2}{dt}\right)_{sp} = -AN_2 = -\frac{\mathrm{N}_2}{\tau_{nr}} \quad \text{and} \quad \left(\frac{dN_2}{dt}\right)_{nr} = -\frac{N_2}{\tau_{nr}}$$

A : the Einstein A coefficient (positive) obtained by thermodynnamics considerations

$\tau_{sp} = 1/A$: the spontaneous emission (radiative lifetime)

The numerical values depend on the particular transition

τ_{nr} : is the non-radiative lifetime

Probability of stimulated emission and absorption

Probability of stimulatd emission and absorption:

$$\left(\frac{dN_2}{dt}\right)_{st} = -W_{21}N_2 = -\sigma_{21}F \text{ and } \left(\frac{dN_1}{dt}\right)_a = -W_{12}N_1 = -\sigma_{12}F$$

W_{21} : the rate of stimulated emission from $2 \rightarrow 1$.

W_{12} : the rate of (stimulated) absorption from $1 \rightarrow 2$

The numerical values of Ws **depend on the particular transition** and F

F : photon flux (photones per area)

σ_{21} : stimulated emission cross section (units of area)

σ_{12} : absorption cross section (units of area)

The numerical values of σs **depend on the particular transition** and F

τ_{nr} : is the non-radiative lifetime

Probability of transitions between degenerate and non-degenerate states

Probability of stimulatd emission and absorption:

$$\left(\frac{dN_2}{dt}\right)_{st} = -W_{21}N_2 = -\sigma_{21}F \quad \text{and} \quad \left(\frac{dN_1}{dt}\right)_{a} = -W_{12}N_1 = -\sigma_{12}F$$

It was shown by Enistein at early 20th century that :

For trasition between **non - degenerate** states: $W_{21} = W_{12}$

For trasition between **degenerate** states: $g_2 W_{12} = g_1 W_{12}$

g_1 and g_2 : degeneracy of level 1 and 2.

For equal photon flux F: $g_2 \sigma_{21} = g_1 \sigma_{12}$

In sammary we can say each stimulated emission process **creates** a photon and each absorption process **anihilates** a photon

The Laser Idea

- Will be completed later

Pumping Schemes

Properties of Laser Beams

Monochromaticity

Coherence

Directionality

Brightness

Short Time Duration

Types of Lasers

HW1