OPTICAL FIBER COMMUNICATIONS SYSTEMS

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Basic Concepts of Light

Sellybus

1. **Basic concepts:**

includes parameters of light wave, index of refraction, Snells law, polarization of light and electromagnetic spectrum

2. **Optical communication system:**

block diagram of an optical communication system and advantages of optical communication system.

3. **Optical fiber:**

optical fiber structure, propagation of light in Optical fiber, some parameters of an optical fiber, types of optical fiber, signal degradation in Optical fiber (**attenuation**: sources, calculations and methods of reduction and **dispersion** : types, calculations and methods of reduction) and advanced types of optical fiber

.

5. **Light sources:**

light emitter and its performance characteristics, laser operation and theory, laser diode (principles of operation, characteristics and efficiency calculations), Light emitting diode (LED) (principles of operation, characteristics, coupling efficiency and optical and electrical bandwidth

6. **Photodetectors:**

photodetector characteristics, photodetector types and comparisons, noise sources and SNR calculations,

7. Optical power and rise time budgets.

8. Analog systems and coherent detection.

9. Optical fiber applications.

10. **Optical amplifiers**:

device physics, types, performance and applications.

11. **WDM, DWDM systems.**

Optical communication system applications (Optical networking, video transmission

References

- Senior John M., Optical Fiber Communications Principles and Practice, second edition, Prentice Hall, 1996.
- Keiser.Gred, Optical Fiber Communication, third edition, Mc Grow Hill, 2000.
- Gower John, Optical Communication System, second edition, Prentice Hall, 1993.

First course exams timing

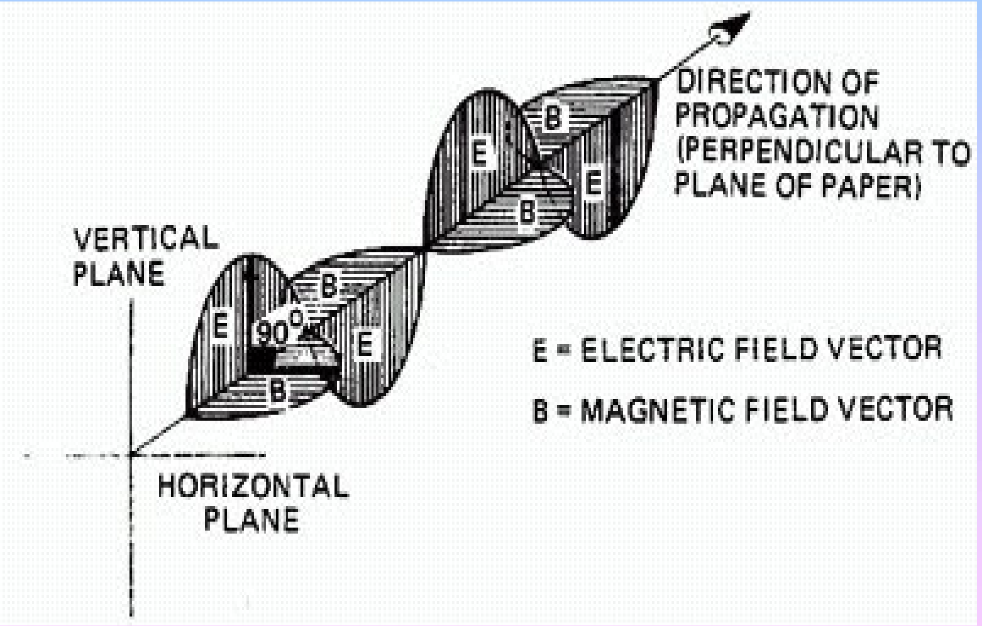
- q1 23/10
- q2 6 /11
- q3 27/11
- q4 18/12
- course exam 4 /12

Lecture One

What is light?

Light is an electromagnetic (EM) wave propagating through space.

Light is a transverse wave. This means that the oscillation is perpendicular to the direction of motion (much like a water wave).



Three-dimensional model of plane-polarized EM waves

Origin of Light

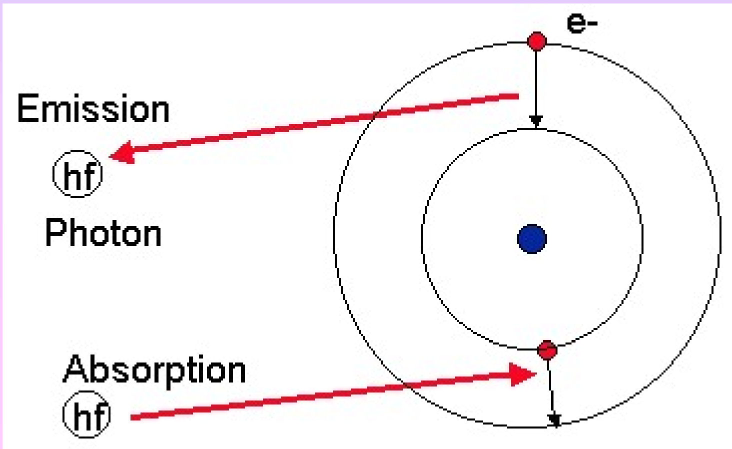
Where Does Light Come From?

The following had been known during the 19th century:

- accelerated charges produce light
- and hence emit energy

If we picture an electron as in orbit around the nucleus, it should radiate light

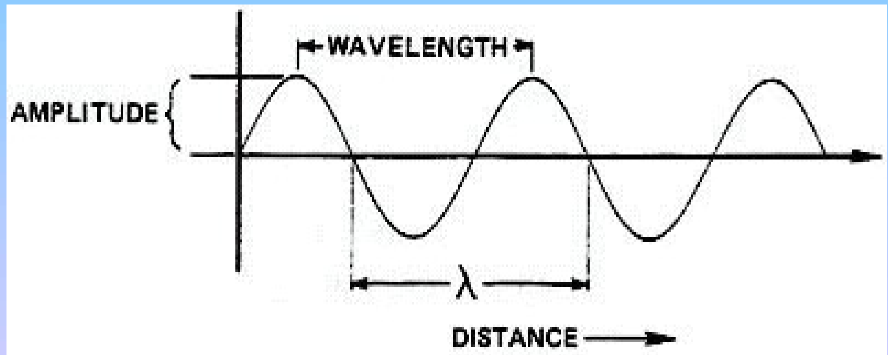
- changing direction is acceleration! (a force is required from something to change direction)



Amplitude is the maximum displacement of the wave.

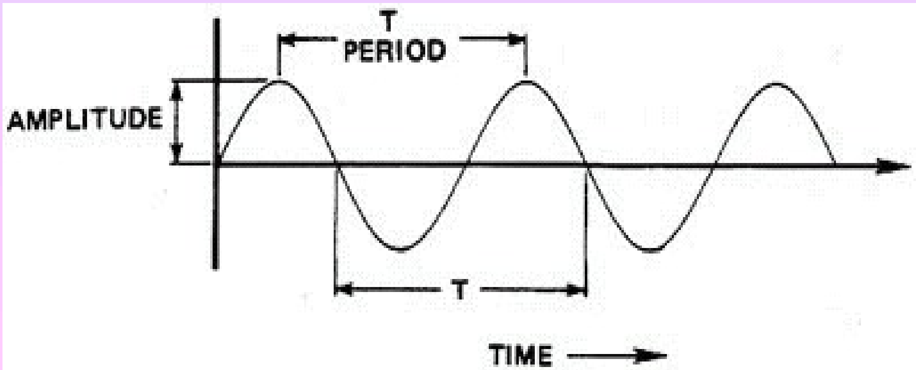
Spatial period (λ) **or wavelength** : is the distance between two similar points in the wave, e.g. the valleys or peaks measured in angstrom, nanometers or micrometers.

Spatial frequency(X): is how many spatial periodsor wavelength in a unit length.



Temporal Period(T): is the time over which the wave repeats it self-the time required for one complete cycle of the wave measured in seconds.

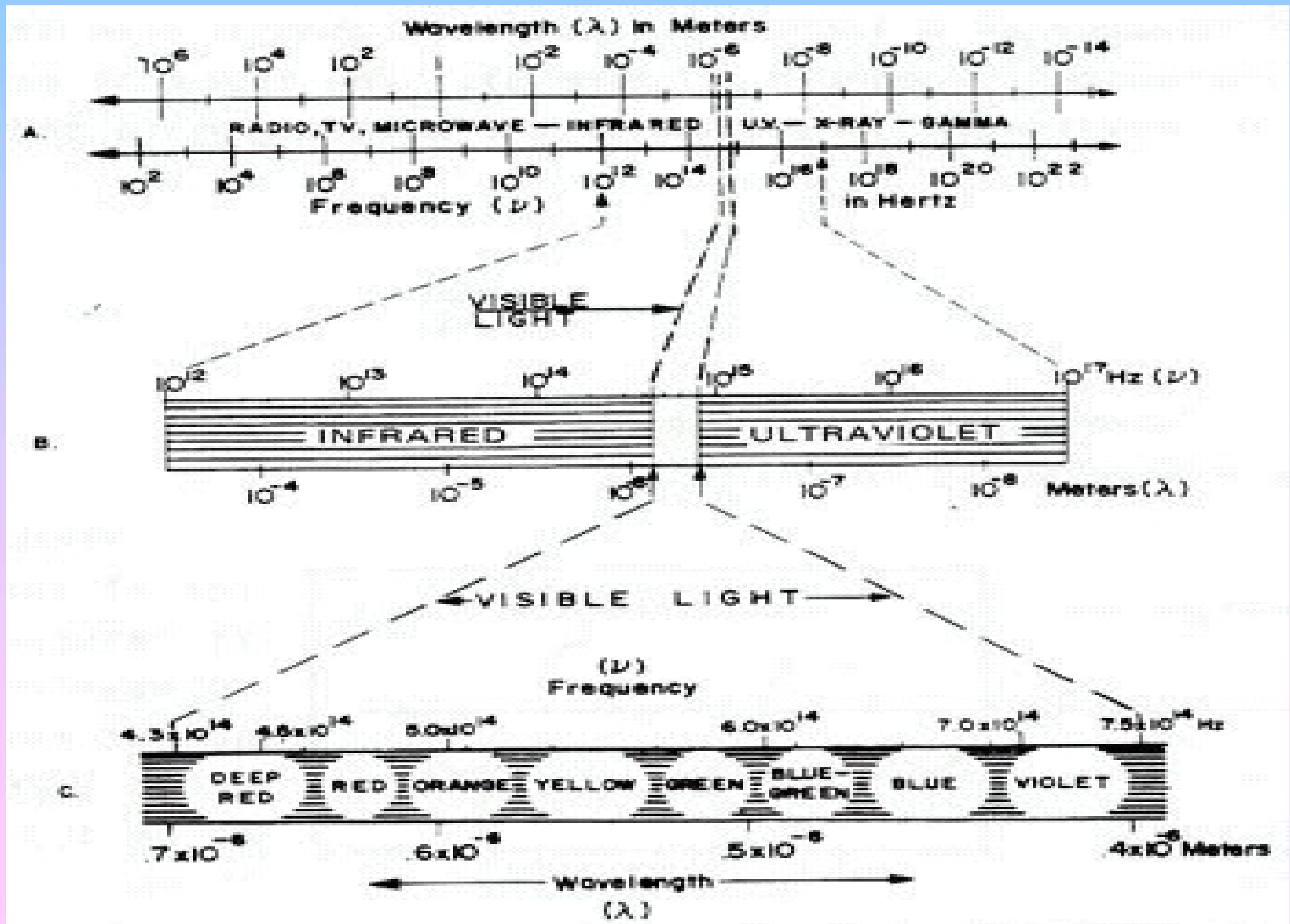
Temporal frequency (υ): is the number of temporal periods of the wave in one second and is measured in Hζ.



$C=\upsilon\lambda$

c is the speed of light in space and = $3*10^{8}$m/s.

Electromagnetic spectrum



Energy units

- **In Joule:**

$$E = h\nu = \frac{hc}{\lambda}$$

h = Planck's constant = 6.624×10^{-34} joule-seconds.

c = The speed of light in vacuum, namely 3×10^{8} m/sec.

- **The wavenumber (k)in cm^{-1}**

$$k = \frac{1}{\lambda\,(cm)}$$

1eV = 8056 Cm^{-1}

$$E(J) = eV \cdot \frac{e}{hc}$$

$$E(eV) = \frac{E(J)}{1.6*10^{-19} J}$$

$$E(eV) = \frac{1.3397}{\frac{1}{k} * 10^{7} (\mu m)}$$

e= $1.6*10^{-19}$C

h= $6.624 *10^{-34}$ Js

Homework: derive the above equations?

Homwork1

1. Given: A HeNe laser photon has a wavelength of 632.8 nm
   Find: (a) Photon energy in joules
   (b) Photon energy in cm^{-1}

2. Given: In energy notation involving the unit cm^{-1}, the energy of a Nd:YAG solid state laser photon is given as $9398.5 cm^{-1}$
   Find: (a) The energy of the photon in joules
   (b) The wavelength of the photon

3. Given: A Nd:YAG laser photon of energy $1.87´\ 10^{-19}$joules

Find: Photon energy in electron volts (eV)

Index of refraction

The **index of refraction (n)** of a material is the ratio of the speed of light in a vacuum (c) to its speed in that material (V) and is given by

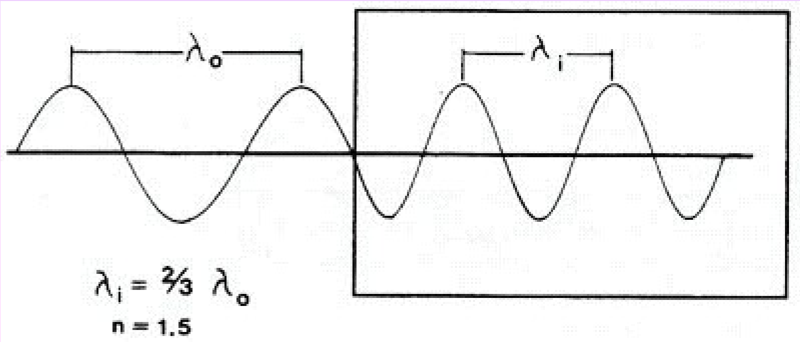
$$n = \frac{c}{V}$$

- The index of refraction is also the ratio of wavelength in vacuum to the wavelength in the material

$$n = \frac{\lambda_o}{\lambda_i}$$

where: λ_0 = wavelength in vacuum.
λ_i = wavelength in the material.

- The frequency of a light wave does not change when it enters a material, but its wavelength is reduced.



The index of refraction of air is about 1.0003, but is assumed to be 1.0 in most applications.

Homework2

1. Given: A HeNe laser beam (λ = 633 nm) travels through a glass window with an index of refraction of 1.65. Find: Speed and wavelength inside the glass.
2. The indices of refraction of several materials situated in air are given below. Calculate the velocity of light in each and Brewster's angle for each.

   a. Fused quartz at 643 nm: n = 1.457.
   b. Zinc crown glass at 434 nm: n = 1.528.
   c. Fused quartz at 397 nm: n = 1.471.
3. The wavelengths given in problem in above are in vacuum. Calculate the wave lengths inside the materials.

Polarization of light:

- Many applications require that the electric and magnetic fields have a particular direction.
- The **polarization** of light describes the orientation of the electric field in space.

➢ **Unpolarized light** has no specific orientation of electric field. The direction of the electric field varies randomly at approximately the frequency of light

An electric field vector of a polarized light

$$\mathbf{E}=\mathbf{i}E_x \sin(wt-kz) + \mathbf{j}E_y \sin(wt-kz+\theta)$$

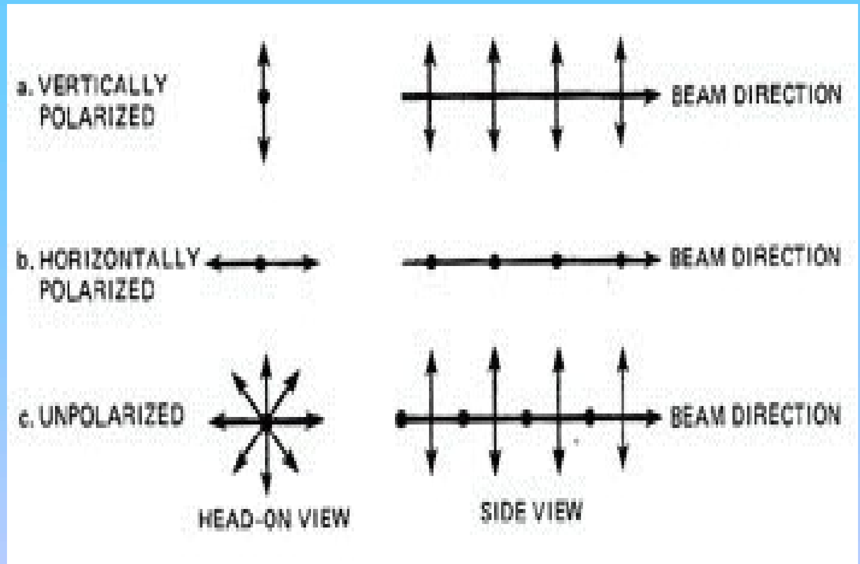
where **i** and **j** are unit vectors.

- **Plane-polarized light** is light in which the electric field oscillates in one plane only

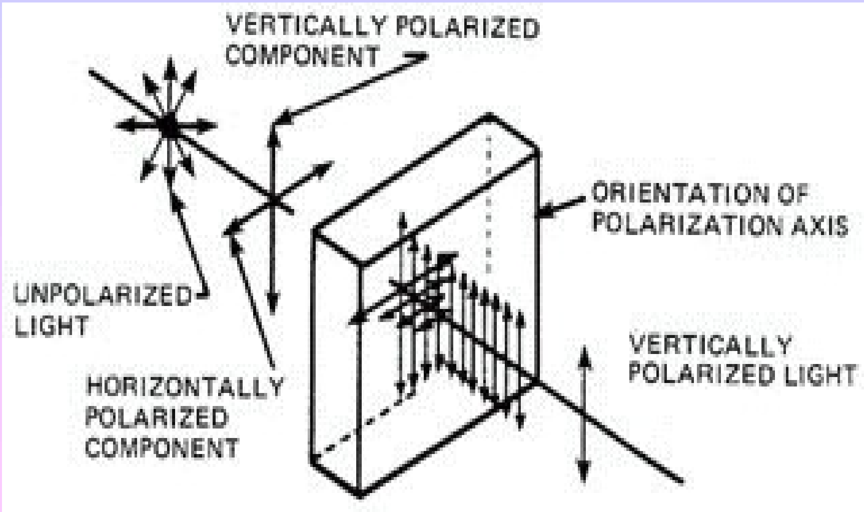
1) **Horizontally -polarized** light, the plane of the electric field is vertical — up and down in the plane of incidence.

2) **Vertically -polarized** light , the plane that contains the electric field is horizontal — perpendicular to the plane of incidence.

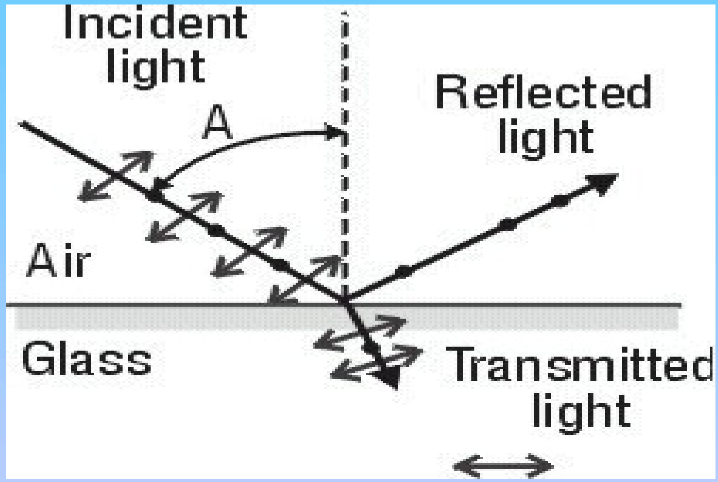
- In **circularly-polarized** light: The direction of the electric field of circularly-polarized light sweeps out a circle during each period of the wave.



linear polarizer:



Polarization by reflection of light from a surface



Homework3:

An electric field vector of a polarized light is given by

$$\mathbf{E}=\mathbf{i}E_x \sin (wt-kz)+\mathbf{j}E_y \sin(wt-kz+\theta),$$

where **i** and **j** are unit vectors. Describe the following polarization status:

1) $E_x=E_y$ and $\theta=\pi/2$.

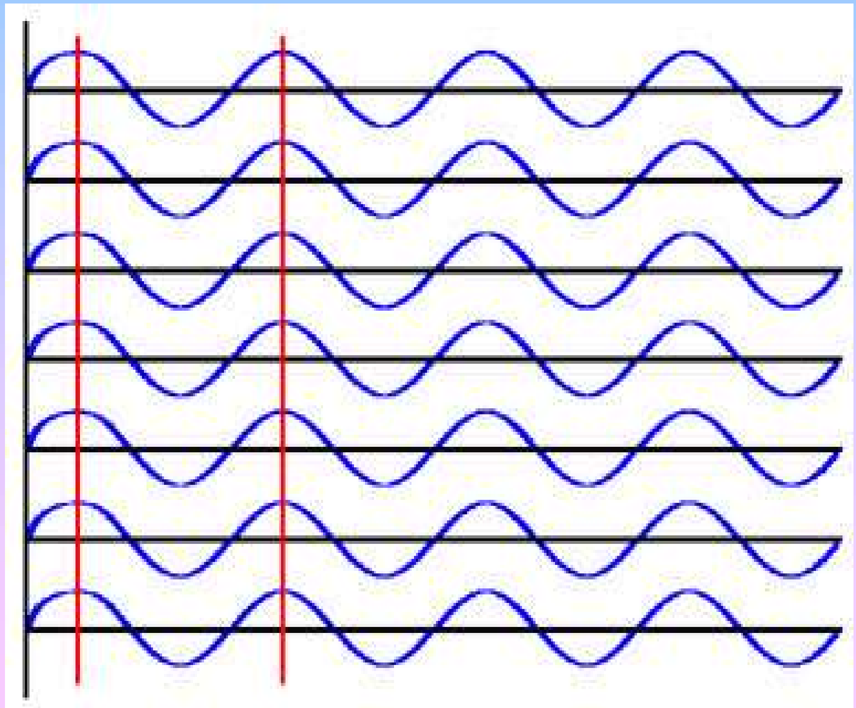
2) $\theta = 0$ or π

3) E_x not equal E_y and $\theta=\pi/4$.

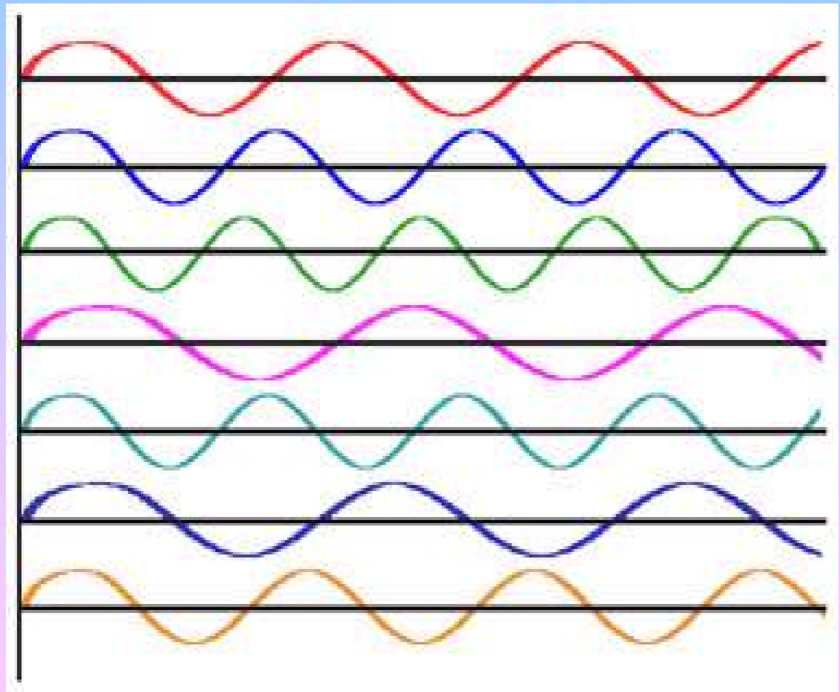
Coherence: is the condition that exists when all the light waves are 'in step, ' or 'in phase.'"

Incoherent light means that the light beam has no internal order.

Coherent light in which all of individual waves are in step, or "in phase,"



Coherent light waves



Incoherent light waves

•Coherence is the most fundamental property of laser light and distinguishes it from the light from other sources. Thus, a laser may be defined as a source of coherent light.

• Real laser systems are neither perfectly coherent nor monochromatic.the monchromacity of a laser beam is described by its ***wavelength linewidth*** λ (in angstroms or nanometers) or its ***frequency linewidth*** υ (in Hz). The two quantities are related as:

$$\Delta\upsilon = \upsilon_1 - \upsilon_2 = \frac{c}{\lambda_1} - \frac{c}{\lambda_2} = c\left(\frac{\lambda_2 - \lambda_1}{\lambda_1 \lambda_2}\right)$$

Which assuming that λ_1 and λ_2 are much larger than $\lambda_2 - \lambda_1$ can be approximated by

$$\Delta\upsilon = \upsilon_1 - \upsilon_2 \approx c\left(\frac{\Delta\lambda}{\lambda^2}\right)$$

The fundamental linewidth for an ideal laser line is extremely smal. In practice, various broadening mechanisms will be increase this fundamental linewidth in real lasers.

The monochromacity of a laser beam can also be described in terms of coherency. Notice that the length of time it takes for two oscillations differing in frequency by Δ υ to get out of phase by a full cycle is approximately 1/ Δυ. thus, the ***coherence time*** δτ is given by

$$\delta\tau = \frac{1}{\Delta \nu}$$

And the coherence length l_c is expressed as

$$l_c = c\,\delta\tau = \frac{c}{\Delta\nu}$$

1) consider an argon-ion laser with a center wavelength of 514.5 nm. Calculate the energy laser transition in eV, the frequency of the transition in Hz, and the spectroscopic wavenumber (1/ λ) in cm^{-1}.

2) consider a semiconductor laser diode with a laser linewidth of 2 Angstrom and a center operating wavelength of 870 nm. What is the frequency linewidth in Hz?

3) consider a HeNe laser with a linewidth of 1.5 GHz and a center operating wavelength 632.8 nm. What is the laser linewidth in angstrom?

4) cosider a Nd:YAG laser with a laser linewidth of 4.5angstrom and a center operating wavelength of 1.064 μm. what is its coherence length?

5) the uninitiated observer might confuse the center frequency of the laser line υ (in Hz) with the laser linewidth (also in Hz). However, the two numbers differ significantly in magnitude. To demonstrate this, calculate the center frequency (in Hz) and the laser linewidth (in Hz) for a semiconductor diode laser with a center operating wavelength of 760 nm and a laser linewidth of 3 angstrom?