Scattering of Light



INTRODUCTION

• Definition:-

"Light scattering is a form of scattering in which light is the form of propagating energy which is scattered. Light scattering can be thought of as the deflection of a ray from a straight path, for example by irregularities in the propagation medium, particles, or in the interface between two media."

"Scattering is a general physical process whereby some forms of radiation, such as light or moving particles, for example, are forced to deviate from a straight trajectory by one or more localized non-uniformities in the medium through which it passes."

- Most objects that one sees are visible due to light scattering from their surfaces. Indeed, this is our primary mechanism of physical observation.
- Scattering of light depends on the wavelength or frequency of the light being scattered. Since visible light has wavelength on the order of a micrometre, objects much smaller than this cannot be seen, even with the aid of a microscope.
- Colloidal particles as small as 1 μm have been observed directly in aqueous suspension.

IMPORTANCE OF SCATTERING OF LIGHT

- The interaction of light with matter give important information about the structure and dynamics of the material being examined.
- If the scattering centres are in motion, then the scattered radiation is Doppler shifted. An analysis of the spectrum of scattered light can thus yield information regarding the motion of the scattering center. Periodicity or structural repetition in the scattering medium will cause interference in the spectrum of scattered light.

- Thus, a study of the scattered light intensity as a function of scattering angle gives information about the structure, spatial configuration, or morphology of the scattering medium. With regard to light scattering in liquids and solids, primary material considerations include:
- 1. <u>Crystalline structure</u>: How close-packed its atoms or molecules are, and whether or not the atoms or molecules exhibit the *long-range order* evidenced in crystalline solids.
- 2. <u>Glassy structure</u>: Scattering centres include fluctuations in density and/or composition.
- 3. <u>Microstructure</u>: Scattering centres include internal surfaces in liquids due largely to density fluctuations, and micro structural defects in solids such as grains, grain boundaries, and microscopic pores.

"In the process of light scattering, the most critical factor is the length scale of any or all of these structural features relative to the wavelength of the light being scattered."

General Process:-

- When light passes through a substance or gas, a part of it is absorbed and the rest scattered away.
- The basic process in scattering is absorption of light by the molecules followed by re-radiation in different directions.
- The strength of scattering can be measured by the loss of energy in the light beam as it passes through the medium.
- In absorption the light energy is converted into the internal energy of the medium and in scattering the light energy is radiated in other directions.

Note :-

"The strength of scattering depends on the size of the particle causing the scattering and the wavelength of light."

Types Of Scattering Tyndall Scattering Mie Scattering Brillouin Scattering Raman Scattering

Rayleigh Scattering

Tyndall Scattering

"The **Tyndall effect**, also known as **Tyndall scattering**, is light scattering by particles in a colloid or particles in a fine suspension."

- It is named after the 19th century physicist <u>John</u> <u>Tyndall</u>.
- In this, the intensity of the scattered light depends on the <u>fourth power</u> of the frequency, so blue light is scattered much more strongly than red light.
- Under the Tyndall effect, <u>the longer-wavelength</u> <u>light is more transmitted</u> while the <u>shorter-</u> <u>wavelength</u> light is more <u>reflected</u> via scattering.

- The Tyndall effect is seen when lightscattering particulate-matter is <u>dispersed</u> in a light-transmitting medium, when the crosssection of an individual particulate is the range of roughly <u>between 40 and 900</u> <u>nanometres</u>, i.e., somewhat below or near the wavelength of <u>visible light</u> (400–750 nanometres).
- The Tyndall effect is commercially exploited to determine the size and density of particles in aerosols and other colloidal matter.

Diagrammatic Representation





Mie Scattering

- Mie scattering is a broad class of scattering of light by spherical particles of any diameter.
- The scattering intensity is generally <u>not strongly</u> <u>dependent on the wavelength</u>, but is sensitive to the particle size.
- Mie scattering coincides with Rayleigh scattering in the special case where the <u>diameter of the</u> <u>particles is much smaller than the wavelength of</u> <u>the light</u>; in this limit, however, the shape of the particles no longer matters.
- Mie scattering intensity for large particles is proportional to the square of the particle diameter.

Mie Scattering Codes

- Mie solutions are implemented in a number of codes written in different computer languages such as <u>Fortran</u>, <u>Matlab</u>, <u>Mathematica</u>.
- These solutions are in terms of infinite series and include calculation of scattering phase function, extinction, scattering, and absorption efficiencies, and other parameters such as asymmetry of parameter or radiation torque.
- Current usage of "Mie solution" indicate series approximation to solution of Maxwell's equations.
- There are several known objects which allow such a solution: spheres, concentric spheres, infinite cylinders, cluster of spheres and cluster of cylinders, there are also known series solutions for scattering on ellipsoidal particles.

Diagrammatic representation:-

Rayleigh

Rayleigh Scattering



Mie Scattering

From overhead, the Bayleigh scattering is dominant, the Mie scattered intensity being projected forward. Since Bayleigh scattering strongly favors short wavelengths, we see a blue sky.

When there is large particulate matter in the air, the forward lobe of Mie scattering is dominant. Since it is not very wavelength dependent, we see a white glare around the sun.

viie

Observer

Brillouin Scattering

 Brillouin scattering, named after Léon Brillouin, occurs when light in a medium (such as air, water or a crystal) interacts with time-dependent optical density variations and changes its energy

(frequency) and path. Brillouin



• The density variations may be due to acoustic modes, such as phonons, magnetic modes, such as magnons, or temperature gradients.

Mechanism

- From a quantum perspective, Brillouin scattering is an interaction between an electromagnetic wave and a density wave (photonphonon scattering), magnetic spin wave (photon-magnon scattering), or other low frequency quasiparticle.
- The scattering is inelastic: the photon may lose energy to create a quasiparticle (Stokes process) or gain energy by destroying one (anti-Stokes process). This shift in photon frequency, known as the <u>Brillouin shift</u>.
- This is equal to the energy of the interacting phonon or magnon and thus Brillouin scattering can be used to measure phonon or magnon energies.
- The Brillouin shift is commonly measured by the use of a Brillouin spectrometer, based on a Fabry–Pérot interferometer.

Comparison:-



Raman Scattering

 "Raman scattering is another form of inelastic light scattering, but instead of scattering from acoustic phonons, as in Brillouin scattering, the light interacts with optical phonons, which are predominantly intra-molecular vibrations and rotations with energies larger than acoustic phonons."



 Raman scattering may therefore be used to determine chemical composition and molecular structure.

 Since most Raman lines are stronger than Brillouin lines, and have higher energies, standard spectrometers using scanning monochromators may be used to measure them.

 Raman spectrometers are standard equipment in many chemical laboratories.

Application:-

- Raman spectroscopy employs the Raman effect for materials analysis. The spectrum of the Raman-scattered light depends on the molecular constituents present and their state, allowing the spectrum to be used for material identification and analysis. Raman spectroscopy is used to analyze a wide range of materials, including gases, liquids, and solids. Highly complex materials such as biological organisms and human tissue can also be analyzed by Raman spectroscopy.
- For solid materials, Raman scattering is used as a tool to detect high-frequency phonon and magnon excitations.
- Raman lidar is used in atmospheric physics to measure the atmospheric extinction coefficient and the water vapour vertical distribution.
- Stimulated Raman transitions are also widely used for manipulating a trapped ion's energy levels, and thus basis qubit states.
- Raman amplification is used in optical amplifiers.

Rayleigh Scattering

- Rayleigh scattering is the elastic scattering of light by molecules and particulate matter much smaller than the wavelength of the incident light.
- The particles may be individual atoms or molecules. It can occur when light travels through transparent solids and liquids, but is most prominently seen in gases.
- Rayleigh scattering intensity has a very strong dependence on the size of the particles.

• NOTE:-

- "It is proportional the sixth power of the diameter of the particle."
- "It is inversely proportional to the fourth power of the wavelength of light."
- This type of scattering is therefore responsible for the blue color of the sky during the day and the orange colors during sunrise and sunset. Rayleigh scattering is the main cause of signal loss in optical fibres.



