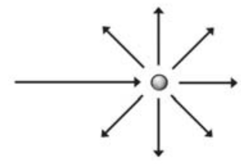
SCATTERING AND POLARIZATION OF LIGHT

Scattering of light

When a parallel beam of light passes through a gas, a part of it appears in directions other than the incident direction. This phenomena is called scattering of light.

Following phenomena happen in daily life due to scattering of light.

- Blue colour of the sky
- Red sky and sun on the time of Sunset or Sunrise
- White colour of clouds
- Tyndall Effect



Rayleigh's Law of scattering

Strength of scattering depends on

1) Wavelength of light
2) Size of particles causing scattering

If particle size < wavelength of light

$$\text{Intensity of scattered wave } \propto \frac{1}{\lambda^4}$$

The amplitude of the scattered wave is given by,

$$a = \frac{AV}{r\lambda^2}$$

Where,

A = Amplitude of the incident light,

V = Volume of the particle,

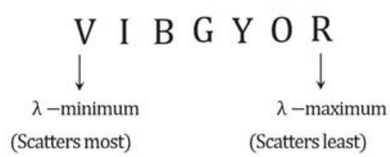
r = Distance of the observer from the particle from which light is scattered,

λ = Wavelength of the incident light

Thus, intensity of scattered light,

$$I' \propto a^2 \Rightarrow I' \propto \frac{1}{\lambda^4}$$

According to the law, the light having least wavelength will be scattered most and vice-versa.



Since red light is least scattered, we use it for signalling purpose.

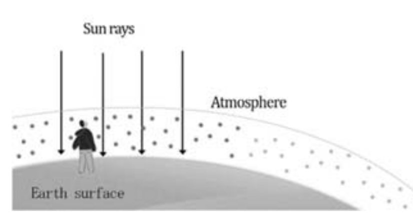
If the size of the particle causing the scattering is greater than the wavelength of the incident wave, then it is assumed that all the wavelength is scattered by almost same amount.

Why clouds appear white?

Because the size of the particles present in the clouds >> the wavelength of incident light, the scattering is same for every colour. Hence, clouds appear white.

The scattering of light can explain these two phenomena.

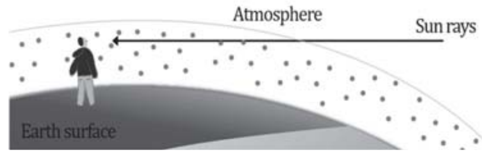
Why sky appears blue ?



The Earth's atmosphere has a huge amount of dust particles and gas molecules. During daylight, the sun rays makes near normal incidence on Earth's surface and according to Rayleigh's law of scattering, we know that shorter wavelength scattered more than any other wavelength. Blue has very less wavelength and also more sensitive to our eye. Hence, blue light will be more visible to our eye than any other shorter wavelength. This is the reason sky appears blue.

Why sun appears red during sunset or sunrise ?

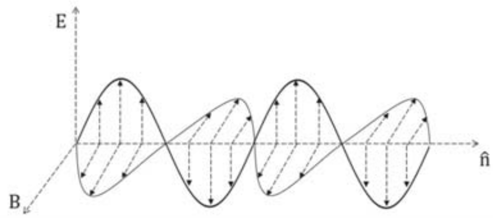
During sunrise or sunset, the sun stays near horizon. Thus, sun rays need to travel longer path in atmosphere. During this path, most of the light which has shorter wavelength gets scattered and doesn't get a chance to reach to us. But, the light which has longer wavelength (red or orange part of visible spectrum) gets scattered less and reaches to us. This is the reason behind the appearance of sun as red during sunrise and sunset.



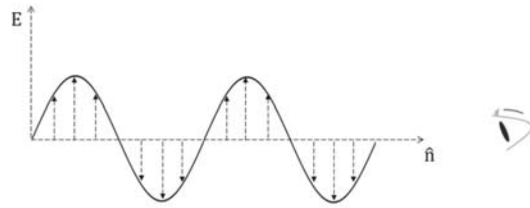
Polarisation

Light is a transverse wave.

Vibrations of both electric field and magnetic field is perpendicular to direction of propagation. Since the ratio of the amplitude of electric field to the magnetic field is $\frac{E_0}{B_0} = c$, we can say that the electric field is dominant over magnetic field.

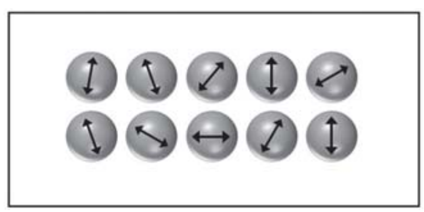


If the light wave is coming out the plane of the paper, then there is infinite number of possible direction for electric field to oscillate as shown in the figure. This is known as "Unpolarized light". If electric field of the light at a point always remains parallel to a fixed direction as time passes, the light is said to be "Polarized light".



Polarized and unpolarized light

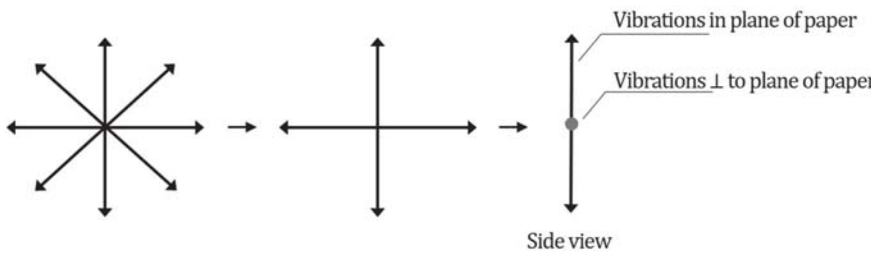
General sources of unpolarized light:



In these sources, electromagnetic waves are generated by atoms that are excited, and since different atoms can have varying electric field directions, the light they emit becomes unpolarized.

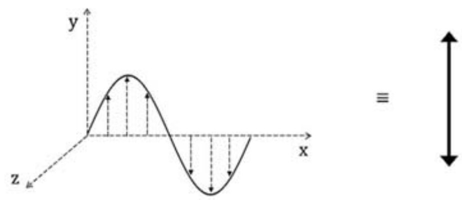
Unpolarized light

Light in which resultant electric field keeps on changing direction randomly and rapidly.



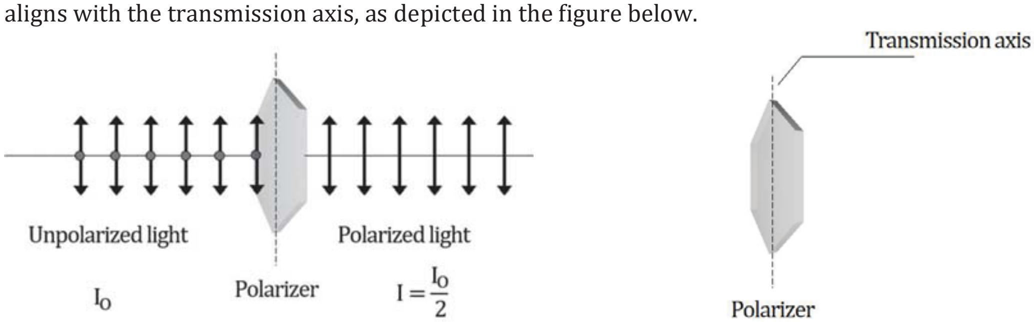
Plane Polarized light
If electric field at a point always remains parallel to a fixed direction as time passes.

Plane of polarization
Plane containing electric field and direction of propagation.



In this scenario, the electric field moves up and down along the y-axis, while the wave travels forward along the x-axis. Therefore, the polarization plane will be the xy plane.

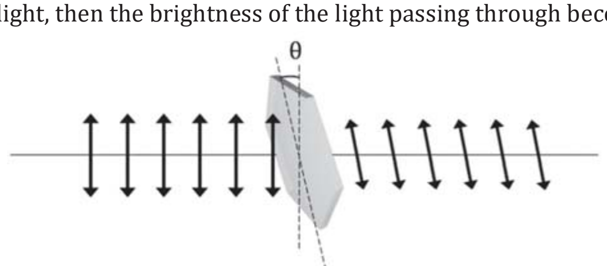
How do we get polarized light ?
By placing a polarizer in the path of unpolarized light, we can polarize the light. When the polarizer is inserted into the path of the unpolarized light, the direction of the electric field's oscillation aligns with the transmission axis, as depicted in the figure below.



If an unpolarised light of intensity I_0 is incident on a polarizer, we get a polarized light of intensity $\frac{I_0}{2}$.

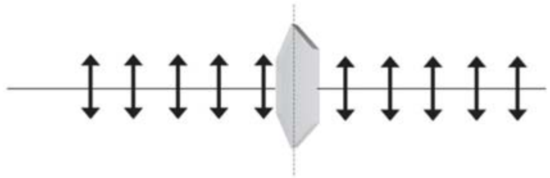
Law of Malus

If a polarized light with an initial brightness of I_0 travels through a polarizer where the transmission direction is angled at θ compared to the electric field's oscillation direction of the incoming polarized light, then the brightness of the light passing through becomes.



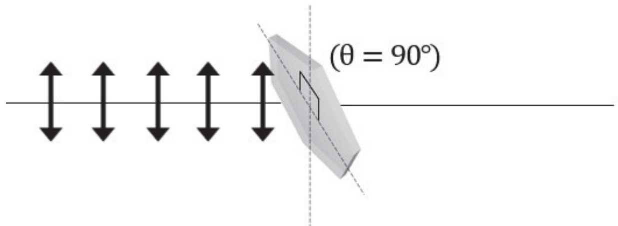
$$I = I_0 \cos^2 \theta$$

I = Intensity of transmitted light
I_0 = Intensity of incident light



E parallel to transmission axis ($\theta = 0°$)

$$I = I_0 \cos^2 0° = I_0$$



$E \perp$ to transmission axis ($\theta = 90°$)

$$\begin{aligned} I &= I_0 \cos^2 90° \\ &= 0 \end{aligned}$$