# Quantum (Photon) Theory of Dispersion

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**Abstract:** ***When white light beam falls on a prism, the emergent light consists of different colors. According to Wave Theory, the separation of different colors present in white light is because of different deviations suffered by them, when they pass through a prism. The wavelength of different colors is different. Red color has maximum wavelength and violet color has minimum wavelength i.e. $\lambda_r$ is greater than $\lambda_v$. Therefore, Refractive index for red color is less than that of violet color, as per Cauchy's formula. So the speed of red color is more than violet in denser medium. But this is not true; the speed of all colors remains same (c) inside the crystal. When light enters the denser medium, the photons are being absorbed & emitted continuously. The speed of photon between two consecutive absorption and emission is $3 \times 10^8 \frac{m}{s}$, but due to difference in number of absorption and emission of various colors (photons) by atoms, they spent different times inside the crystal. According to this Quantum theory, massive photon suffers more absorption and emission. Due to this they spent more time inside the transparent medium and also deviates more. In every absorption and emission process, they suffer unit deviation. Therefore, violet deviates more than red photon.***

**Keywords:** Refractive index, deviation, emission, absorption, wavelength

## 1. Introduction

Dispersion of light: - The phenomenon of splitting of white light into its constituent colors is called dispersion of light. When white light beam falls on a prism, the emergent light consists of different colors i.e., Violet, Indigo, Blue, Green, Yellow, Orange and Red which are constituent colors of white light. These constituent colors may be remembered as VIBGYOR. The arrangement of constituent colors of white light forms the visible spectrum, when white light is dispersed through prism.

Cause of Dispersion of Light: - The separation of different colors present in white light is because of different deviations suffered by them, when they pass through a prism because refractive index of a medium is different for different colors. According to wave optics $\mu = \frac{c}{v}$, and $\mu_v$ is greater than $\mu_r$, so the velocity of red light is more than velocity of violet light, so the cause of dispersion is change in velocity of different colors in dispersive medium.

According to Cauchy's formula, $\mu = A + \frac{B}{\lambda^2} + \ldots$.. where A, B are constants and λ is the wavelength of light. This relation shows that the refractive index of material or medium depends upon wavelength or color of the light incident on it. The wavelength of different colors is different. Red color has maximum wavelength and violet color has minimum wavelength i.e. $\lambda_r$ is greater than $\lambda_v$. Therefore, Refractive index for red color is less than that of violet color. So the speed of red color is more than violet in denser medium.

Now deviation produced by small angled prism is given by

$$\delta = (\mu - 1)\, A$$

$$\delta_r = (\mu_r - 1)\, A$$

$$\delta_v = (\mu_v - 1)\, A$$

Hence $\delta_r$ is less than $\delta_v$. This shows that the red color deviates least and violet color deviates the most. Thus, violet color is seen at the bottom and the red color is seen at the top of the spectrum of white light. The other colors suffer deviation in between the red and violet color.

### 1.1 Angular Dispersion

It is defined as the difference in the deviations suffered by the two extreme colors in passing through the prism. It is denoted by θ and is given by,

$$\theta = \delta_v - \delta_r \qquad \ldots\ldots\ldots.1$$

The deviation produced by small angled prism is given by

$$\delta = (\mu - 1)\, A$$

For red color, $\mu = \mu_r$

So $\delta_r = (\mu_r - 1)\, A$

For violet color, $\mu = \mu_v$

So $\delta_v = (\mu_r - 1)\, A$

Putting the values of $\delta_r$ and $\delta_v$ in equation 1, we get

$$\theta = (\mu_v - 1)\, A - (\mu_r - 1)\, A$$

$$\theta = (\mu_v - \mu_r)\, A$$

This is the expression for Angular Dispersion.

### 1.2 Dispersive power

**1.** Dispersive power of the material is its ability to disperse the constituent colors of incident light. Dispersive power is equal to the ratio of angular dispersion to the mean deviation produced by prism.

It is denoted by ω and is given by

$$\omega = \frac{\theta}{\delta} = \frac{\delta_v - \delta_r}{\delta}$$

Here mean deviation $\delta$ means the deviation suffered by the yellow light.

**2**. According to wave optics when light goes from rarer to denser medium, the velocity of light changes due to change in wavelength but frequency & energy remain same. On applying de- Broglie hypothesis $\lambda = \frac{h}{mc}$, we have to say that this decrease in wavelength is due to increase in velocity, as on increasing mass, energy and frequency will increase, which is not possible according to wave optics. So the explanation of decrease in wavelength is only due to increase in velocity of photon, which contradicts Special theory of relativity as well as Foucault's experiment etc.

Let us consider a red light (λ =750 nm) enters in a denser medium whose refractive index μ = 1.19, due to this the wavelength of light changes from 750 nm to 630 nm. But 630 nm is the wavelength of orange light. So the question is, inside the denser medium, whether the light is red or orange?

An example that is currently of great interest is the way the ozone layer protects us from the dangerous short wave length ultra violet part of suns spectrum. In the classical description i.e. light as a wave, when a wave passed into and back out of a medium, its frequency is unchanged and although its wave length is altered while it is in the medium, it returns to its original value when the wave emerges. Luckily for us this is not at all what ultraviolet does when it passes through ozone layer or the layer would offer any protection at all.

It has been experimentally verified that light takes longer time to pass through denser medium. Also it has been proved that, different component spent different time inside prism and deviation of different component is also different. But Wave theory, whether, it is Classical or de- Broglie's, fails to explain the cause of time elapse, when light enters into the denser medium.

## 2. Objective

1. My objective is to explain Dispersion on the basis of particle theory.
2. Second objective is to show that velocity of light is not constant in the denser medium.
3. Third aim is to show that Refractive index of medium depends also on length and time taken by photon to cross the denser medium.

## 3. Quantum Theory of Dispersion

### 3.1 Theory

Let us consider a photon is incident on a denser medium. Suppose the incident photon of energy hν interacts with an atom having kinetic energy $\frac{1}{2}mv^2$ and intrinsic energy E. After interaction, the photon is being absorbed by the atom and let $v_1$will be the velocity of atom and its intrinsic energy will becomes $E_1$.

Then according to law of conservation of energy

$$h\nu + \frac{1}{2}mv^2 + E = 0 + \frac{1}{2}m{v_1}^2 + E_1$$

Since there is no change in temperature during absorption, there is no change in kinetic energy.

So $$\frac{1}{2}mv^2 = \frac{1}{2}m{v_1}^2$$

Hence $$h\nu + E = E_1$$
$$E_1 = h\nu + E$$

Now $$E_1 - E = h\nu$$

Here $E_1$ is energy of excited state. The excited state atom emits a photon of same energy as was absorbed by it and comes to its ground state. Due to this time elapse photon takes longer time to pass through the medium. This does not means that the velocity of photon inside denser medium is less than c, but it is equal to c, due to time elapse in absorption and emission, photon takes longer time to pass through denser medium. When light enters the denser medium, the photons are being absorbed and emitted continuously. The speed of photon between two consecutive absorption and emission is equal to $3 \times 10^8 \frac{m}{s}$.

### 3.2 Refractive Index

According to wave optics, the refractive index of a medium is given by $\mu = \frac{c}{v}$, where 'v' is the constant velocity of light in denser medium. If we consider glass medium, then according to wave optics, the constant velocity of light inside glass is, $v = 2 \times 10^8 \frac{m}{s}$. But if we consider particle nature of light and consider photon as a particle of light, velocity of photon does not remain constant at all the point inside the crystal. Between two lattice points the velocity of photon is greater than $v = 2 \times 10^8 \frac{m}{s}$ and at the lattice point during absorption and emission, it is less than $v = 2 \times 10^8 \frac{m}{s}$. The average velocity, not constant velocity of photon in the glass is $v = 2 \times 10^8 \frac{m}{s}$. So the expression for refractive index for photon will be $\mu = \frac{c}{l}t$, where 'l' is total length path of denser medium and 't' is the total time taken to cover the length 'l'.

So the change in velocity is not due to change in wavelength of photon. So wave theory, whether it is Classical or de-Broglie's fails to explains the cause of average velocity of photon inside denser medium, as well as, why photon take longer time to pass through denser medium, since its velocity inside it is c.

According to Einstein Mass – Energy relation $E = mc^2$, E is directly proportional to mass. Since gamma photons are more energetic than X- ray photon, so we can say that gamma photons are more massive than X- ray photon. Similarly we can say that violet photons are more massive than red photon. Due to more mass of violet photon, they suffer maximum collision and hence maximum absorption and emission by the atoms of crystal. Due to this they spent more time inside the crystal and their deviation is also more than red photon. This is the reason for splitting up white light into its constituent's color, when white light enters the glass prism.

Quantization of Deviation:

(1) When the photon goes from rarer to denser medium, there is unit deviation of photon per interaction towards the normal of incidence.
(2) When the photon goes from denser to rarer medium, there is unit deviation of photon per interaction away from the normal of incidence.

## 4. Conclusion

Main point is the time of spent of various components of light inside denser medium. Since different components of light spent different time inside denser medium, that's why they get separated from each other. This difference of time arises due to difference in number of absorption and emission of photons by atoms and time taken for absorption and emission. If there will be more absorption and emission, this will take more time and there will be more deviation. Deviation is quantized inside & outside the crystal.

According to the theory, massive photon suffers more absorption and emission. Due to this they spent more time inside the transparent medium and also deviates more. In every absorption and emission process, they suffer unit deviation. Therefore violet deviates more than red photon. In points we can summarize this as follows:

1. Wave theory fails to explain the actual cause of Dispersion.
2. Dispersion is not due to change in velocity but due to change in time, which is due to continuous absorption and emission.
3. Massive photon suffers more absorption and emission. Due to this they spent more time inside the transparent medium and also deviates more
4. The deviation is due to interaction of photon with atoms or ions of transparent crystal.
5. The deviation of photon is quantized.
6. In every absorption and emission process, photon suffers unit deviation.
7. From this research work, we can write the new formula of Refractive index of the medium, $\mu = \frac{c}{l} t$, where t is the time taken by photon to cross the denser medium and l is the length of denser medium. The previous formula of refractive index is talking about constant velocity of light in denser medium, which is 'v'. Also 'v' is not the constant velocity of light in the medium; it is the average velocity of light in the medium.

## 5. Scope

1. This work helps us to understand the particle nature of light.
2. This work helps us to understand that, refractive index of transparent medium not only depends on nature of material medium but also on length and time taken by particle to cross the denser medium.
3. This work will help the physicists to understand the refractive index of transparent medium.

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