Remote Sensing: Principles and Applications
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Lecture-05
Properties of EMR - Part 2

Hello everyone, welcome to the course Remote sensing principles and applications. And in today's lecture, we are going to continue with the properties of EMR. In the last class, we discussed two important properties of electromagnetic radiation.

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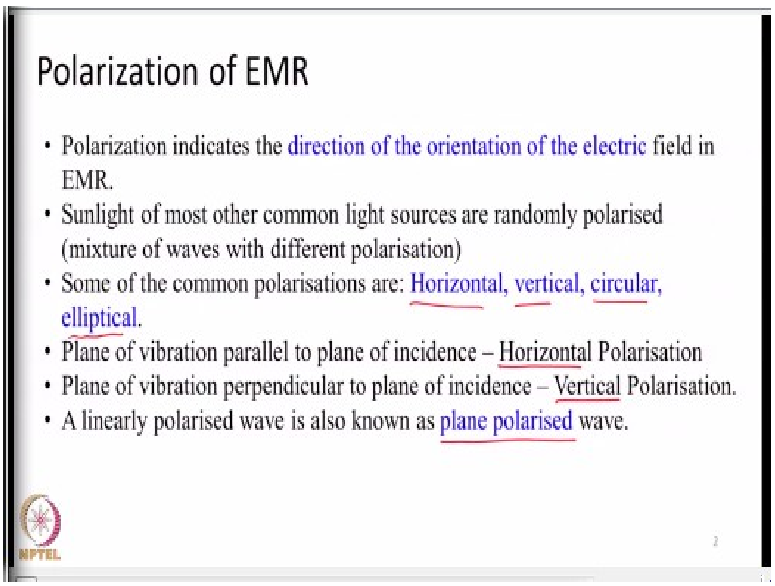

One is polarization which indicates the orientation of the electric field within the electromagnetic radiation. So, based on the orientation of electric field with respect to the plane of incidence, we can classify the polarization as horizontal, vertical or even circular. I also explained you that based on the polarization the amount of incoming energy will vary. That is the total energy coming in will be having different, different polarizations.

And by limiting our view to any one type of polarization will actually limit the total energy that is reaching us. And it has major implications in how objects interact with EMR especially in the microwave regions. In microwave regions when we do remote sensing, we will be more interested about understanding the polarization behavior of the materials also.

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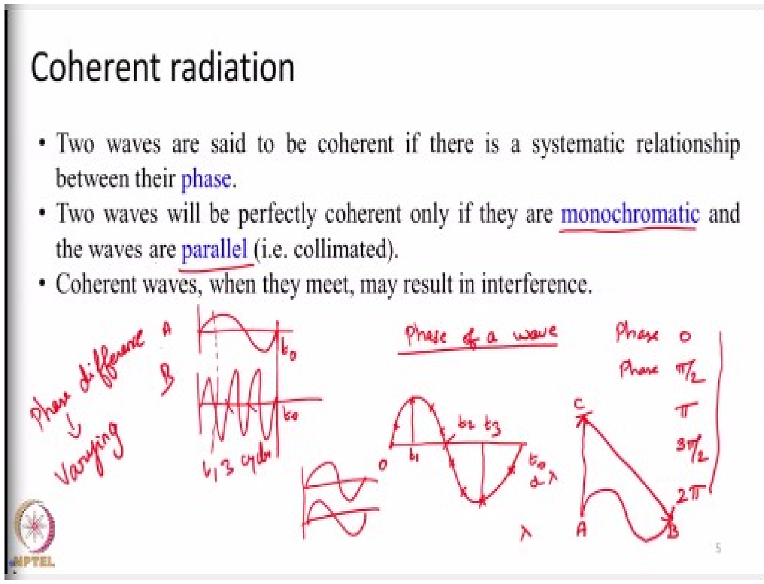
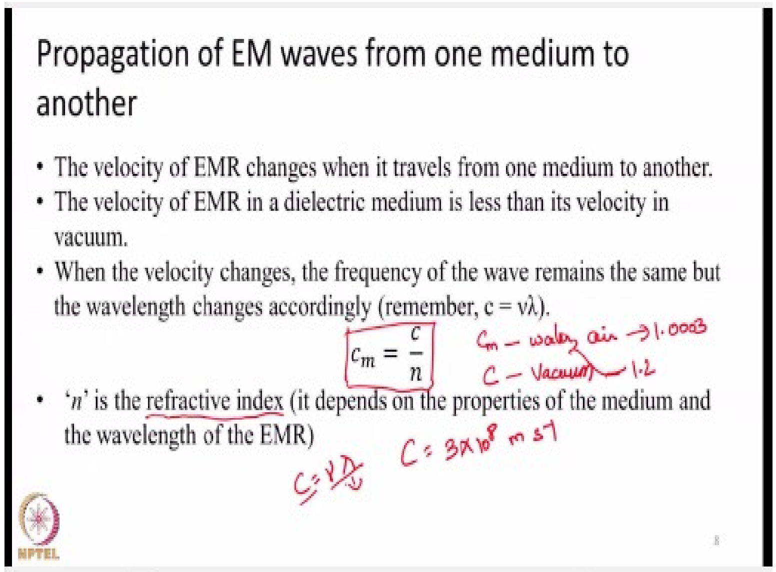


So, the next important property of electromagnetic radiation that we looked upon is coherent radiation. So, coherency is defined as whether the electromagnetic radiation has a systematic phase relationship between them. When 2 waves are progressing if they have a systematic relationship between them, we call them as coherent or non coherent based on that. So, if 2 waves are coherent, then and if they are superimposed on top of each other, they will produce interference, that is their amplitudes will add up.

And if those two coherent waves are in phase, the amplitude of the resultant wave will be higher than the amplitude of the individual wave components, this we call constructive interference. On the other hand if the amplitude of the resultant wave decreases after the superposition of two waves, we call it as destructive interference. Destructive interference will happen when the 2 waves that are meeting together or out of phase or like not in phase with each other. So, they will be kind of cancelling out each other when they add up.

Today we are going to continue on seeing different properties of electromagnetic radiation. One of the major change that will happen when electromagnetic radiation travels from one medium to another medium is the change in velocity of the EMR. **(Refer Slide Time: 02:52)**



Here medium I mean is like whether it is travelling through air or travelling through vacuum or travelling through some other materials like water and so on. So, the medium through which electromagnetic radiation travels will influence the velocity of the electromagnetic radiation. That is when the medium's density increases, naturally the velocity of electromagnetic radiation within that particular denser medium will lower.

Actually that is given here in this slide, here I denoted as c_m where c_m is the velocity of electromagnetic radiation in the particular medium. Say for example, water or air whatever and c is the velocity of electromagnetic radiation in vacuum. So, we all know that c roughly equals to 3×10^8 m/s. And when it travels through another medium, depends on the medium's refractive index the velocity will change.

So, refractive index is, how much the light ray will bend or how much the medium will bend the light ray when travelling through it? It is roughly the refractive index. So, based on the refractive index of the medium, the velocity will change correspondingly. That is if the refractive index of medium is higher than the refractive index of vacuum, then the velocity in the medium will go down.

Say the velocity in air is or the refractive index in air is roughly about 1.003 or something and for water it will be around like 1.1, 1.2 something of that sort, and refractive index of vacuum is 1.

So, if you substitute in this equation, we can observe that the velocity of EMR travelling through water or air is less than the velocity of EMR in a vacuum. So, we also know the relationship that $c = \nu\lambda$. So, when velocity changes, this relationship will change, so how it will change? The wavelength of the medium will change but the frequency will be preserved. That is, when EMR travels between one medium to another medium, the wavelength will change according to the change in velocity. On the other hand the frequency will remain constant, it will not change.

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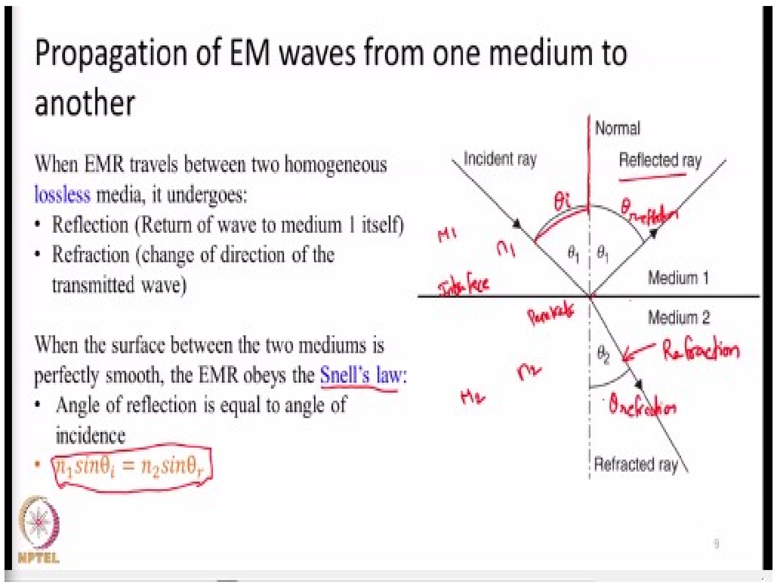

Also when EMR travels from one medium to another medium, it will undergo different processes. From the figure, this is medium 1 air, this is medium 2 a waterbody and this is the interface between the two mediums, say EMR is travelling from air to water. When EMR is incident, it will be first partially reflected as if like a mirror reflects any objects and it will reflect the EMR in any direction. And also if the object is transparent or translucent then the EMR will penetrate that particular second medium. And by virtue of difference in refractive indices, the EMR will undergo what is known as refraction.

So, two things will happen when EMR travels from one medium to another medium. Like first thing I said velocity will change, that is one thing. Second thing is from the surface that acts as interface between the two mediums, part of incoming radiation will be reflected back. Similarly some portion of EMR will penetrate through the second medium and based on the refractive indices between the two mediums, the path in which the light ray travelled will differ, will vary.

Say the incident ray here in this slide travel in this particular direction. By virtue of difference in the refractive indices of medium 2 it actually encountered a slight bend like its direction will change. So, the EMR will undergo reflection as well as refraction. If the surface acting as a interface between the two mediums are smooth and also the mediums are non lossy, (non lossy in the sense energy coming in is like preserved while passing through the medium) then what will happen is? they will obey Snell's law. That is, if the surface between the two medium is perfectly smooth, the EMR will obey Snell's law which is defined as the angle of incidence is equal to the angle of reflection.

So, here the angles are measured with respect to the normal to the surface, this is the surface separating the two mediums. So, the angle with which EMR is reflected will be equal to the angle at which it was first incident on the surface. This will be obeyed if the surface is perfectly smooth. Also in relation to refraction this law also will be obeyed, that is

$$n_1 \sin\theta_i = n_2 \sin\theta_r$$

Where n_1 and n_2 are the refractive indices of the two mediums and θ_i is angle of incidence, θ_r here is angle of refraction. Like how much the ray is bent actually.

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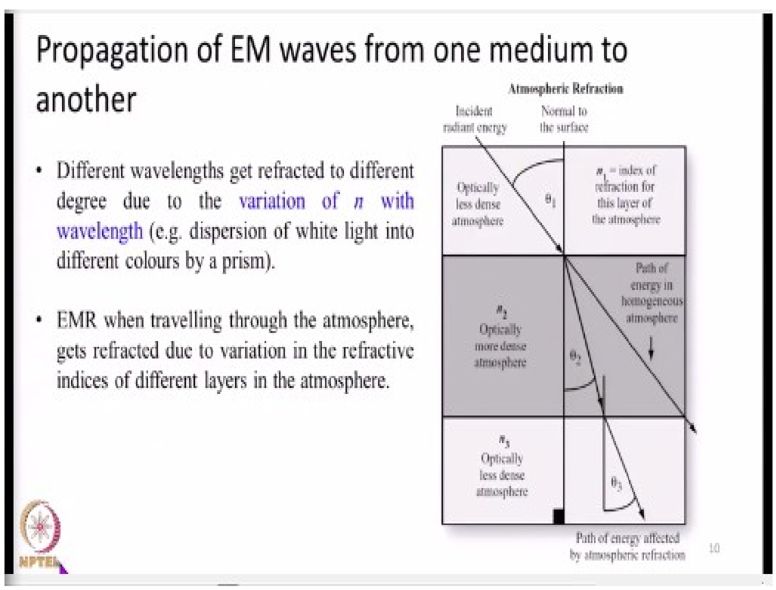

What is the implication of this refraction of EMR? Actually our atmosphere consists of multiple layers, like different, different layers have different, different constituents at various temperatures at different densities and hence the refractive indices also will vary. So, there are several layers within the atmosphere and also after travelling through atmosphere, the EMR will reach the earth surface.

So, while travelling through atmosphere and also when reaching the earth surface, EMR will undergo refraction several times by passing through mediums with different refractive indices. If the medium say medium 2 has a higher refractive index than medium 1 then light ray will be bent towards the normal. Or on the other hand if medium 2 has lower refractive index, then the light ray will be bent away from the normal. Like this light tray will be travelling in different, different directions, when it travels through mediums with different refractive indices.

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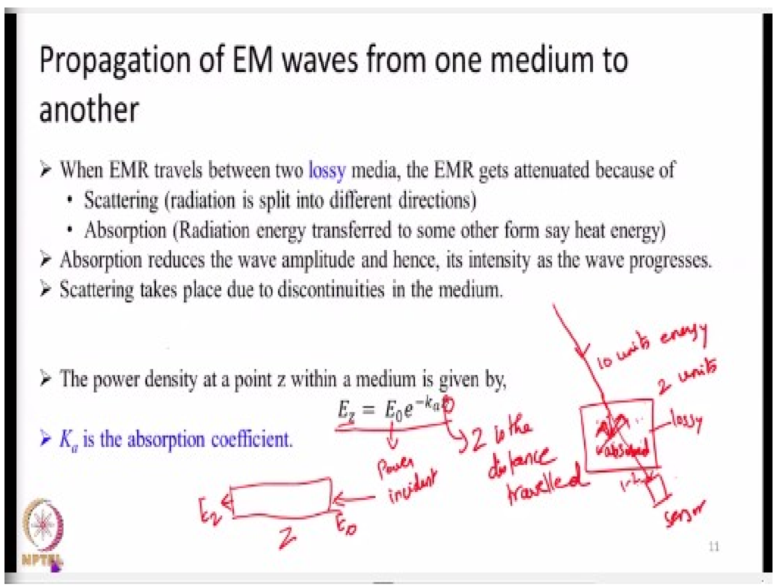

While discussing reflection and refraction, I said we are not going to care over the energy loss. We assume two mediums through which EMR passing is lossless, non lossy medium. But most of the mediums through which EMR passes on the earth surface is actually lossy. Loss in the sense when some units of energy enters one medium and when it emerges out of the medium the energy will be reduced by a certain factor.

We call such mediums in which energy is lost actually or lossy mediums. Atmosphere, earth surface features, almost everything are lossy medium. When EMR interacts with them some part of EMR will be lost from it. So, how this actually happens? Why EMR is actually lost? EMR energy is lost primarily due to two processes, one is known as scattering and another one is known as absorption.

So, absorption, we all know like whenever some energy is incident on any material, the molecules inside the material will be using up that energy to do some work. Like the molecules will undergo some sort of rotation or orientation change or they may heat up increasing the temperature of object, anything can happen. So, that particular energy which is incident on object is actually used by the molecules within the object, this is known as absorption.

On the other hand scattering means, the incoming energy rather than being passed as such will be split into different, different directions. Say when energy is coming in this particular direction and some medium is there, let us say, the medium is full of some sort of molecules. So, when it is incident on it, if it is a lossy medium, then some portion of it will be absorbed that is used up by the molecules within the medium and some portions will be scattered in different direction, so what essentially happen?

Let us assume some 10 units of energy is coming in and some observer is waiting here to receive the energy, like some sensor is placed here to receive the energy. And this electromagnetic radiation is passing through this medium, when it comes out of it, let us say like two units is absorbed, so we will be expecting eight units here. But that eight units also will be now scattered in different, different directions, now it will be reflected in multiple directions maybe leaving only one or two units coming out in this particular direction. So, the sensor will receive actually much lesser energy than what is anticipated. So, essentially absorption is the energy being used up by the object itself or the medium itself whereas scattering is that the energy coming in one particular direction is now split into several directions.

Hence that particular energy is lost in the direction in which we are expecting it. If we keep a sensor on the other side and waiting to measure the energy, we will be receiving much less energy than what was anticipated. This is scattering. So, actually there are very simple relationships between the incident energy and energy coming out so as to calculate how much is the absorption taking place.

Normally in remote sensing, we would not be looking at scattering separately, absorption separately. Like whenever energy is lost it will be due to both of these components together, if we take both of these components together, we call them as attenuation or extinction.

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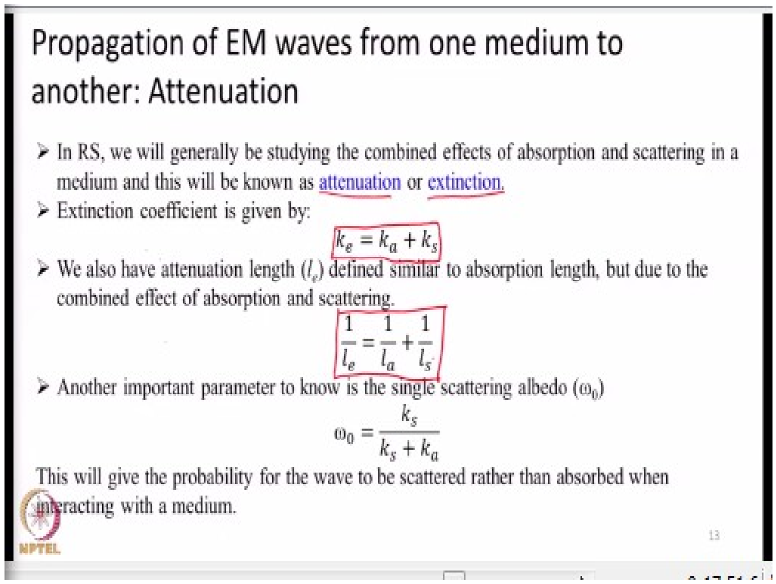

So, what is attenuation or extinction that is the total amount of energy that is lost. So, there is like a general small equation relating the power incident on an object and the power that has been coming out of an object. So, the equation will take a form like this

$$E_z = E_0 e^{-k_a z}$$

where E_0 is the power incident on the particular medium, z is the distance travelled within the medium and E_z is the power of the EMR that is actually present after travelling through the medium. So if this is like a medium, EMR is coming in like this, it travels a distance of z and it is emerging out here. So, here we measure the incoming power as E_0, here the power is E_z. So, this relationship $E_z = E_0 e^{-k_a z}$ is the simple equation relating the incoming power with the emerging power, after it travel through certain distance in the medium.

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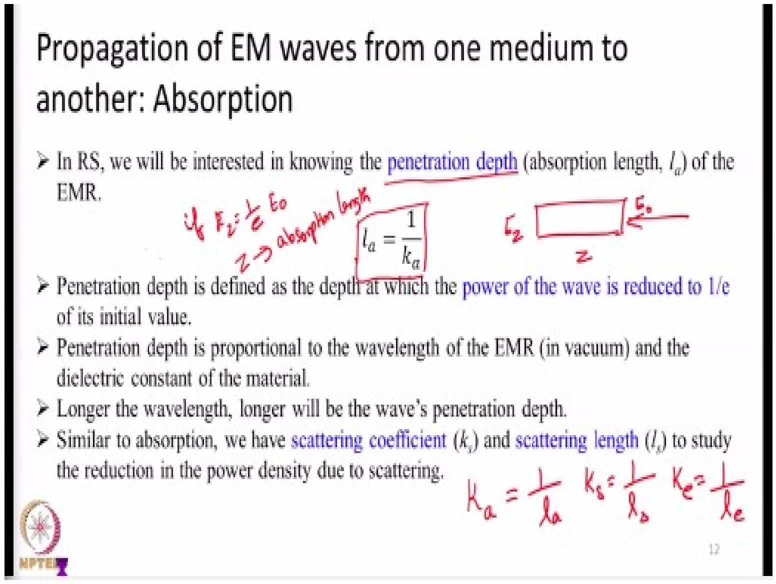

k is called absorption coefficient if we consider only absorption and it will be called scattering coefficient if we consider only scattering. Or if we consider both of them together it will be called attenuation coefficient.

For us to understand attenuation coefficient, first we will understand what is known as a penetration depth. So, a penetration depth or absorption depth whatever we can call, is defined as the particular distance through which EMR has to travel within a medium such that the final power will be one E of the power that entered into the medium. For example if this is one particular medium, EMR is entering through this particular direction with a power of E_0, the total length of the medium is z, the power we receive out is E_z. So if $E_z = (1/e)E_0$ then we call z as absorption length or penetration depth in general. That is the power that is entering a medium will become one E of the power that is emerging out, ok. So, this is called penetration depth or absorption length.

So, the coefficient either the absorption coefficient or attenuation coefficient by considering whatever processes we take into account is defined as,

$$k_a = \frac{1}{l_a}$$

And scattering coefficient is,

$$k_s = \frac{1}{l_s}$$

Or if we take both of them together we call it as extinction coefficient, that will be,

$$k_e = \frac{1}{l_e}$$

And also the extinction coefficient is equal to absorption coefficient plus scattering coefficient.

$$k_e = k_a + k_s$$

and the attenuation length can be written as,

$$\frac{1}{l_e} = \frac{1}{l_a} + \frac{1}{l_s}$$

So, these are some of the relationships which will help us to know what is the amount of absorption that is taking place in the medium or scattering total losses taking place within a medium.

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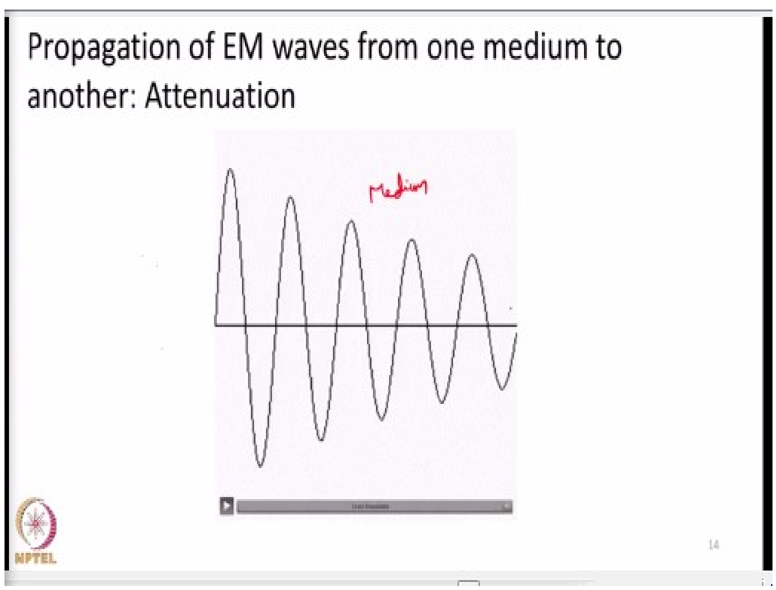

So, this is like a schematic representation of attenuation. Like some medium is present here, when EMR passes through a medium its amplitude will be going down. And finally it may also be totally absorbed within the medium. So, its amplitude will be reducing and hence its total energy content will be reducing.

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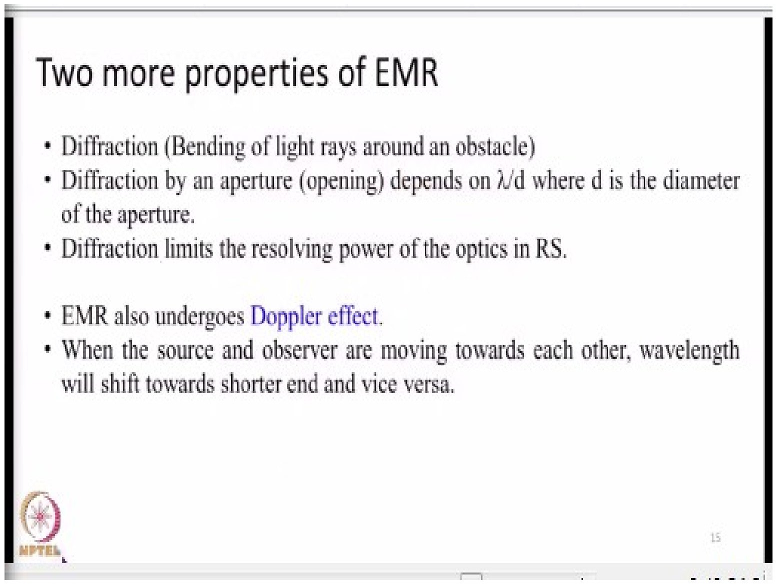

When EMR find some obstacles on its path rather than being completely stopped with obstacle, it has the property of bending around the edges of the obstacle. Like in our school physics labs we might have done experiments with prism where we try to split white light into seven different colors which we called as diffraction by a prism. So this explains how light ray is bent around the edges of some obstacles within there.

So, whenever it encounters like a lens, around the lens border it will be like bending at some angles. The angle at which the light ray is bent depends on the medium and also on the wavelength. Similarly when there is a relative motion between the source and observer that is they are moving towards each other or moving away from each other, there will be an apparent shift in the wavelength of the EMR as observed by the observer, this is known as Doppler effect. Like Doppler effect we might have heard in sound, that is there will be a change in frequency of the sound. We should have studied this in school, like that EMR also will undergo such Doppler effect.

This kind of Doppler effect is used mostly in astronomy to study about stars because like earth is in continuous motion, stars are also in motion. Due to this relative motion between the source and the observer, the wavelength observed by the observer will be different from what is originally coming in. But this means the wavelength will not change actually, the observer will perceive as it is, that is why we call it as an apparent change, there will be like an apparent change.

So, maybe just few important points I have given here. So, when the source and observer are moving towards each other, the wavelength will shift towards shorter end. Shorter end means it will become a shorter wavelength. Say for example some object is emitting like red light and that particular object is moving towards the observer, then the observer may perceive that particular object in a different color with shorter wavelength maybe green or blue or whatever. This depends on the relative velocity between them but this is only apparent, it is not the actual change.

So, with this we complete the lecture on the basic introduction to the properties of EMR. In the properties of EMR, we studied about polarization, coherency and also we studied about reflection, refraction, and what sort of losses will occur? Like scattering and absorption, all the things I introduced to you very briefly. For your deeper understanding we will talk about them more in detail in the coming lectures, thank you very much.