Physics of Linear and Non-Linear Optical Waveguides
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Module – 02
Basic Fiber Optics
Lecture – 05
Step – Index Fiber (SIF), Light Guidance in SIF

Hello student, to the course for Physics of Linear and Non-linear Optical Waveguide. Today we have Basic Fiber Optics we will going to start basic understanding of the basic fiber optics. In today's lecture I will try to cover the concept of Step - Index Fiber and the method of Light Guidance in self then in this kind of Step Index Fiber right.

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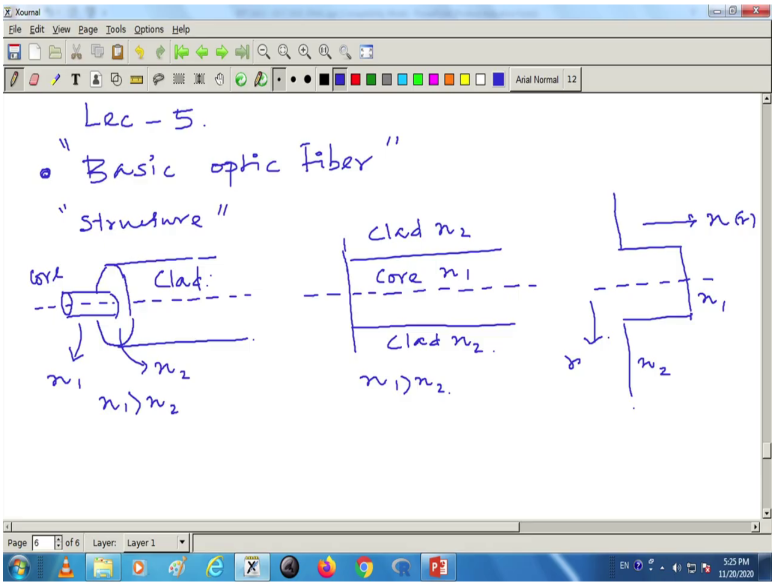

So, today we have lecture 5; so our topic is understanding of the basic properties of fiber so basic optical fiber. So, first we start with the structure of an optical fiber and the structure is precisely like this; we have all have a rough idea about the optical fiber, but still I want to give you an idea.

So, optical fiber is a cylindrical kind of structure geometrically it is a cylindrical structure and this portion have a refractive index n 1 and this portion has a refractive index n 2, where n 1 is greater than n 2 this portion is called core and this portion is called clad. So, the light is eventually; so if I make a cross section a transverse cross section I should have a structure like this, this is the transverse cross section.

So, this is the axis of the fiber, this is the core part having a refractive index n 1 and this is a cladding part refractive index n 2, this is also clad with refractive index n 2 where n 1 is greater than n 2. So, I can write this thing in this format also I can draw a refractive index profile for this structure as well. So, this is the refractive index profile and you can see along this direction we have the refractive index n which is a function of r where r is a distance from this axis to this direction.

So, for step index fiber we have a step like refractive index profile in the co region we have a refractive index n 1 and the cladding region we have a refractive index n 2. And this n 1 and n 2 there is no change in n 1 and n 2 it is a step like profile. So, mathematically if I want to write the profile; so let me write it more convenient way.

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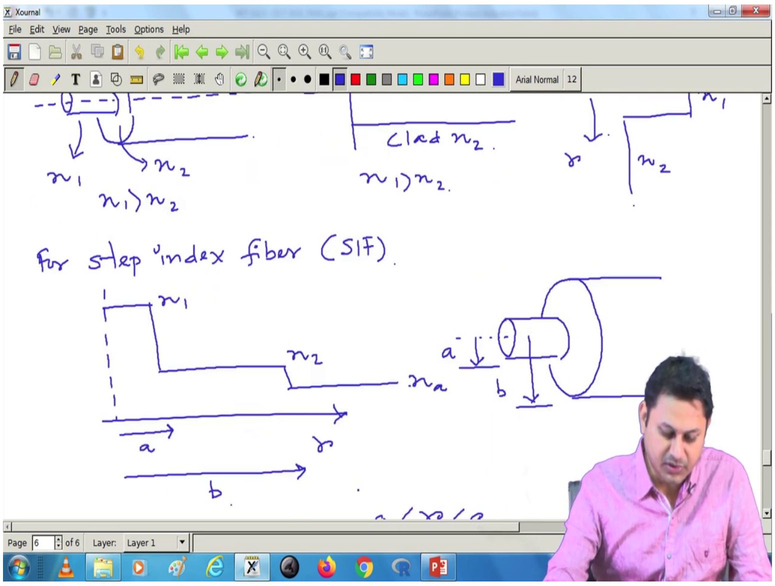

So, for step index fiber in short SIF I have this is the axis I am having, this is the r, I have a refractive index profile like this, this is refractive index of the core n 1, this is refractive index of the cladding n 2 and outside the cladding we normally have air. So, this is the refractive index of the air I write n a.

Now, if I want to write this mathematically the form of the refractive index mathematically then I need to define the distance from here to here which is the radius of the core I write it as a and then from here to here I write b this is the radius of the fiber. So, I have a structure like this is the core part and over that I have a cladding. This is the axis; so from here to here up to this it is a and from here to this length this is b.

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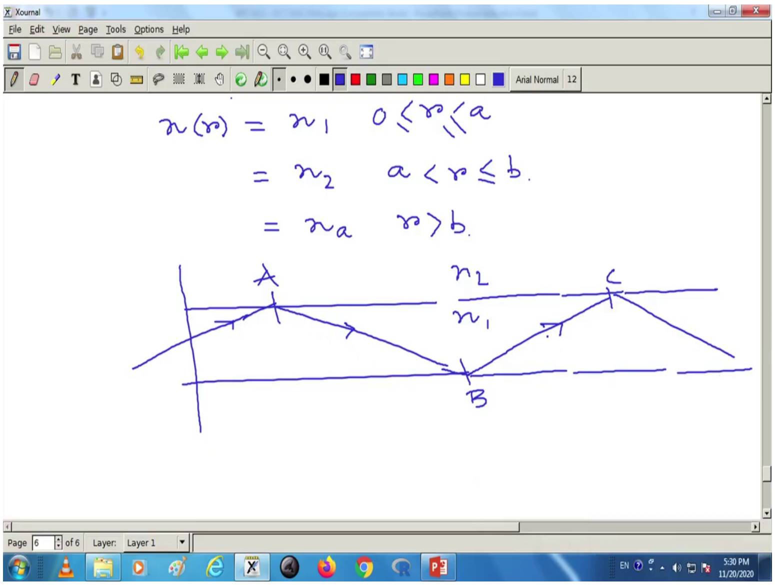

Well, mathematically refractive index n r is n 1, when r is this it should be should it should be less than because that there is a sudden jump in the refractive index this equal to n 2 I have and outside the fiber; that means, when my r is greater than b I have the refractive index of air if the fiber is placed in the air.

So, this is roughly the structure of a standard fiber step index fiber where the refractive index n 1 is the refractive index of the core which is higher than cladding. So, the light guidance is whatever we just mentioned in the class last class that; if I launch a light here then it from this interface I have n 1 n 2. So, n 1 is greater than n 2. So, I have a total internal reflection.

So, the light is guided in this fiber by multiple total internal reflections. So, here I have a one reflect reflection then I can have another reflection from this point and so on. If this is a, this is b, this is c. So, multiple total internal reflection can take place and eventually the light is guided through this structure.

Now at this point we know there are rays that is passing through the fiber and it experience multiple reflections in the core clad boundary and total internal reflection is the basic principle through which light is propagating, but there are few rays which are crossing the axis because this axis I am talking about is like that. So, this is the axis of the fiber.

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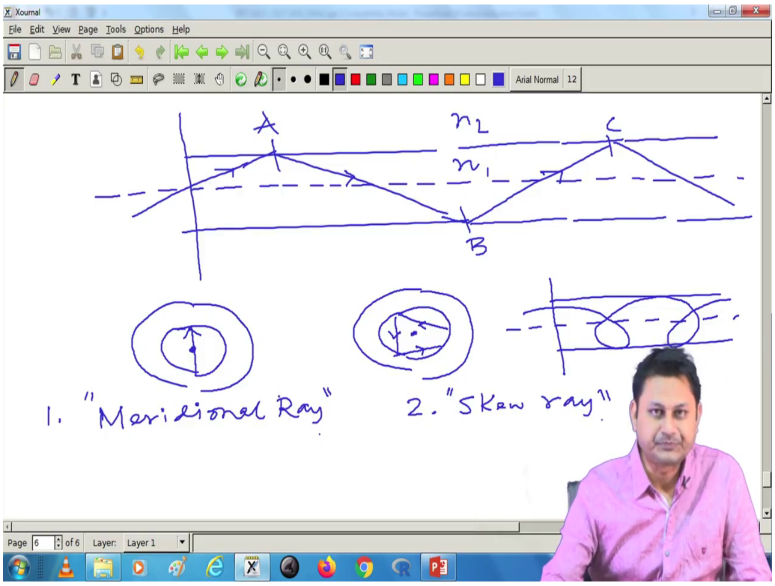

So, there are few rays which will going to cross the axis, but there are certain rays which will not going to cross the axis. So, if I draw like this is the fiber structure, the cross section this is the core and this is the clad suppose this is the. So, I have a axis here and when I launch a light it can cross this axis this is one kind of ray through which and then it takes the total internal reflection every time from this in this boundary core and cladding boundary and gradually propagate.

On the other hand there is a possibility. So, this is again a fiber structure this is my axis point an axis is now perpendicular to this plane and there is a possibility that the light will not going to cross this axis it will reflect it like this from here to here to here every time it is reflecting, but it is not crossing the axis at all. When the ray crossing the axis it is called there is a name on that it is called the Meridional Ray.

On the other hand if the light it not crossing the axis whatever the axis we have here in the fiber is called the Skew Ray. In one case it is crossing the axis every time, in other case so in this case if I try to draw for meridional ray if I try to draw it is difficult to draw in two dimension. So, it like it crosses like this. So, it never crosses this axis it hits one boundary and then again hits another boundary, but without crossing the axis. So, this is a special kind of ray it is called the skew ray.

And also we have a general meridional ray this meridional ray is a ray which is passing through the fiber and every time it crosses this axis point; so this is the difference. Well, after having the idea of skew ray and meridional ray then the next important thing that we need to understand is called the numerical aperture.

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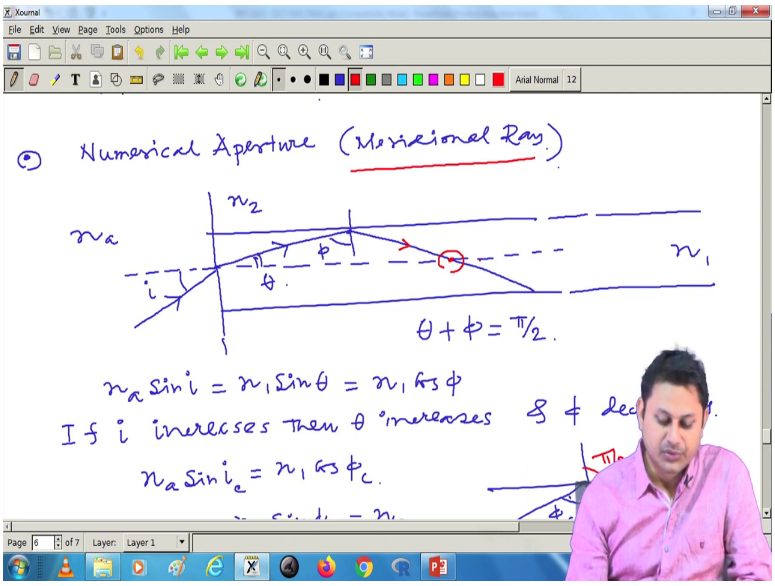

And we need to calculate what is the value of the numerical aperture. So, we will now calculate numerical aperture. So, what is the value of the acceptance angle that we will going to calculate and this is this calculation is for meridional ray; this is for a meridional ray.

So, let me draw once again the fiber cross fiber structure cross section. So, this is my when I calculate a numerical aperture I have to be very careful about the light rays and how it is crossing etcetera. So, this is the structure cross section I have a core, I have a clad and this is the axis and the light is falling like here.

And then here we have the air; so refractive index is n a in this is cladding. So, refractive index I have n 2 and this is core so refractive index n 1. So, if I extend this portion like this.

So, this is the length of the fiber along this direction. So, light is falling like that with an initial angle say i this is the angle at which the light is falling.

Now, this is the interface I have a refractive index n 1 and refractive index n. So, some kind of deviation one can expect like this and the light will hit after that going to hit this point some point. And if this angle whatever the angle is it is hitting say phi is greater than the critical angle again this boundary we have two boundaries one is n 1 and another is n 2, n 1 is the core part and n 2 is the cladding part. So, if this angle phi is greater than the critical angle we have a total internal reflection at this point.

Now, let us consider this angle as theta. So, you can see that if i increase. So, what is the relationship between the angle if I quickly understand try to understand then one equation is readily in our hand that theta plus phi is equal to pi by 2 there is a constant theta plus phi.

Now if i increases so what happen, theta will going to increase if theta is increasing then phi will going to decrease and there is a possibility at certain phi that the critical it falls less than critical angle and if it is fall less than critical angle. So, there will be no total internal reflection from this point.

So; that means, there is a limitation of i and all the rays with that limitation can pass through the fiber in principle can pass through the fiber through total internal reflection phenomena. And our now aim is to find out what is the value of that i, what is the; what is the value of that i and this is called the acceptance angle this is called the acceptance angle. So, it should be like a cone through which all the light will pass through.

So, let us quickly find what we have so far. So, n a; so first interface with these and what is the relationship between i and theta we quickly find. So, n a sin i Snell's law is equal to n 1 sin theta , again n 1 sin theta I can write in terms of phi it is n 1 cos of phi because theta plus phi is pi by 2 we just use that.

So, as I mentioned that if i increases; if i increases then theta is also increase theta increases then theta increases and phi decreases. So, I can have a value critical value and at critical value I have n a sin i c sin i c is my critical value for which I have n 1 cos phi c. What is cos phi c, cos phi c is the angle here which is the critical angle.

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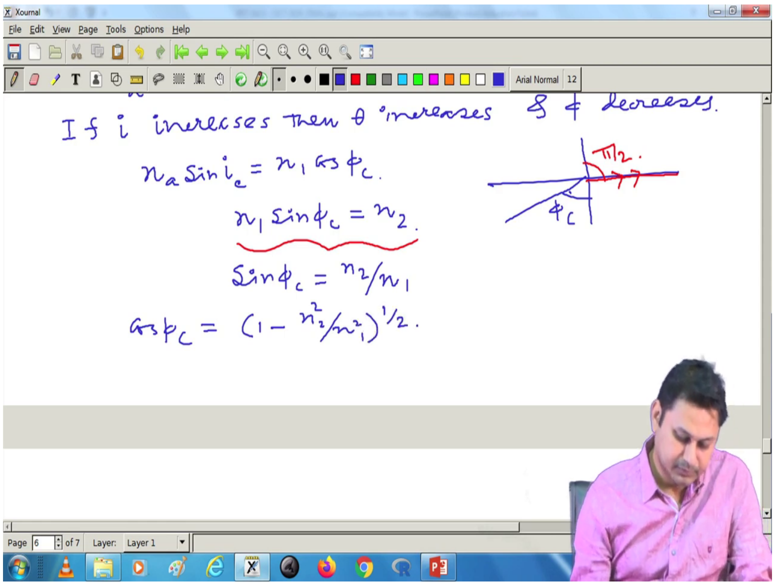

So, if cos phi is a critical angle I can write n 1 sin phi c according to the Snell's law is n 2, because if this is critical angle then this ray is just about to so at critical angle what happened. So, let me draw these things here. So, at critical angle when this angle is phi c the rays will be just passing through this. So, this angle will be pi by 2. So, I can use this relation.

Next, I will write down because I know what is my sin phi c, sin phi c is equal to n 2 divided by n 1. So, cos phi c is; simply 1 minus into square divided by n 1 square whole to the power half.

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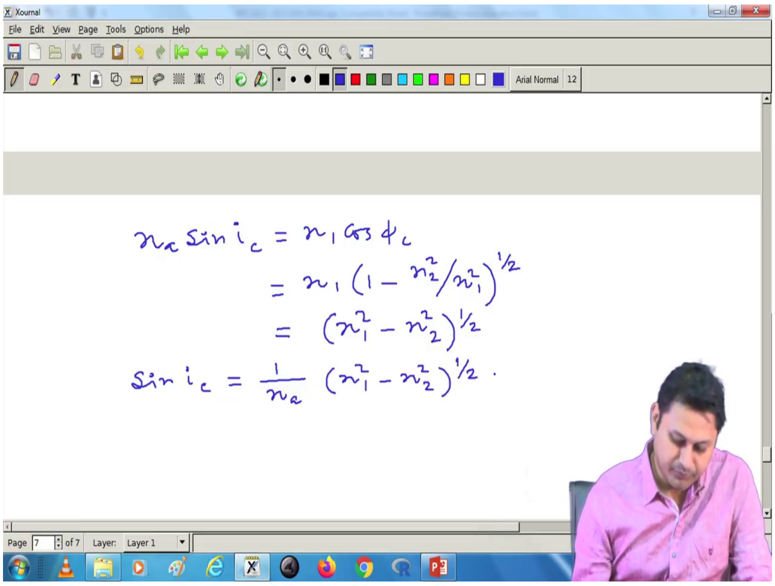

Now, I will going to use this cos phi c here. So, n is we have n a sin i c is equal to n 1 cos phi c cos phi c I derived. So, it should be n 1 into 1 minus into square divided by n 1 square whole to the power half. This is the value I have for n a sin i c.

I can put this n 1 inside. So, it should be n 1 square minus n 2 square whole to the power half. So, from here I can have sin i c is equal to; sin i c is equal to 1 divided by n a n 1 square minus n 2 square whole to the power half.

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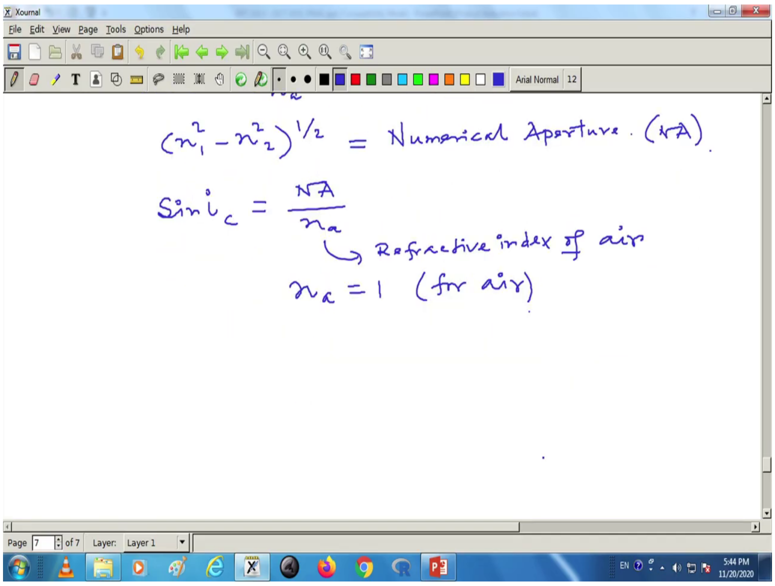

So, this quantity n 1 square minus n 2 square whole to the power half is called numerical aperture; numerical aperture or in short N A. So, sin i c is N A divided by small n a mind it this is the refractive index of air, if the fiber is placed in the air. If it is placed in some other medium so this n a value will be changing accordingly, but in case of air normally we consider n a is equal to 1 for air.

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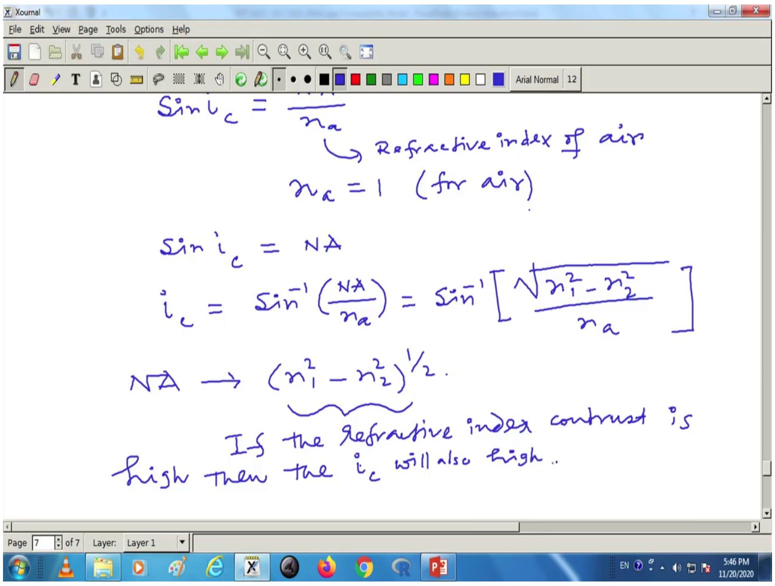

Then this equation simply becomes sin i c equal to N A, where N A is a N A is the numerical aperture. So, i c which is the acceptance angle is simply sin inverse N A divided by if I want to put this n a as well then the refractive index of the air which is sin inverse of if I write completely what is the form it should be n 1 square minus n 2 square divided by n a.

So, one can see with this one we can see that the value of the N A which is defined. So, N A is defined as n 1 square minus n 2 square whole to the power half. So, if the refractive index contrast is high if the refractive index contrast is high then the acceptance angle then i c will all will also high.

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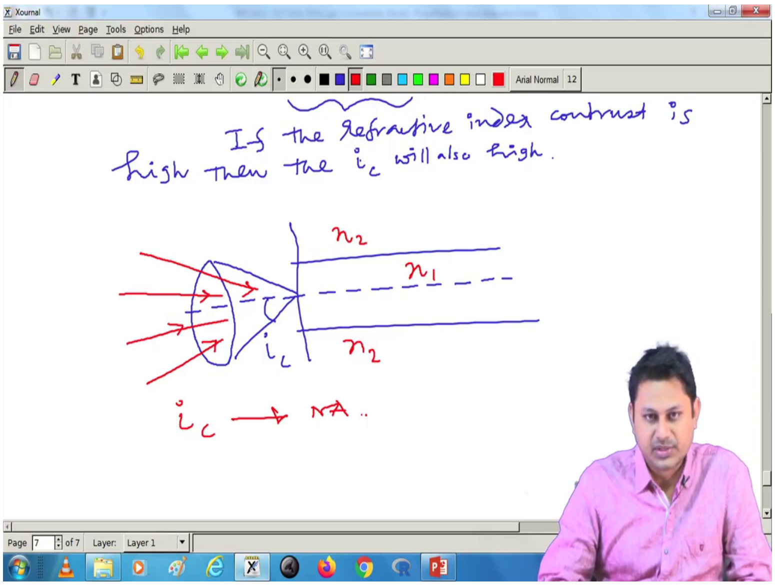

So, if I increase the refractive index. So, this is the structure the fiber and from my expression we find that sin i c is equal to N A. So, if N A increases then also i c will going to increase because sin function increases when the argument increases then these values also going to increase. So, I have a acceptance angle which basically in 3 D which basically forming a cone like structure and this is basically my i c.

So, all the rays that will fall here that will fall here will pass through the fiber in principle and if the refractive index n 1 this is n 1 and this is n 2 n 2 then I can increase this value I can increase i c by increasing N A the refractive index contrast. So, when we want to gather more and more light we want to pass more and more light on the fiber then if the contrast between the core and cladding is very high then we can increase in principle the acceptance angle.

However, in the later part of our course we can see that if I increase the value of n the contrast between n 1 and n 2 then some other problems will going to appear, one of the major problem is dispersion and that thing we will going to discuss in the in the future classes. But next class we also calculate the same thing acceptance angle, but we will going to calculate the acceptance angle for another kind of ray which is skew ray.

Mind it whatever the calculation we did in this particular lecture is for meridional ray; so this is for meridional ray. So; that means, every time this ray is passing through the axis here it is passing through the axis. So, it is passing through the axis that is why it is called the meridional ray.

But, in the next class we will going to calculate the numerical aperture for another kind of ray which is called the skew ray. And the skew ray will not going to pass through the axis and we will going to see how one can find out and that condition how one can find out the condition for acceptance angle. So, with this note let me conclude.

Thank you very much for your attention.