Optical Engineering
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Lecture - 05
Stops and Rays

Good morning, we continue our lessons in Optical Engineering. In the last class we looked at different lens conditions lens imaging conditions. So, we had derived the thin lens equation and then I had left you an exercise to do in the lab. You took each lens and put the object at different positions and the exercise was for you to look at where the image forms and the nature of the image, was it real; was it virtual; was it magnified? So, let us just run through some of those results that you should have got.

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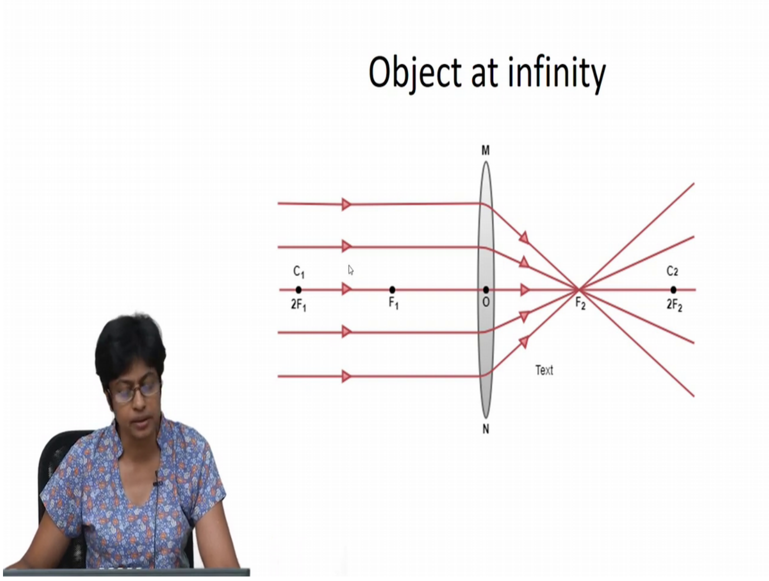

If I take a lens and we are right now considering a single lens if we take a lens a thin lens a convex lens and we have the object at infinity. The rays can be considered as coming in parallel and they focus at the focal point of the of the lens. Now, as you move the object closer and closer to the lens, the image location is going to change and it turns out as you move the object closer to the lens, the image is going to move further and further away. So, when the rays came in from infinity that is the object was at infinity, the image was formed at the focal point.

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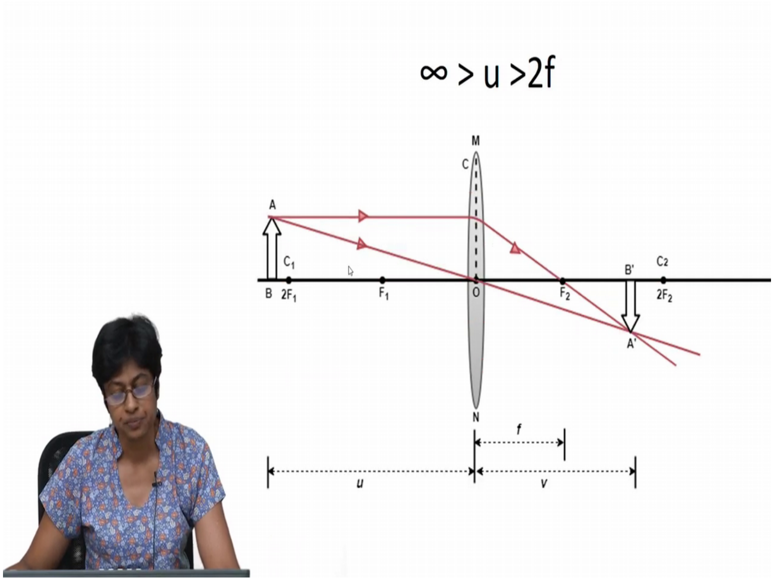

But, as you move the object closer so, it is closer, but it is still beyond twice the focal distance, the image then formed between F and 2F and you can see in this case you had an inverted image.

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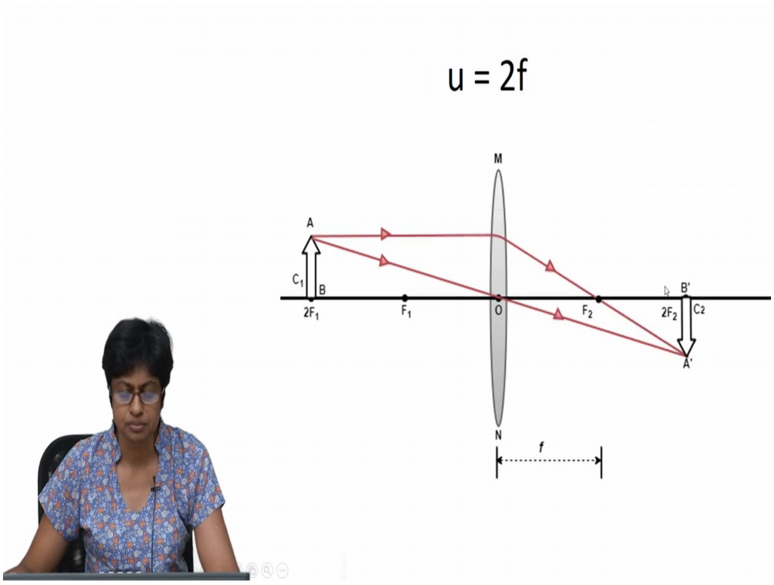

You could move the object even closer so, it comes to the point where it is twice the focal distance away.

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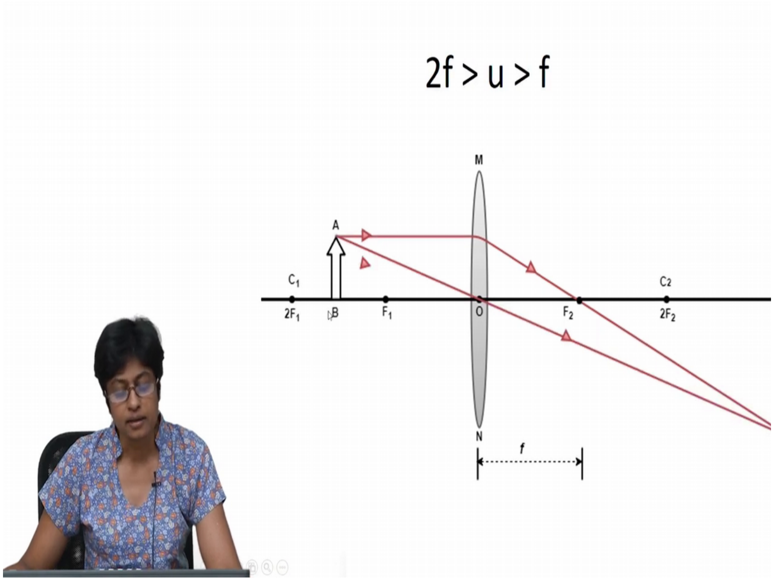

And the image, in that case, is also twice the focal distance away, and if you moved it between 2F and F, the image then focused beyond 2 F. And at the focal point you got the well-known condition that the image now formed at infinity.

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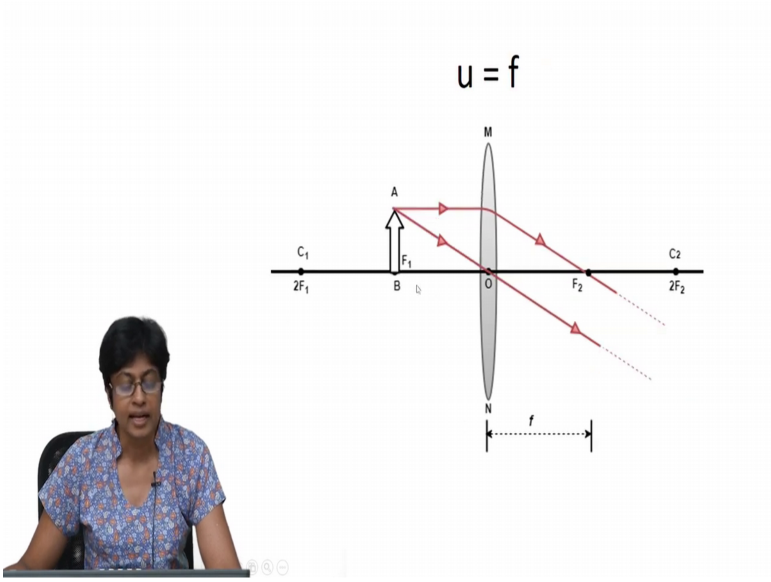

Now, you still have this distance between the focal point this F1 and the lens so, the object still has space to move forward; the object can still be moved closer to the lens, but the image for this condition shown here is already at infinity. So, moving the object closer means the image cannot move any further away and what ends up happening if you work out the equations is that the image now forms, the image that is now formed it is not a real image anymore. All the previous conditions give us a real image, but what we get now is a virtual image.

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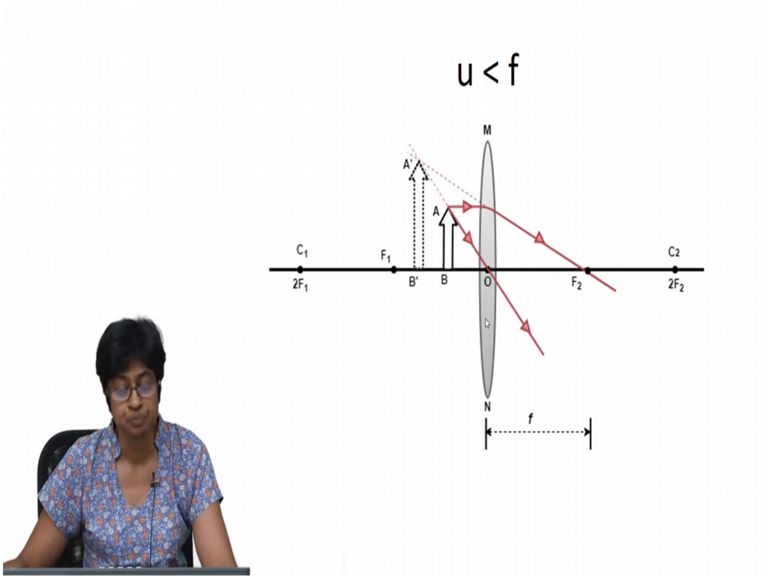

That means the rays are still diverging; so, the rays are in image space and they are diverging they appear to come from a point in object space and so, the image appears to exist in object space. And you can see the image is erect it is larger than the object and thus most striking difference is it is a virtual image; that means, that if I were actually to put a screen at this location, I would not be able to record the image because there are no actual rays forming an image at that position, ok.

So, this is an exercise I had asked you to work out in OSLO and the idea these are concepts not new to you, you would have done them in school. But, the idea was first to refresh your memory of these concepts as well as to get you used to work with the software OSLO.

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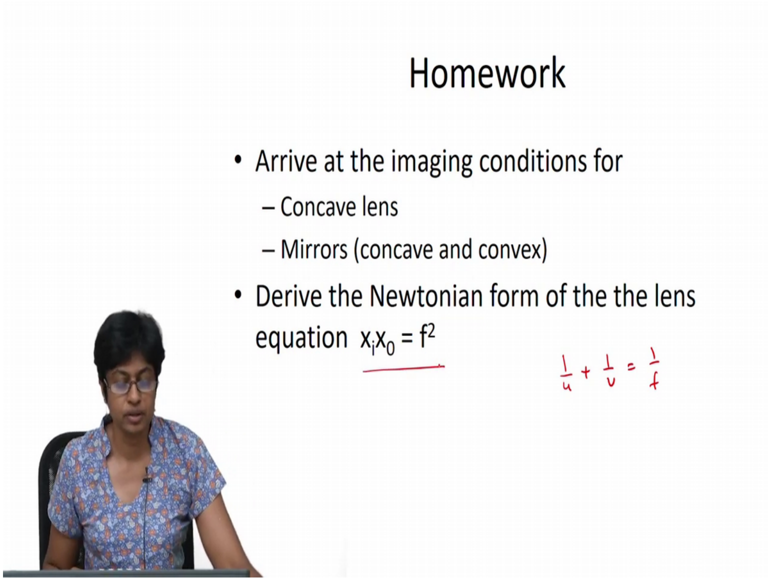

So, I am going to leave you with some homework now, we have only looked at the thin lens which was a convex lens. I would like you to now arrive at the conditions the imaging conditions for a concave lens and for mirrors both convex and concave.

So, we looked at or we derived an imaging equation the Gaussian lens equation where we said $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ or in other words we took into account the object distance the image distance and the focal length of a lens, but that is not the only equation that can be used to arrive at imaging. So, another piece of homework that I am leaving for you is to derive what is called the Newtonian form of the lens equation, that is this equation and I will just explain what the different parameters are.

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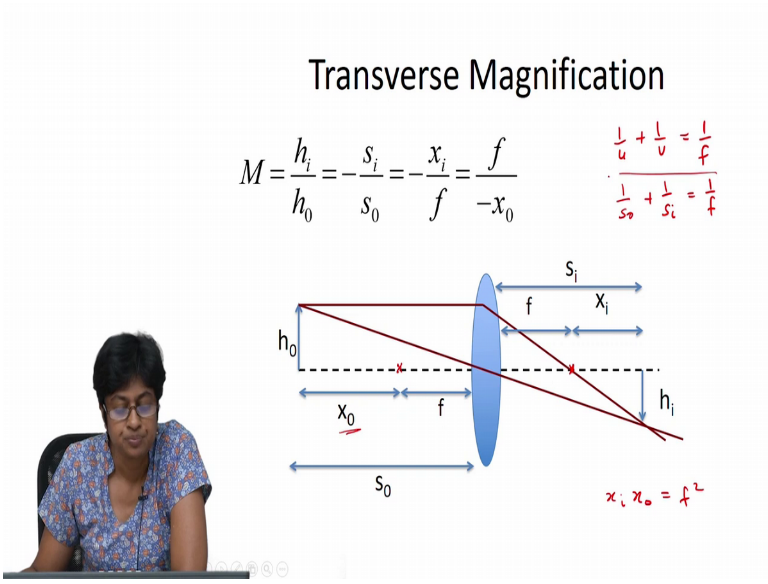

So, this equation was a function of the parameters u and v, and u and v or as they indicated in this graph over here, in this picture over here is $\frac{1}{s_o}+\frac{1}{s_i}=\frac{1}{f}$ they were functions of distances measured from the vertex of the lengths. So, S_o and S_i are measured from the vertex of the lengths. But, sometimes it is easier to make measurements from the focal points of the lens and the Newtonian form of the equation that is this $x_i x_o = f^2$. So, let me just write that here again, it is written in terms of the distance of the object the distance of the lens the image from the focal point, ok.

So, these; this equation is another way of doing imaging and you we also another parameter of importance was the magnification. So, we had arrived at the magnification in terms of the image and object heights. So, that was this relationship, but of course, the height is related to the distances is simple trigonometry. So, you could write the magnification that is how much larger is the image compared to the object.

Also in terms of image object distances and since we are now writing the imaging equation in a different form the magnification can be arrived at in terms of the parameters used in that form. Anyway you have a negative sign that is just telling you that the image is inverted with respect to the object. So, I want you to work out the Newtonian form of the equation and also arrive at the transverse magnification in terms of these parameters x_i and x_0

We have arrived at an equation that allows us to do the imaging or calculate where an image will occur given that we know the object position and the focal length of the lengths. But, it is often quite easy and useful to be able to arrive at this information graphically.

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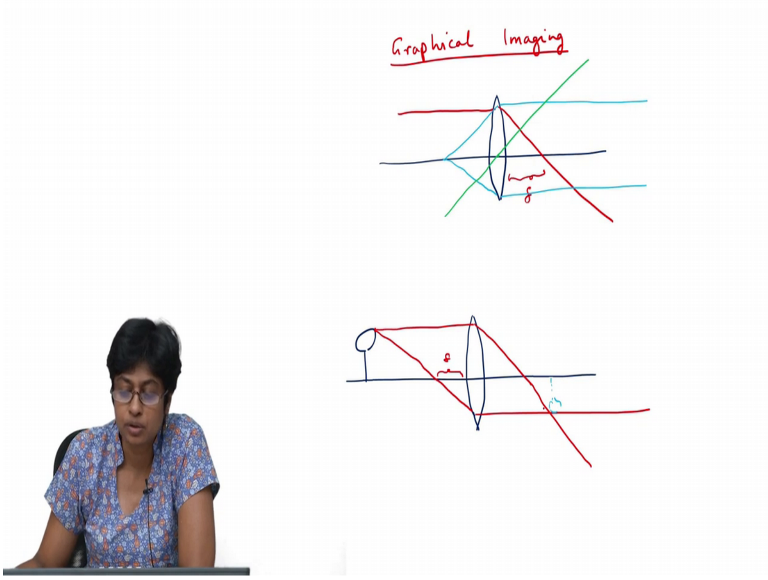

So, when we say graphically what we mean? So, if we consider a lens; so, I always draw the optical axis and the lens. I now can use some parameters that I know about any lens and that is if you have a ray coming in parallel, we know that ray is going to bend and travel through the focal length of the lens that is unknown.

So, if we assume this is the focal length, we know this ray coming in parallel is going to bend. The second point we know is if you have a ray that comes in from the focal length, it is going to travel parallel or to make it useful let us do this side and do this. If we have a ray that travels through the center of this lens it is going to travel un-deviated through the center of the lens.

So, we have three pieces of information over here and we can use these pieces of information to help us locate an image. So, for example, let us say I have an imaging system a length and I have an object that I want to image, this point of the object is going to be imaged. So, I could trace the ray that is parallel, I could trace the ray that goes through the focal length of the lens assuming this is f, and this ray is going to travel through the focal length on this site, this ray is going to travel this way and therefore, I know then that the image is formed like this.

So, I can always use a graphical technique to help with imaging at least in very simple systems, this allows me to locate the image. We have looked at different imaging conditions we have taken we have arrived at the equation for a thin lens. But, now to move on to more complicated systems; our optical systems are not going to consist of a single lens, our optical systems are going to consist of a varied number of elements in them; they could have a number of lenses, a number of mirrors in them.

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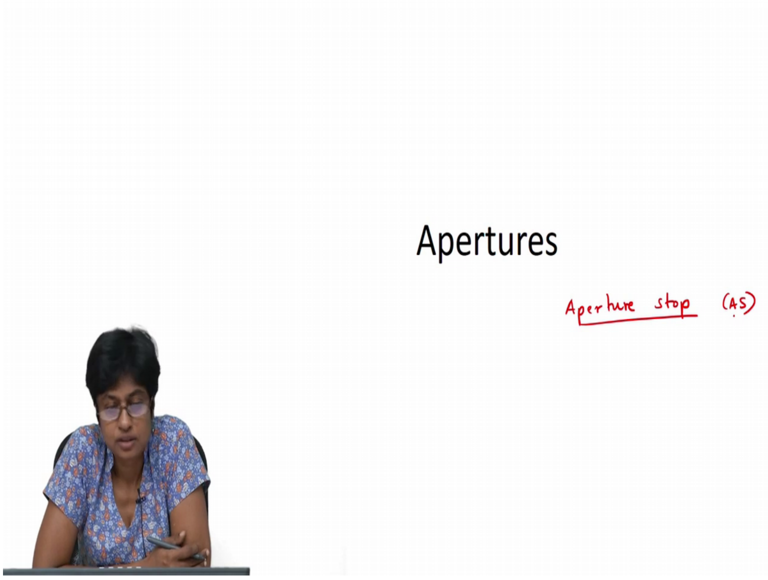

So, when we want to trace rays through the system, we need to understand the effect of having a number of multiple sets of elements in the system. How does having many elements in a system affected? And one very important concept that has to be learned to understand this is the concept of apertures.

Now, we understand the meaning of the word aperture as an opening and every optical element in the system of course, has an opening that is the transparent region through which the light is going to travel We need to look at very specific openings and especially something that we call the aperture stop of the system or sometimes it is just called the AS of the system.

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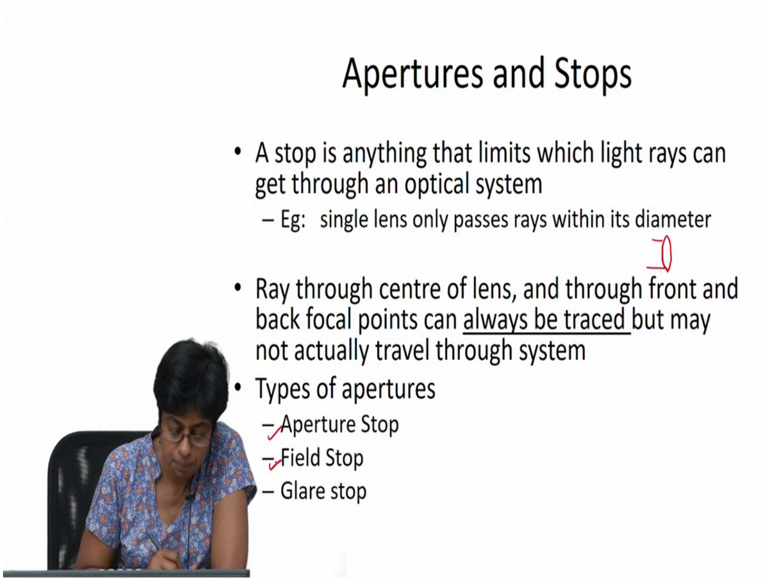

So, what do we mean by the apertures and in general the stops of a system? So, any system will have a number of elements in it and as the light travels through these elements; some of these elements are going to limit how much light actually reaches the image. So, I can consider in general a stop is any element that limits light rays getting through the optical system.

An example is if we take a lens only the light that passes through the clear opening of the lens is what gets to the image plane or what serves as forming part of the image. So, the opening of the lengths is or the diameter of the lens is the aperture that we are talking about.

Now, we know that we can trace rays through a system, we just done that I took a single lens and I trace the parallel rays or the rays coming from the focal point or the rays through the system center of the lengths. I might trace those rays when I draw a diagram but do those rays actually reach the image plane that is going to depend on all the elements in the system and to understand this better we split up the apertures the type of apertures we have into three different types. So, we have the aperture stop I mentioned that just now we have the field stop and we have what is called the glare stop and I have come to each of these in detail.

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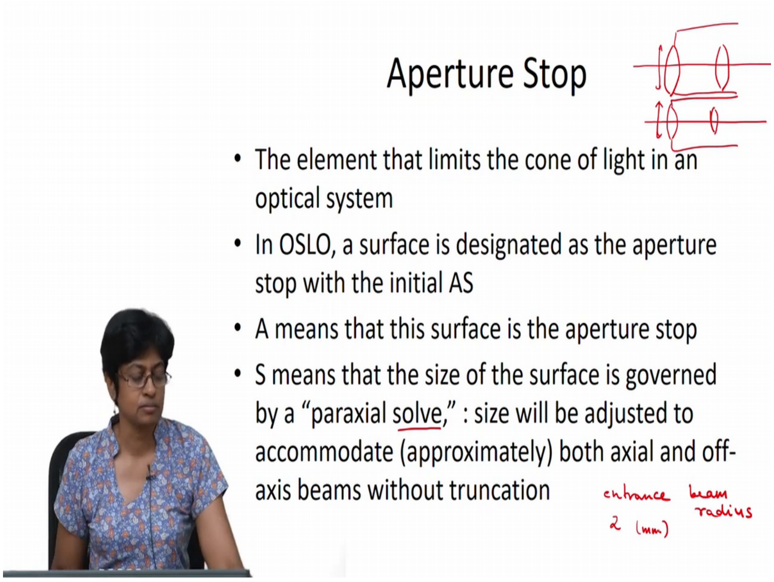

So, the aperture stop is a very very important element in the system, it is the element that limits the cone of light in an optical system. Now, what do I mean by limit the cone of light in an optical system? You might consider a system having more than one lens in it. So, let us say you had an optical system that comprised two lengths, they may be of the same size, they may be of different sizes.

Now, if you are looking at this element this system maybe you can see the optics inside and you can only see the outer optics, it may appear to you that the outer optics has a certain diameter. The aperture stop or the concept of the aperture stop must make you understand that this diameter here is not necessarily the opening that allows light to travel all the way through the end.

There could be another element within the system that it is limiting the amount of light that reaches the image plane and we need to calculate that to understand exactly, what is the amount of light that reaches the image plane. In a software ray tracing software like OSLO, the surface is designated as the aperture stop with the initials AS.

Now, actually AS does not stand for aperture and stop, the A is for the aperture stop and the s is for another operation that you can carry out in OSLO called a solution. Now, there are various solves that you can do in OSLO and we will learn about them in the coming classes. This solves means, we are giving OSLO the instruction to solve for the diameter of this element, such that all rays that travel will travel through to the end of the system.

Now, what do I mean in OSLO if you remember you had to give an entrance beam radius. So, you were designing a system for an optical beam off a certain radius. So, you this is one of the first parameters you enter right. So, maybe you enter two; that means, it is two millimeters; so, you have a beam of diameter four millimeters coming through the system.

OSLO will take that to understand that it is not the first element or the second element or the third element that must allow this 4-millimeter diameter through, what the software understands is that the element you have designated as the aperture stop that is the element that must allow this 4-millimeter diameter beam through. And therefore, it will adjust the size of the aperture stop such that the 4-millimeter beam is allowed through the system.

And, every other element will be adjusted accordingly such that this beam size that you have put as the beam that makes it through the system is allowed through the system ok, this will become clearer as we go along and you also understand the other solves. So, the point to take is that when I give an entry for the beam radius, I am actually saying this is the beam that makes it through the aperture stop of the system, ok.

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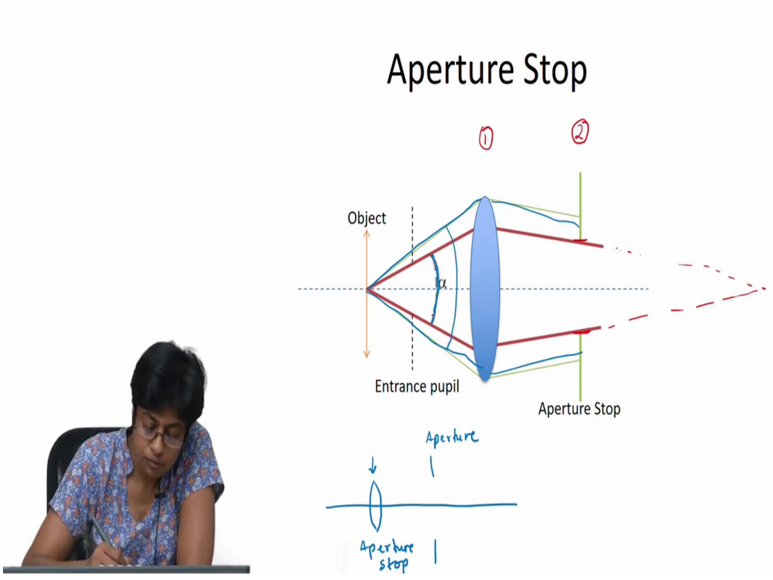

Now, let us explore this concept of the stop a little more. Assume I have a single lens as shown in this diagram. Now, this is a simple system it consists of two elements; I have one element with power this is this lens and I have this aperture here which has no power; that means, it only blocks light or allows light through it, it does not bend the light that is traveling across it.

Now, in the diagram I have an object that is given by this orange arrow over here. So, you see it has some finite extent, but it is not a point this object has a vertical extension and we have traced just two rays coming from one point of this object and the point they are coming from is the object point on the axis.

Now, if I were to actually be imaging this object I would have to trace rays from every point on this object, but for this explanation I am tracing just two rays coming from the same point. I have not even traced these rays all the way to the image point if I did that of course, you would be talking about where they cross the axis again because this is clearly an axial object point and they should form an axial image point.

Now, I have chosen these particular two rays because you notice these are the rays that make it through the extreme and this is this is the edge of your aperture and these two rays happen to go through the extremes of the or the edges of your aperture. If I had taken a set of rays with a larger angle, yes they would make it through this lengths.

But, you can see they get blocked by the aperture stop and that is why in this particular case the second element is labeled aperture stop and the first element is not because what is limiting the cone of light in this example is the second element. You might get confused, you might say well the second element is an aperture and the first element is a lengths.

So, of course, the second element must be the aperture stop, but I could have a system where I had a length and an aperture and really what would limit the cone of light through the system would be this element not the aperture in which case this would be the aperture stop.

Now, in this particular example I have drawn the aperture diameter slightly, this is also an aperture it is just not the aperture stop and I have drawn the diameter slightly larger. So, that it is easy for you to imagine that what limits the light through the system is the lengths and not the aperture, but you will see that we cannot just decide which is the aperture stop based on the diameter of the element. Because never forget that as light travels through the optical system it is bending and that bending determines whether some ray goes through an element or not.

It is; so, it is not just the size it is the fact that the light arriving at that element may have been bent and therefore, even if it was very large maybe the rays are only traveling through a central region. So, or even if it is very small that is the region where rays are traveling through because all the elements before it have bent the rays.

So, it is because of the fact you have elements with power that you need to actually do a very careful calculation to figure out which is the aperture stop of the system, ok. So, this is one of the most important elements of your system, you are going to when you design you are going to have to say this is an aperture stop of the system and then a lot of other parameters are going to follow based on this factor if you are given a system you can calculate and find out which is the aperture stop of the system, ok.

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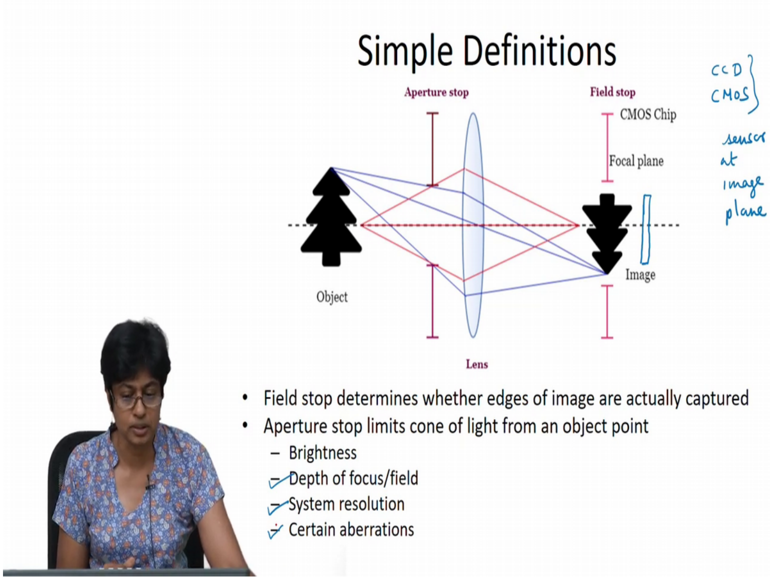

So, we need now some more definitions and the second definition is that of the field stop. So, the aperture stop limited the cone of light through the system. So, if you look at this example, this was the cone of light that made it through the system this cone did not make it through. So, the amount of light is coming in this cone. The fields stop has a completely different effect.

So, if I look at this example again I have an object, I have a length, I have the image formed at the image plane and let us say my field stop is a at the image plane let us say I am capturing the image on a CCD or a CMOS sensor, ok. So, this is at the image plane.

Now, what would happen if the sensor and the image were not of the same size and importantly, what would happen if the sensor was smaller than the image? So, let us say this was the size of my sensor and you can see the image is larger. The optical system is well designed so, the image that I get is perfectly in focus I have a very good quality image, but the edges the extreme points of the image do not appear simply because the sensor is not able to capture them. This is the definition then of the field stop.

Do you capture the entire field and the element which limits whether you capture the entire field or not is the field stop? More often than not the field stops may be at the image plane itself, but there could be some other element which is limiting the rays that form the extremities of your object and in that case that would be the field stop of your system. In this particular example, the sensor array or the size of the sensor that is going to limit whether the entire field, the entire image is captured or not and so, the fields we can consider this to be the field stop.

So, we have looked at the aperture stop we have looked at the field stop and while I said the aperture stop controlled the cone of light that was coming in. It is not the only parameter that it controls, now because it controls a cone of light should not be hard to imagine that it controls the intensity of light; so, it controls the brightness of the object. But, it turns out the aperture stop controls many other parameters as well it is not controlled, but it allows us the ability to vary some other very important parameters and I have listed out some of those parameters here, the depth of focus and field we will in learn about these in later classes.

The system resolution how finely spaced do two can two objects be and still be distinguished as two objects and it also can help control or reduce the amount of certain aberration. So, you can see these are all extremely important points and the aperture stop plays a role in all of these, and that is why it is so important to be able to calculate which is the aperture stop of your system, ok.

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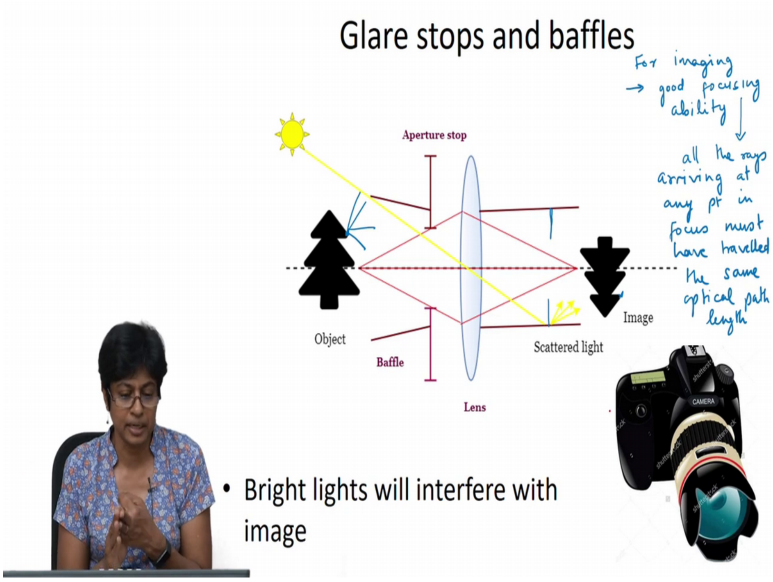

The glare stop is slightly different from either of these. So, when I may be to get to what is the glare stop it is better to go back and ask the question what exactly is image. So, a what; so, for imaging this is what we have been talking about in the last few classes, for imaging you need to have a good focal good focusing ability, ok.

But, I could ask at this point what do I really mean by good focusing, what does it mean if I say to rays are in focus. And, then different ways of answering this, but if you remember what we covered in the first few lectures. A very good definition of good focusing is to say that all the rays arriving at the focal point or arriving at any point in focus must have traveled the same optical path length. So; that means, say I am creating an image like this system is creating an image of this tree; that means, all the rays from this point I am talking about each point of the object.

So, let us consider one point of the object, all the rays from this point of the object must the whole host of rays from this point. All of these rays must arrive at this point on the image after having traveled the same optical path length, if the system is designed such that that happens when I say I have a good system and I will get a good image. If some other ray arrives at that point and from some other place, it is not going to contribute to the image and in fact, it is going to make the image quality worse.

Now, where can other rays come from; so, in this figure you can see you can have ambient light stray light which is existing around which is not coming from the object or not coming from the particular point of the object that is being imaged. And yet, it makes it through the optical system and because of scattering and reflection a the container or the amount of your optical system. It also happens to arrive at this point and such light stray light tends to lower the contrast of your image and thereby lower the quality of your image.

So, sometimes we put stops into a system or something that is called baffles. Baffles can just be mechanical structures like this that has served no purpose other than to block stray light. And you if you have seen anyone with a slightly professional camera, you will notice as shown in this picture over here that they have this shield around the lengths and this is just to prevent stray light from entering their system and arriving at the image plane and spoiling the image, ok.

So, these are the three main classes of stops that we have the aperture stop that limits the cone of light, the field stop that limits how much of the extremities of the object are captured and a glare stop that prevents stray light from actually traveling all the way to the image plane.

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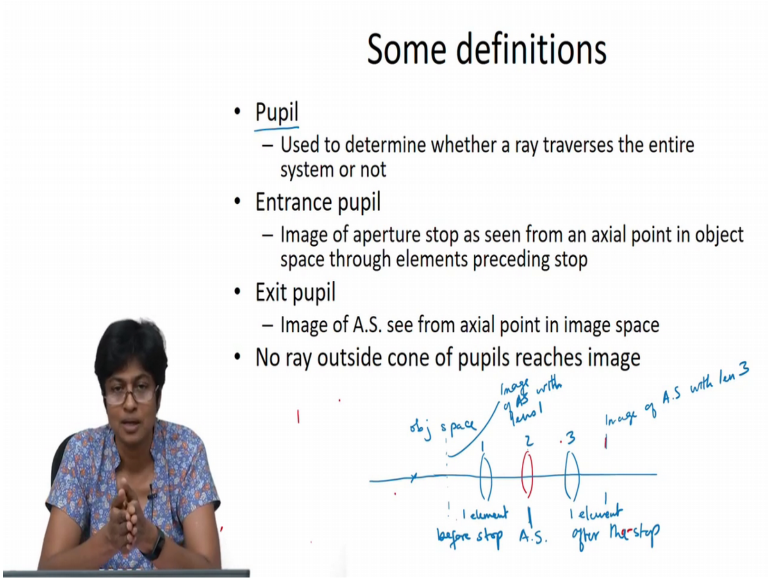

So, some more definitions. It should be clear by now that aperture stop is a very very important element, but rather than directly use the aperture stop it turns out since I have an imaging system. I can use images of the aperture stop to help me determine whether the ray traverses the entire system or not.

So, the images of the aperture stop are called pupils, and in particular we look at the entrance pupil and the exit pupil. So, what are these two pupils if I have a lengths and let us say I have a system with several lengths, but and we will see later why to suppose this was the aperture stop of the system how would I find out what is the entrance of the exit pupil where the entrance pupil is the image of the aperture stop. So, the image of this taken by entrance pupil is the image of the aperture stop as seen from an axial point in object space through all the elements preceding the stop in this case there is one element preceding the stop.

So, I will form an image of this aperture stop using this element and wherever it is image exists that becomes the entrance pupil of the system, maybe the entrance pupil will be somewhere here. Similarly, I can take an image of the aperture stop using the lens there is one element in this case after the stop. So, I will find the image of the aperture using this element and maybe I get an image over here this is the image of AS with lens 3. This is the image of the aperture stop with lens one and lens two itself is the aperture stop.

So, the exit pupil is the image of the aperture stop as seen from a point in image space formed by all the elements after the stop and the entrance pupil is exactly the same thing as seen from object space formed by all the elements before the aperture stop. Do not worry if these definitions are a bit confusing right now as we go along they are going to become clearer and clearer and you will also work with these ideas in the software and it will become clearer there.

The main point to take is no ray outside this cone, this cone and the cone is determined by the stop, but in other words it is determined also by the images of the stop because the images of the stop are nothing, but the way light bends and travels through the system. So, all that these definitions are giving you is telling you that only rays that lie within the pupils, within the cone of the pupils are the rays that travel from the object to the image, they are the rays that play a role in forming the image.

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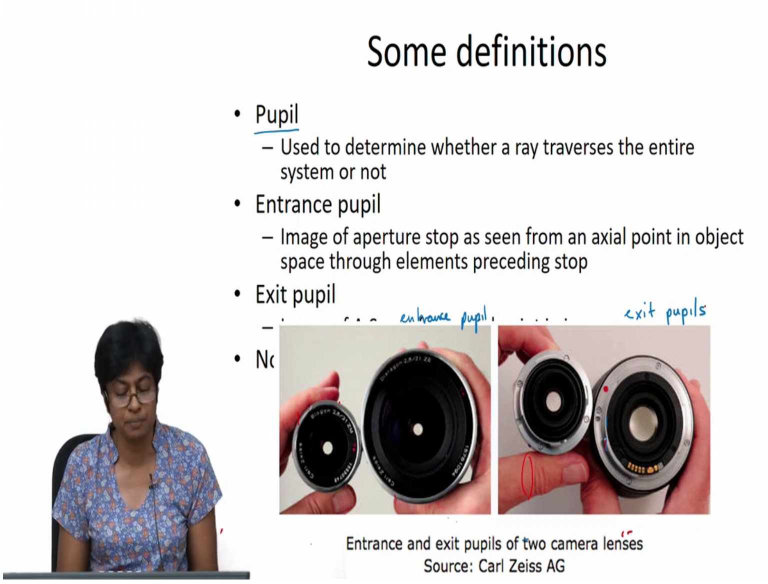

So, you can look at this particular image, I do not know if any of you are photographers and I do not mean cell phone photography I mean, where you use conventional camera sorry just removing this so, you see this a little clearer. So, these are the lenses that for a conventional camera you would attach these lengths. So, you can remove them and attach them. So, you get different focal lengths and different speeds of the lens and so on.

And, you notice the lens diameter is quite large. So, the person is holding the lens and that is the diameter almost the little bit is the mount, but that is almost the entire opening of the lens. And yet, you see a bright circle only in a very small region and these are actually nothing, but the entrance and exit pupil this is the cone of light that makes it through the system.

So, you can see the lens is so large, but the cone of light is only this small and this is very evidence so, this picture on the left is the part of the lens that faces the object. So, this is nothing, but the image of the aperture stop and in other words you are looking at the entrance pupil over here. So, this is entrance pupil and similarly, if you look at the other side of the lens that is the side that connects to the camera and therefore, facing the sensor.

So, these are the images of the aperture stop as seen from image space and these are therefore, nothing but the exit pupils. So, you can see that even though the lens diameter is very large the amount of light that makes it through the system is a much smaller cone and that is very evident or should be evident from these photographs, ok.

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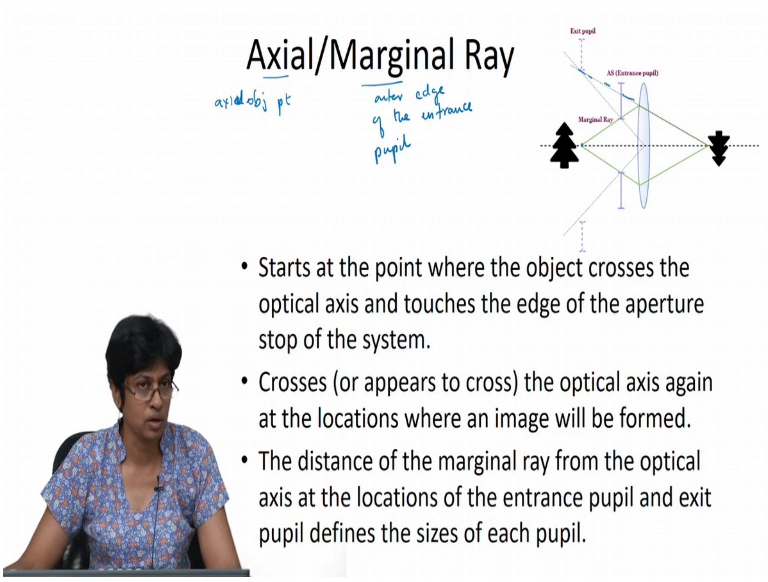

So, we have looked at stops of various kinds and we focused and we will focus largely on the aperture stop at that is the one that limits the cone of light and affects many other parameters as well. What we need to do further is to look at some specific rays that make it through the system.

Now, there are infinite rays that a number of rays that I could trace through the optical system. I need to be wise in picking certain rays because I want to be most efficient in how I design my system and I want to pick the rays that give me the most information about the system. So, there are some specific rays that we will always trace through the system and one of them is called the axial or the marginal ray.

Now, it is called this because it is the ray that starts from the axis the object point that is on-axis what is shown over here and makes it through the outer edge of the entrance pupil. So, it is called the axial ray because it is coming from the axial object point, it is marginal ray because it goes to the outer region or outer edge of the entrance pupil, ok.

Now, in this system that I have drawn here, you can see I have two elements again; I have an aperture and I have an entrance pupil, you have been told that the apertures the aperture stop. Now, I ideally I should calculate the entrance pupil now why have I not bothered to do that here because if you remember the definition we said the entrance pupil is the image of the aperture stop as seen by all the elements in front of the stop, but in this example there are no elements in front of the stop. Therefore, the aperture stop at the entrance people are one and the same thing and therefore, the ray is traveling through the edge of the aperture stop.

Now, I trace this ray as a straight line from the object point on-axis through the edge of the aperture stop and it of course, is a straight line all the way to the lens and the lens has power. So, once the ray reaches the lens it is going to bend, and it bends depending on the power of this lens and the point where the image is formed is of course, the point where the ray crosses the axis it, crosses the axis and if I were to trace this ray, back.

So, this ray if I were to trace it as if it had not bent, you would see that it goes through the edge of the exit pupil. How did we calculated the pupil? Well the exit pupil is an image of the aperture stop. So, it is the image of this element as seen by all the optics after, it there is one lens after it. So, we have used this is the object this is the lens imaged this object and found out that the image lies here.

What can I say about this image? This image lies in the same side of the object it is larger, I know this is a virtual image it should not be surprising it is virtual because you can see that the aperture is very close to the lens. So, it is most likely and I know it is in this case that the this distance between the aperture stop and the lens is less than the focal length of the lens which is why the exit pupil on the image of the aperture stop happens to be on the same side and is magnified.

So, let us get back to the axial ray. It starts at a point when the object crosses the axis touches the edge of the aperture stop of the system and it crosses the optical axis again where the image is formed, the distance of the marginal rate from the optical axis here gives you your entrance pupil size and here gives you your exit pupil size. So, wherever it appears to cross the edge of those apertures, ok. So, I hope that is clear again these ideas will get clearer as we go along.

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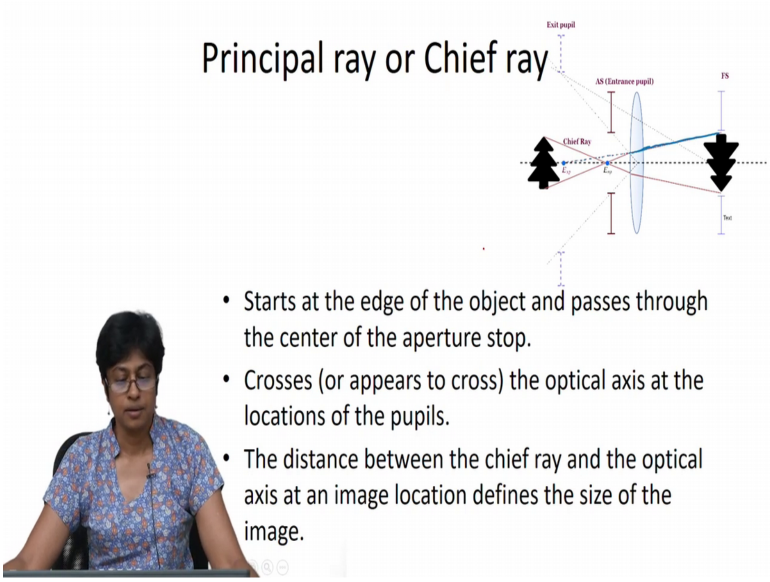

The principle of chief ray is a ray that comes not from a point on the axis, but from a point at the extreme edge of the axis and if it is quite opposite to the axial rays. So, the axial ray started from an axial object point and went to the edge of the entrance pupil, here the chief ray starts from an extreme object point and goes through the center of the entrance pupil.

Now, I am again I have the same system I had in the previous case. So, the aperture lies before the aperture stop lies before the lens therefore, the aperture stop and entrance pupil on the same element, but the image of the aperture stop as seen by this lens forms here and therefore, the exit pupil forms here.

The chief ray goes as a straight line from an extreme object point through the center of the entrance pupil continues as a straight line till it hits the lens. Now, what happens at the lens it has to bend, the lens has power. It will bend and of course, at some plane it forms the image, you could use the graphical technique or your lens imaging equations to find out where that is, but at some plane it forms the image. If I were to trace back this line so, it has bent after the lens, but if I were to trace back this rays.

So, this is the ray that has is the rays that has refracted after the lens, if I were to trace it as if it were a straight line the point where it crosses the optical axis that is the location of the exit pupil. So, the chief ray always goes through or appears to go through the center of the entrance and exit pupils of the system that is the main point to remember, ok.

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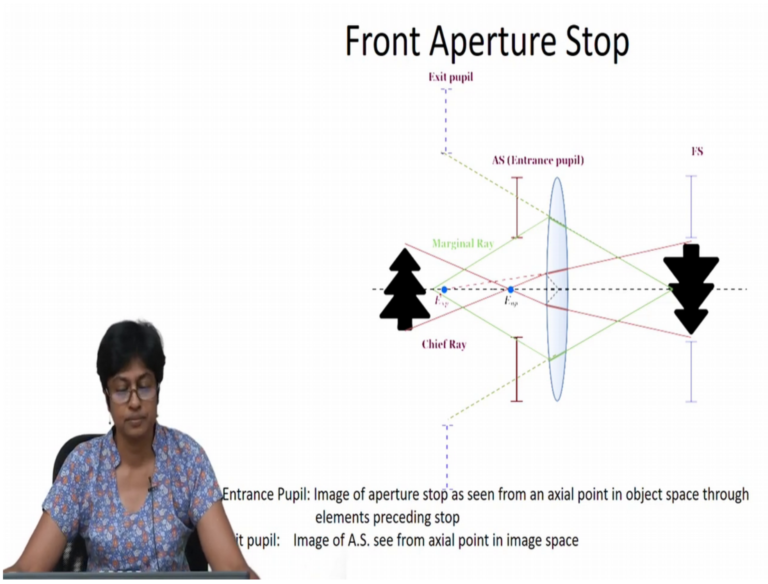

So, let us just go over these ideas again because they are so important and I know they are a bit confusing, I have an object, I have an image and the point coming from the axial object point that is my axial or marginal ray it goes through the edge of the entrance pupil whereas, the chief ray goes through the center of the entrance pupil. On the other hand, the ray after refraction the axial ray after refraction will appear to have come from the edge of the exit pupil, the chief ray will appear to have come from the center of the exit pupil, ok.

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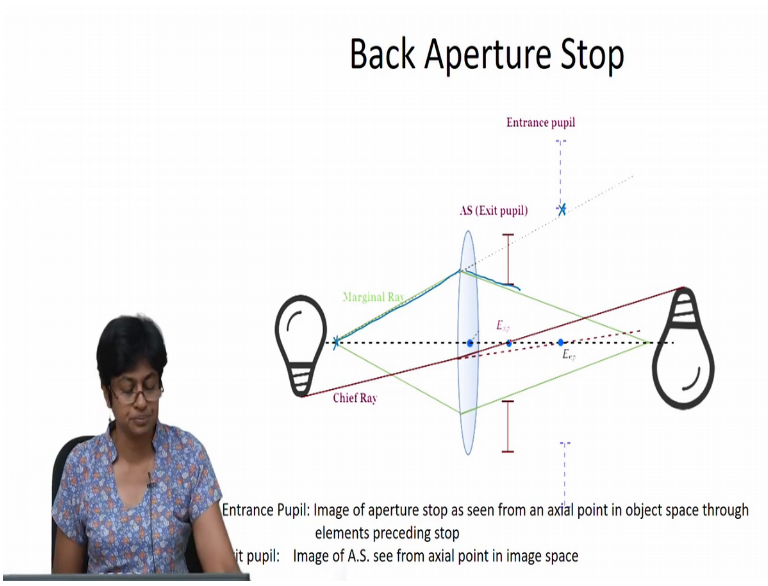

Just to make sure that you understand this is true always I have taken an example where we have moved the aperture now from instead of being in front of the lens to after the lens. And in this case I cannot trace the directly through the axial ray directly through the edge of the entrance pupil because of course, there is a lens as an element with power before this. So, if I have an element with power before it, it means the ray has to bend.

So, how will I trace the marginal or the axial ray, I will start off at the axial point and I will go to the entrance pupil. I will start drawing array in that direction to the edge of the entrance pupil it will travel as a straight line till it reaches the lens or the element with power and there it will bend, it will bend such that it crosses the edge of the exit pupil, ok. So, I start out with a ray that appears to be going to the edge of the entrance pupil.

Similarly, the chief ray starts from an extreme point of the object and appears to go through the center of the entrance pupil sorry, the exit pupil, but of course, the moment it hits the element with power it is going to bend and it is going to go through the center of the exit pupil. So, I am not sure if I said that clearly, the chief ray comes from the edge or the peripheral point of the object it travels as if it is going to the center of the entrance pupil, but of course, the moment it hits the lens it is going to bend, it is going to refract and it will finally, actually go through the center of the exit pupil, ok.

So, spend some time understanding these definitions because they are important and they will help you understand the aberrations of a system. So, if you know which are the key phrase, which is the marginal ray they will help you understand the optical system a little better and help with the locations of the aperture stop entrance pupil exit pupil and so on.

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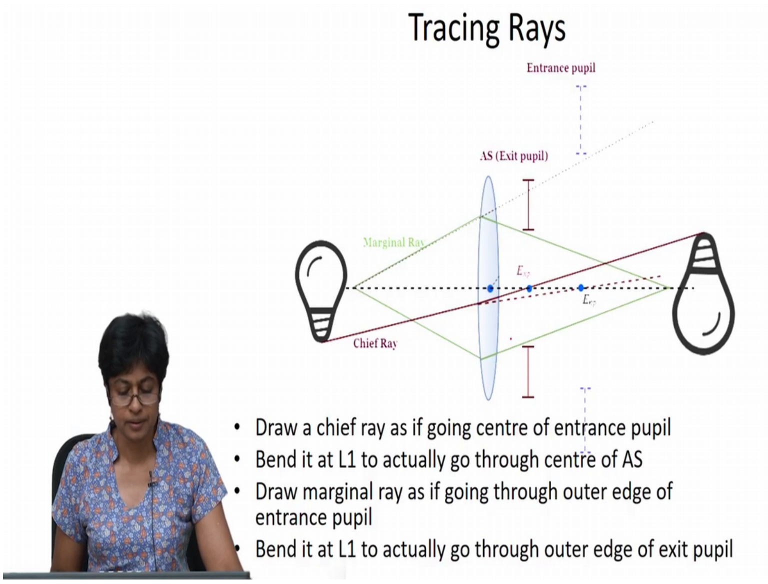

So, I am repeating this point just to make it very very clear, you always draw the chief ray as if it were going through the center of the entrance pupil, you always draw the marginal ray as if it were going through the edge or the outer edge of the entrance pupil, ok. The moment you hit an element with power the rays will actually have to bend.

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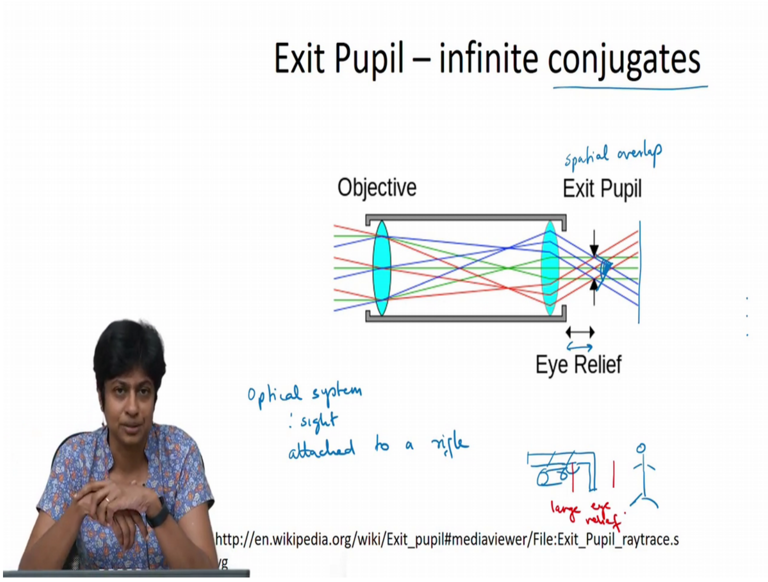

So, if I look at an optical system, I now know that one of the elements in the system limits the cone of light. There may be a system if you think of a zoom lens which has many different lenses in it, you may only see the surface of the outermost lens, but you could have 20-30 more elements in there. The point or the point that you have to note or what is important to do, you the point you should have got from today's class that first element is not necessarily the element limiting the cone of light, it could be any one of the elements within that system.

So, in this example that I am showing over here, you this is two lenses, but three sets of rays have been traced and the rays are indicated by different colors. So, each color indicates a set of rays coming in at a different angle, and you can see that all of these rays make it through the system and at this plane over here which is the exit pupil you can see all three rays perfectly lie on top of each other.

Now, these rays are parallel sets of rays coming in. So, this is why we are calling this a system of infinite conjugates because the rays are coming in from infinity, they are coming in as parallel rays and they are also going out as parallel rays and that is why we call it a system of infinite conjugates. But, what is interesting to note in the system of infinite conjugates is, what is happening at the exit pupil? At the exit pupil all three sets of parallel arrays overlap, it is its not this plane where the parallel rays are all at different locations, there is a spatial overlap at the exit pupil and what does that mean if you were looking at this.

So, you are this was some system where you were using your eye to form an image, you would place your eye over here and each of these parallel rays beams would be focused by your eye and you would see three spots of light, ok. So, the exit pupil. So, another point to notice in this particular case if I say that the final imaging device is the human eye clearly the exit pupil of the system must lie outside the entire optical system. Now, it may not have occurred to you, but the exit and entrance pupils could actually lie anywhere in the optical system.

We are after all saying one of the elements in this optical system limits the cone of light and I can further use this concept instead of talking about the aperture stop directly I talk about the images of the aperture stop and those images can lie anywhere in the system if; however, you need access to a pupil then that pupil must lie outside the system and this is something you must take into account when you are designing your optical system.

So, in this case if this was a part of a telescope for example, you would need for the exit pupil to lie outside. So, that you could view the final image with your own eyes, ok. Now, the distance between the exit pupil and the outer casing of your optics is called the eye relief and it should be fairly clear why it is called the eye relief because of course, if the exit pupil is too close to the outer edge it will be very uncomfortable when you are viewing. You need to have a little space and that space is called the eye relief.

Different optical systems will be designed such that the eye relief has different values if I am going to attach a camera here then the eye relief has to be adjusted to where the location of this camera sensor would be if; however, it is going to be a person viewing this has to be adjusted to give a little space. So, that it is comfortable to bring your head forward, it should not be too far away because, it is not comfortable maybe to hold your head viewing something, but that something is at a little distance.

So, depending on your application you have to design the system. So, that the exit people is at a comfortable location; example that I like to give here is that off what is called a sight. So, you have an optical system called a sight, this is attached to a rifle to allow you to view what the target that is going to be shot. I do not know how many of you are movie fans, but you surely have seen a movie where you have an assassin sitting hiding somewhere viewing. So, the person those assassin is going to shoot is very far away and the unfortunate target is innocently walking somewhere the assassin is very far away and the optics the sight is what allows the assassin to focus on the target, the unfortunate target.

Why how is this optics, where is the exit pupil of this optics is it very close to the optical system or is it very near the optical system what do you think, where do you think the exit pupil should be? So, you have a rifle I know this is not how a rifle looks, but I am just going to draw it like this and attach to this you have an optical system and then you have the person whose going to shoot. Where is the exit pupil of this system ok, it could be right next to this optics, it could be much further away where should it be, think about that.

Now, if you recall how this gun works, there is going to be a massive recoil of the gun after it is shot which means the gun moves back as the bullet moves forward and therefore, this optical system is also going to move back. The eye relief therefore, has to be placed quite far away you need a large eye relief otherwise this is assassin is going to be an assassin for one job only, because the eye relief would hit back on his eye and he would be blind and well that he would not have much of a career after that, right.

So, this is a rather violent example, but the idea to get is that you have to design your optical systems in such a way that the exit pupil is in a position that is useful depending upon the application, ok.

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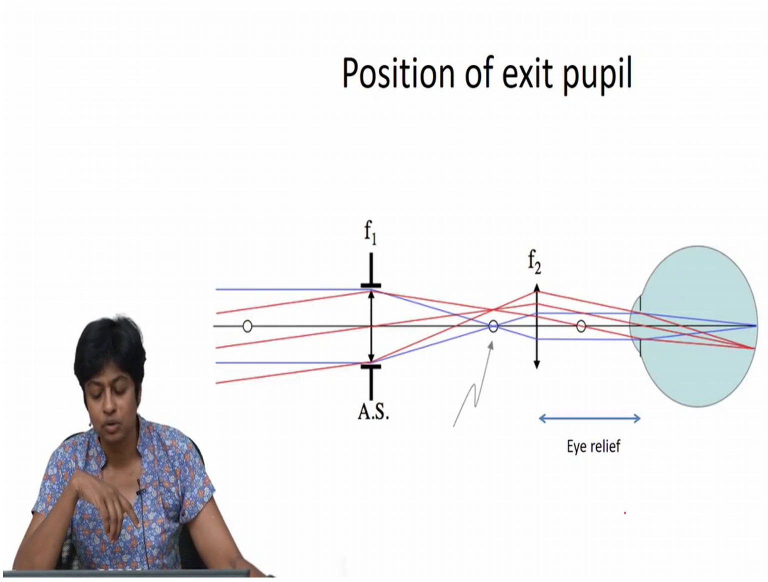

So, we will continue on this in tomorrow’s class and please do complete the homework that was assigned at the beginning.

Thank you.