Materials Science and Engineering
Dr. Vivek Pancholi
Department of Metallurgical & Materials Engineering
Indian Institute of Technology, Roorkee

Lecture – 07
Optical Aberration

So after going through optical microscope let us see some more problem with any optical system ok. So, already we have seen the one of the issues with any microscope which is related to resolution, that how close I can bring two objects and still I will be able to see them a two different entities, other than that there are more problem with optical, optical system and these are call optical aberrations.

You must be wondering for example, you can get camera for like 3000 rupees, 5000 rupees and if the price of a camera can go up to 1 lakh rupees in a SLR camera. And you must be wondering that why some cameras are coming.

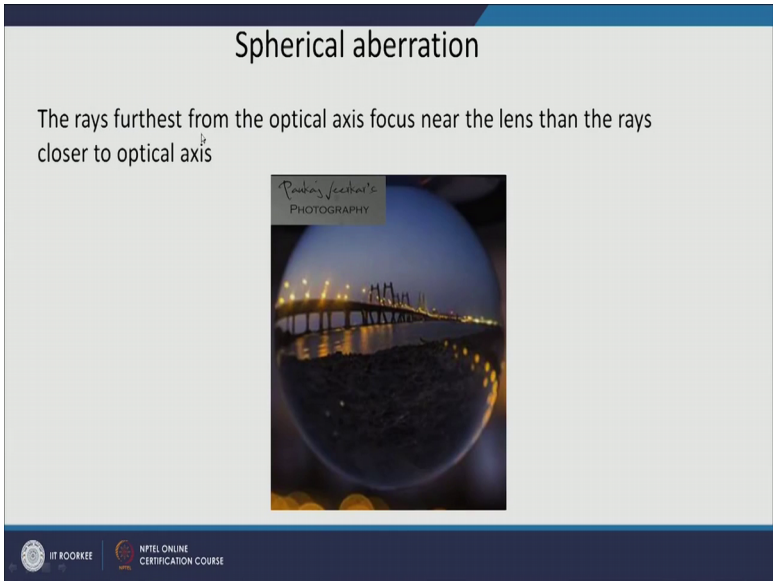
So, cheap, so they are getting you the same photograph ok, in case of optical microscope also you will see that some optical microscopes are coming as cheapest 25000 or 30000 rupees, and some optical microscopes are costing us around 3 or 4 lakh rupees ok. So, there is a large variation in the prices of cameras or microscope and so on.

And one of the reason for this wide variation in the pricing is because, how you produce these optical systems basically lenses and whether they are aberration free or not ok. So, just making a lens or an optical system aberration free add to the cost ok, and I tell you it is very expensive to make a perfect optical system ok. So, that you can get rid of all the aberrations in the optical system which in, which are introduced because of the lenses which we use ok.

So, when you buy a or your friend buy a expensive camera ok, do not make fun of him because he is spent money in getting their kind of optical system. So, in our ideal optical system, basically what we want is that all rays which are coming from the object they should fall on the same point to get a very clear and sharp image, but this is not what happens you have variation in the focal point depending upon different type of aberrations.

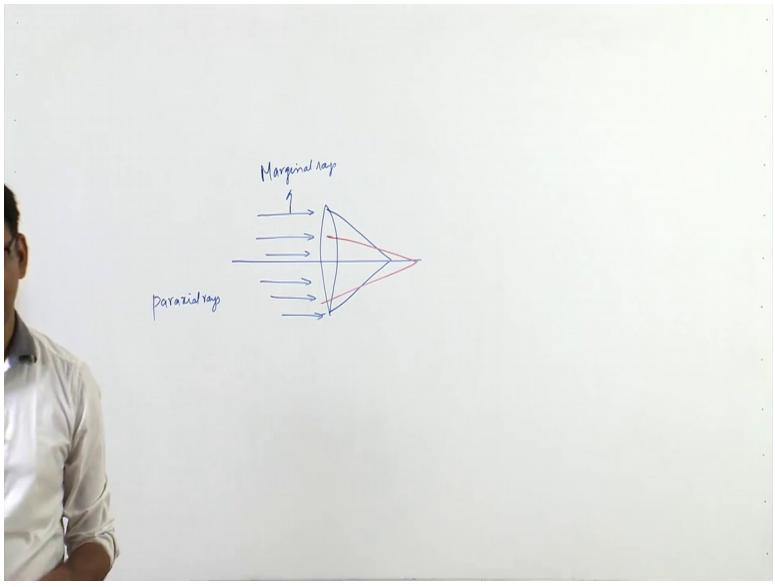
So, basically because of this aberration the light focuses at different point ok, and we will see that what are these different aberrations; some are because of the lens some are because of the light or electromagnetic radiation which we use ok. So, we categorize or classify this aberration based on that. So, one of the most important aberrations is called spherical aberration and as you can see on the slide it says.

(Refer Slide Time: 03:40)



The rays furthest from the optical axis focus near the lens then the rays closer to the optic axis ok.

(Refer Slide Time: 03:54)

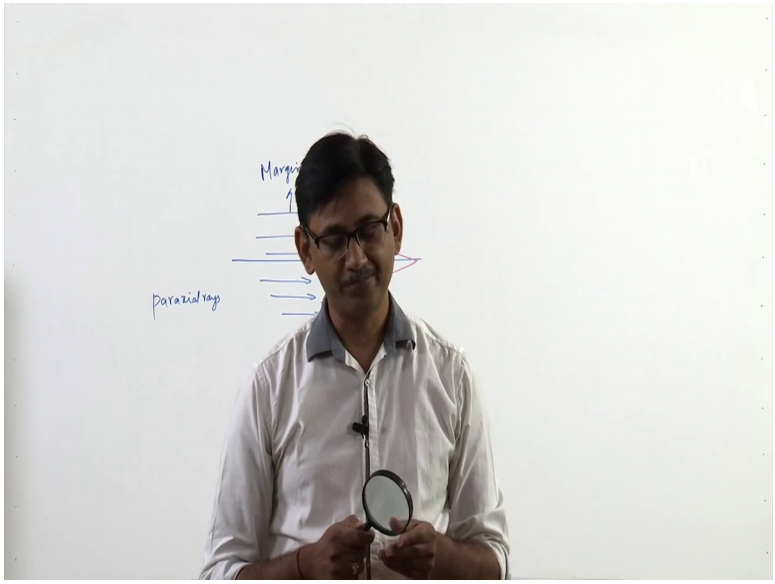


So, let me show you this particular aberration by a schematic here again I am making a lens here, and suppose I have a light source let us say I am getting all parallel rays here on the lens. So, in this ray diagram I the rays which are closer to the edge of the lens these are call marginal rays ok, all these rays are called marginal rays and the rays which are closer to a peak are called paraxial rays.

Now, the spherical aberration says that the rays which are marginal rays, they have focused at a, focal point which is closer to the lens and the spiritual rays let me draw it with some other pen ok, they kind of focus at a, position further away from the lens ok.

So, there are two focal points depending upon from which part of the lens the rays are converging ok, a photograph sent by one of my friend and his name is also given there he gave me this photograph and you can see that in the center the image looks focused ok, but the features which are on the periphery of that they are all look slightly out of focus. Of course, there is some kind of to change in the angle also of that particular feature. But the main thing to see here is that, when you look at the outer portion ok.

(Refer Slide Time: 06:06)



They look out of focus and that you can see in your normal magnifying lens also which we use at home ok, and you try to read it any newspaper or anything or we try to see any object using this ok. And what you will notice that you are reading only from the center of the lens ok, because that is where you are focusing or your focus is best and the

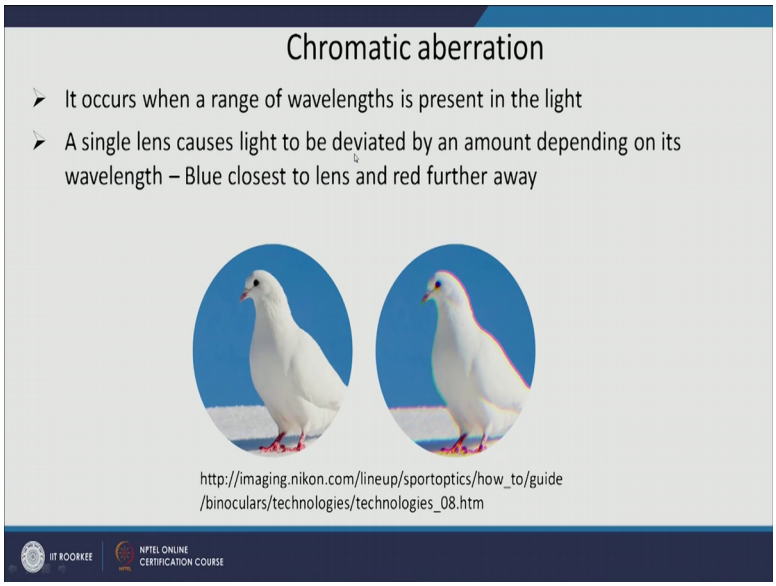
remaining portion is kind of slightly out of focus the, the rays which are coming from the periphery of the lens.

So, what happens now suppose, I keep my screen or my eye at this point what will happen the features which are on the outer side of the lens that will be in focus, and the features which are coming from the center of the lens they will be out of focus. If I change the position of a screen to this one what will happen now the center portion features are clear to me, but outer portions are usually out of focus and that is what you can see in this particular image in the slide also. It the center portion looks more or less focus, but the outer portion is looking out of focus ok, so that is what is the spherical aberration ok.

So, usually good a lenses or good microscope are in that this particular problem is taken care ok. So, you would not see a spherical aberration, the next one comes because of the light or the electromagnetic radiation which we use and this is called chromatic aberration ok.

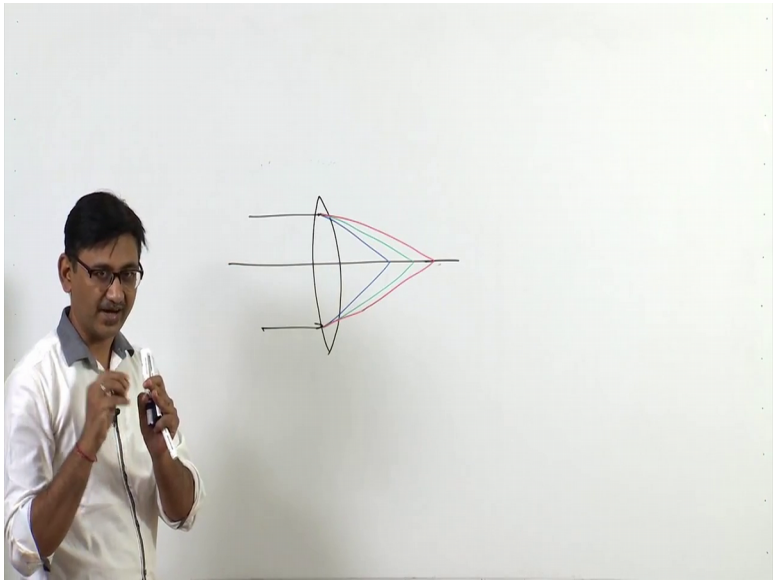
So, what is chromatic aberration it occurs when a range of wavelength is present in the light? So, our visible light, our white light, or white radiation has multiple wavelengths it is composed of a range of wavelengths from a red up to blue green blue and so on ok.

(Refer Slide Time: 08:16)



And when this kind of light goes through a single lens it causes light to be deviated by an amount depending on its wavelength ok. So, blue will be the closest to the lens and red will be further away from the lens ok. So, again let me draw a schematic here.

(Refer Slide Time: 08:34)



So, this is my lens, and suppose a white light is being is falling on the objective here, objective lens here or any lens here now depending upon the wavelength. So, this particular ray; which is composed of different wavelength ok, now it will get converged depending upon its wavelength.

So, as we said the blue will be the closest, then comes the green wavelength, and then you will have red one slightly draw it better. So, now, what happens in this case if my screen or my eye if it is here at the blue one?

So, blue image will be clear and there will be hallow of red and green around the around the image ok. If my eye your screen is here then the red reddish that image will be clear and there will be a blue hallow around the image ok.

So, there will be a after the features or whatever is the edge of a building or something you will get some multiple colors next to that particular image for example; here a pigeon is shown I have taken it from this website ok. And you can see that there is a red hallow around the where the edge of this is the body of the pigeon is there is a red hallow around that ok.

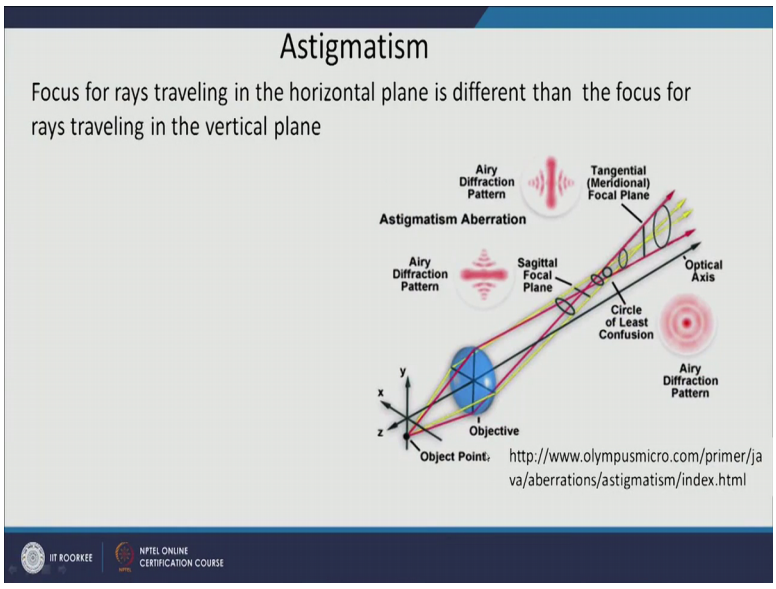
So, because we are not focusing at that particular image that particular hallow is been being shown here ok, so this kind of multiple image ok. So, one, one light is the affected into different rays and you will get this multiple image of different colors superimpose on each other ok.

And that will of course, bring down the clarity of the images you can see in these two images this one is very clear ok, does not have that problem and this one has the problem and you cannot see features for example, if you want to see the sharpness of the beak of this particular pigeon is not clear where it is in this case it is very clear ok.

So, this is what is the chromatic aberration usually, because of the multiple or range of wavelength in the, if use in a visible light ok. The next comes is astigmatism and this what happens where depending upon the plane through which rays is are passing your image the focal point will change depending upon that ok.

So, let us take for example, this lens ok. So, if my image is going through this vertical plane that will have a different focal point then the image which is going through the this horizontal plane. So, it will have a different focal point of course, it is little bit difficult to draw this thing. So, I have taken it this particular image from again another website.

(Refer Slide Time: 12:31)



So, this red one light which is going through the vertical plane it has a focus at some point here, and the yellow light which is going through the horizontal plane of the lens

has a different focal point this type of problem also come in a human eye. So, lot of time the people who wear, glasses or maybe some of your friend who wear glasses ok.

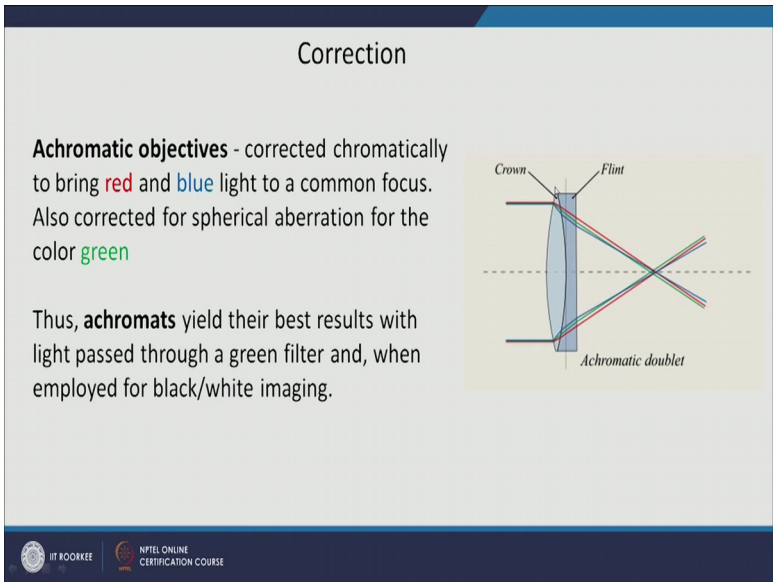
If they do not have this astigmatism problem their lens will be on the prescription if you go through the doctor it will be written as spherical ok, spherical lens of this much power. If you have a astigmatism then in your prescription it will also be written as cylindrical there will be a cylindrical lens in conjunction with the spherical lens ok, to correct the astigmatism which has come in your eye for example, in my case also I have in my right eye I have a astigmatism.

So, my lens has some power of a spherical lens and some power of this cylindrical lens to correct the astigmatism in my eye. So, basically again the problem is the lies the rays which are coming through in this vertical plane has a different focal point, and which is coming from the horizontal plane as a different focal point. So, to correct that to make the image at the same at the retina both should come at the same point I have to have a cylindrical, lenses also they are coupled with the spherical one ok, you, you would not be able to see the difference in your glasses, but it will be there ok.

So, this is the problem which we call as astigmatism two different image will be forming depending upon the, from which plane the rays are going ok. Now of course, when you have these problems there must be corrections also and as I told you then that when you do all these corrections that add to the cost of the microscope or camera for example, ok. So, there are few lenses which are available in the market ok.

So, when you want to buy a microscope or if you go in the market to buy a microscope you have to specify that I want this particular objective or this particular eye piece. So, one of the cheapest one in this is what we call as achromatic objectives.

(Refer Slide Time: 15:12)



As you can see it is a combination of convex lens, and a concave lens half concave and they are made of two different materials ok, to change the refractive index and by doing all this jugglery of combination and two different refractive index, they are able to correct the chromatic aberration here. And they are able to bring all the wavelengths together at one single point.

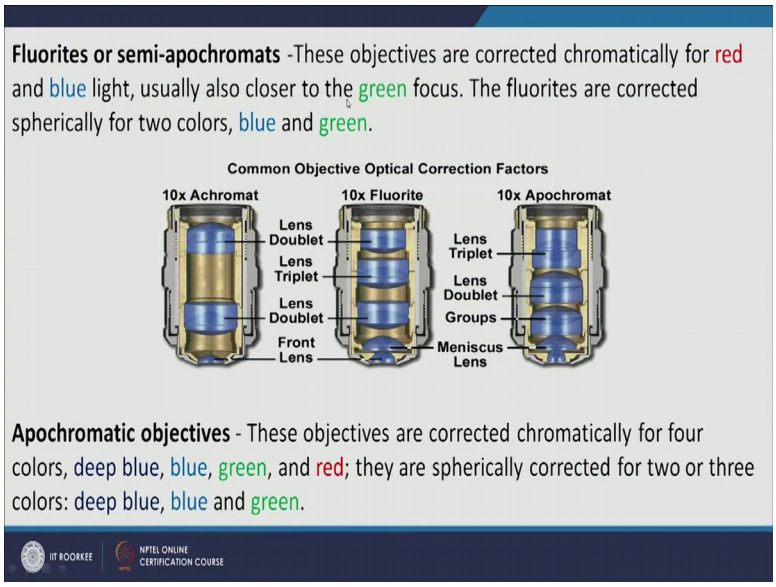
So, in achromatic objectives they are corrected chromatically for red and blue light they bring it to common focus at is also corrected for spherical aberration for the color green. So, green light for green light they have also corrected it for spherical aberrations ok.

Now you will understand if you have gone into your metallography lab lot of time we use this green filters ok. So, what this green filter does that one thing they does, is that it has eliminated all other wavelengths from your light ok. So, you have only one radiation now which is green, so you do not have to worry about chromatic aberrations because you are using only one wavelength.

The other thing is that some of these lenses is for example, achromatic objectives are corrected for green light for spherical aberration ok. So, using a green filter get you a much better result because chromatic aberration will not be there, spherical aberrations will not be there, because the lens is corrected for that ok. And that is why black and white imaging it works better in this case with green filter because most of your aberrations are taken care of ok.

Then there are more complicated lenses in the market ok, and these are called semi apochromats ok. These objectives are corrected chromatically for red and blue light and also.

(Refer Slide Time: 17:12)



If they are closer to the green focus the fluorites are corrected spherically for two colors blue and green ok. So, now they this spherically also they have corrected in this particular lens for both blue and green ok, the next which is the one of the most expensive objectives, apochromatic objectives these objectives are corrected chromatically for four colors deep blue, blue, green and red and they are spherically corrected for two or three colors deep blue, blue and green ok.

And in the on the slide you can also see that these different lenses are shown here ok. So, first one is apochromat 10 x apochromat, second one is 10 x fluorite or a semi apochromats, and the third one here is again 10 x apochromat ok. And just look at the complexity of the lenses here, when we see a microscope we see this objective or this ip we think there must be one lens which we usually draw or as a schematic, and we think of there will be one lens and it is doing all the job ok.

But it is not so you see that there are. So, many double lenses are there one will be convex one will be concave or a concave there is another doublet here. So, this whole big lens piece contains. So, many different small lenses in combination also this material for each of these lenses will also be different it will not be same we just saw in the previous

example ok. Now, if you go from achromat to fluorite in achromat only two doublets were there.

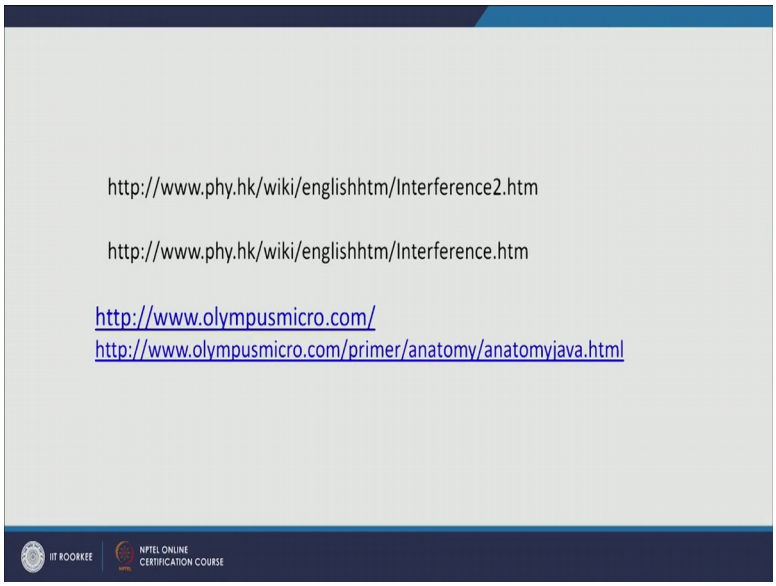
Now there are four doublets some meniscus lens is there then some doublet here another doublet here one more. So, now, you see that complexity of objective has increased and now you have to add these many objectives in the system ok. And these many lenses in the system with different combinations ok, and for each of these lens the making is a very tedious process you have to have a very nice curvature on that for example, astigmatism is also if you see it is a making a manufacturing defect ok.

So, while making the lens you could not maintain the same radius of curvature at each point ok. Somewhere the radius of curvature has changed then that is why in vertical plane and horizontal plane you have different focal point. So, astigmatism is a manufacturing defect which you can eliminate if you do, if you have better manufacturing capabilities ok.

So, when you add these many lenses you can see that for usually is you have to have good manufacturing capability to get lens without any defect in the lens then of course, apochromat you see more complexities ok, more lenses are there you can understand that the, the cost of the microscope increases almost exponentially with change in the type of objective we are using ok.

So, when you go to any manufacturer and if he is saying that he is going to supply you a apochromat ok. He is going to charge you for that and of course, the quality of image which you will get will be exponentially better than what you will get from a simple achromat ok. So, these are some websites which from which we took some of the images here.

(Refer Slide Time: 21:05)



So, just to acknowledge that we took and some you will also if you go through these website you will also understand the lot of details about microscope and of course, camera and other optical systems and with that I would like to say thank you today ok. I think if this particular lecture will be of interest to you because you understand that how microscopes are made and, what are the different components of a microscope?

Thank you.