Applied Optics
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Lecture 01
Course Overview

Hello everyone, welcome to this course. I am Akhilesh Kumar Mishra, Assistant Professor in the Department of Physics at IIT Roorkee. The title of this course is Applied Optics. Optics play a very significant role in our life.

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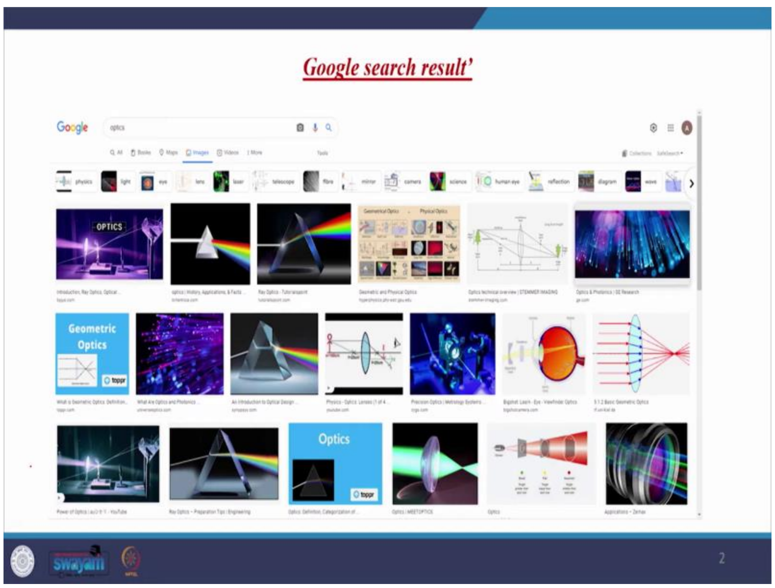

Even if you search the word optics in Google then you will see several results. Now, when I searched, I found a few pictures which I am sharing with you. You see that there are pictures of lenses and then the prisms are there, you can see you are launching a ray from left hand side and then on the right hand side of the prism, you see different colors and the incoming ray is white light and the prism is splitting this white light in its constituent colors.

The second picture is also of prism. Now, there are so many lenses you can see in this figure and then there comes eye, the diagram of our eyes and because we know we see things through our eyes and therefore, this is the major sensory organ which we have and we see the world through our eyes. And then therefore, light has a very deep relationship with our eyes, it gives us the perception of darkness, brightness, the colors of the light. Now, in this figure, you also see that different colors are appearing here, here in lenses.

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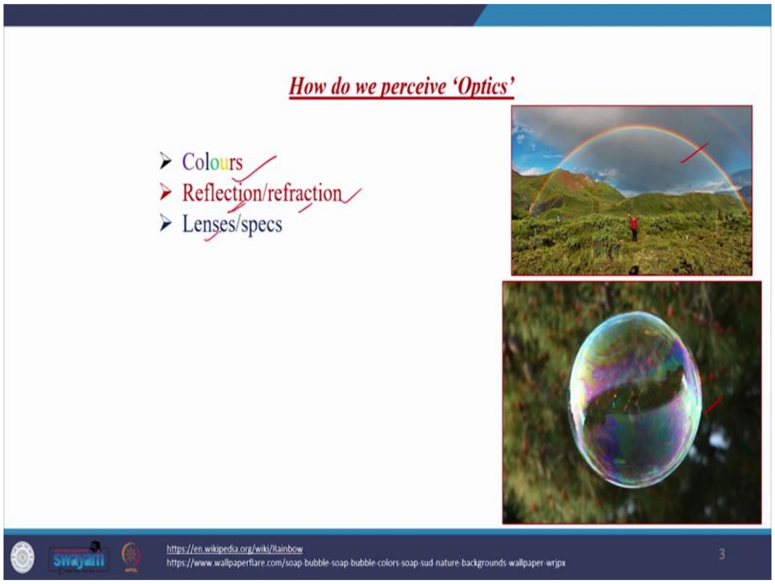

Now, whenever we say the word optics the things which comes in our mind is color, the first thing which appear in our mind is colors. Therefore, we can relate optics to colors, which we see in our daily life. Here we see colors in rainbow, we see color in soap bubbles, we see color in our daily life. Now, apart from colors, if we move deeper, if we go in follow some academic route and then from, if we go in our junior classes, then in science course, we all are introduced to reflection and refractions, this is our first interaction with the formal interaction with the optics here.

And apart from reflection and refraction, the optics also comes in play when we talk about lenses, or specs, the glasses which we wear this also has to do with the optics. Now, what are lenses? Lenses are glass substance and which has particular shape.

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Now, you see here I have brought a lens which is called convex lens and this convex lens is made up of glass and which has curved surface. Both surfaces, the left and right surfaces, they both are curved like this. The surfaces are bulging out. Therefore, it gives a different type of image. Had it been a plain glass plate, you would have seen me as it is. You would have not seen any modification in my image. But if you see through this convex lens, then you can see that my eyes look a bit bigger. I hope that you must be seeing my eyes through this convex lens.

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Similarly, instead of having this convex surfaces, if we make a lens which have this type of surface which is concave surface, then the lens is called concave lens. In this case, the surfaces are pressed in the middle and this is a concave lens. Now if you look in my eyes through this lens, then my eyes will look a bit smaller, although it depends upon the position of the object with respect to the lens or the position of the observer with respect to the lens which defines the original shape and size of the image.

But if I put it here, then you can see that my eyes through this lens which is convex lens, it looks bigger while with this lens it looks smaller, this one is called concave lens and this one is called convex lens and these lenses are used in our specs.

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Now, apart from these lenses, you have also seen the picture of a prism and this is prism. Now, you see that it is a three-dimensional triangle, you draw a triangle on a paper and then stretch it out then it will form a prism. And you see that this surface of the prism is not transparent and this is called base of the prism. We put prism like this, and then if you launch a white light on this interface, then from this face, we will see different colors of light coming out of, now here you launch white light and here you will see range of colors coming out of this face.

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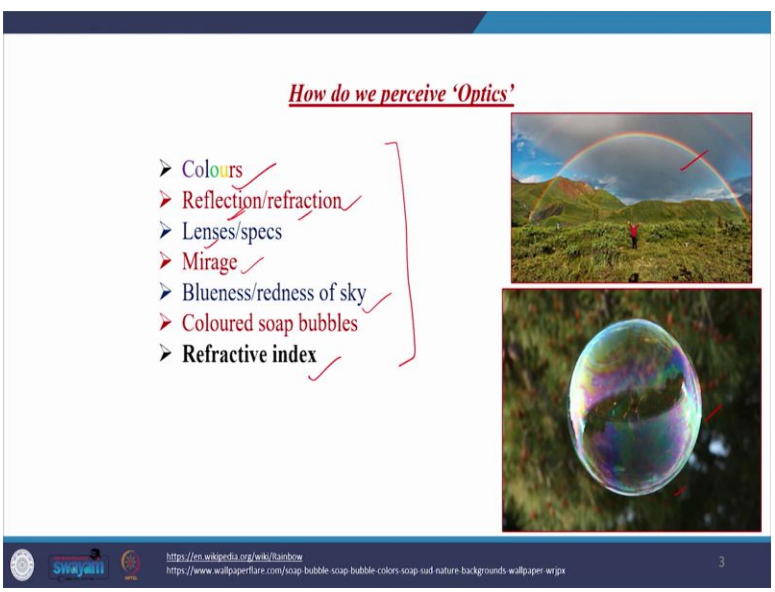

Now, you must have seen Mirage also in deserts, we see Mirages, it is also an optical phenomena and therefore, wherever we see it, we can relate it with optics. Now, in our junior classes, we also study blueness or redness of a sky, this is also explained through optics. These are the phenomena which we observe in our daily life and then understand optics, we can understand optics through these phenomena.

Colored soap bubbles, we have already talked about, there is a phenomena called interference, which we will devote few lectures on and due to this interference this thin films look color and bubble is made up of thin film and it give different colors, you see different colors floating on the surface of the bubble. This is due to the interference.

Now, a parameter which plays a major role in all this phenomena is called refractive index. We will talk about refractive index also in greater detail in this course, but this is through this word or through this phenomena we can perceive what optics is. Now, we will go much deeper with the progress after course and try to understand different phenomena in a greater detail. Now, I have shown you the pictures of this convex lens and concave lens.

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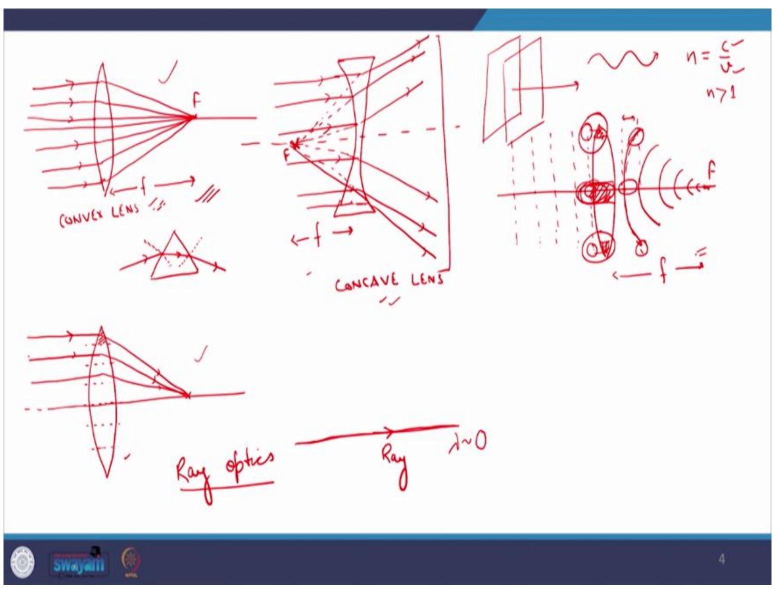

In your junior classes, you must have seen that when we draw a convex lens, this is called convex lens then this is the axis of the lens we draw and then when we launch a parallel beam of light from the left hand side then what does this lens do is that it focuses all these rays on a certain point.

You can see that it is converging all these rays which falls on this lens and this the distance of this point from the lens is called focal length and this point is called focal point of the lens. When you launch a parallel beam of light or when you launch parallel rays on a lens then it converges them to a point.

Here what you are seeing is that there is a convex lens or a converging lens which is converging the rays to a focal point, similarly if you draw a concave lens and then launch a parallel beam of light then what will happen is that this lens will diverse these rays and you can say if this is the axis of the lens, then it will diverge in such a way that these rays after refraction, it seems that they are coming from a point.

You will see that these rays are diversed rays, but if you extend them back then they meet here at point F on the axis this is again called focal point and this distance is called focal length. Therefore, the first lens which is convex lens is called converging lens and this concave lens is also called diverging lens. Now, how to explain why does this lens converges or diverges?

Now, to understand this what people do is that they split lens in smaller prisms, the dashed lines they are splitting the lens into smaller prisms. Now, suppose a ray is launched in this direction. Now, this is a prism what will it do? It will bend the light towards its base because we know that a prism, what does it do is that, when we launch light then it refract and this dashed line is perpendicular to the point of incidence.

Now, this after refraction the ray within the prism falls on the second interface here we draw a perpendicular and then again exercise Snell's law and then this is how the refracted ray look like and this ray which is coming out of the prism, it is bend towards the base of the prism and similar things happen here in the lens in this first, in this first prism the ray falls and then it get bent.

Similarly, the second ray it falls under second prism and it also get bent and this is how all the ray get focused on same point and this is why this convex lens is also called converging lens. In case of convex lens, in case of concave lens, the prisms are inverted their base is on top and the vertex is downward and therefore, the bending is up in upward direction and therefore, the rays get diverged.

Now, these explanations they fall in the category of ray optics, why? Because we only talk about rays. And how do we represent a ray? We draw a line with an arrow, the direction of arrow tells about the propagation direction and this line is called a ray, while defining a ray, we neglect the finiteness of wavelength. Here, we have assumed that wavelength is almost equal to 0.

And this can be assumed in cases where all the optical instruments are very large as compared to wavelength and we know the lenses like these, they are very big as compared to the optical wavelength, optical wavelength varies from 400 to around 750 nanometer and as compared to those wavelengths, these lenses, the dimension of these lenses are very huge.

Therefore, we can safely neglect the finiteness of wavelength. We can assume that wavelength is almost equal to 0 and there we can define ray, there we can explain things through the concept of rays. And the phenomenon of optics which can be defined through ray diagram through ray tracing it falls in the category of ray optics. But there are certain phenomena which cannot be defined or which cannot be explained through ray optics.

And therefore, people researched more and they came up with wave theory or wave optics. What is wave optics? Now, in wave optics, what people do is that instead of drawing this straight line, they consider waves for representing this light and these waves they oscillate with certain frequency and they propagate in certain direction. Now, how to explain this convergence and divergence in convex and concave lens using wave theory, here is the explanation let us again draw this convex lens and this is the lens axis.

Now, instead of drawing rays, we will draw wave front or phase front. Wavefronts are locus of points which oscillate in same phase. Now, suppose you have a point source and from this point source the wave is coming out in all the directions. There what we will see is that since the point source is having spherical symmetry therefore, it will emit spherical wavefront, why? Because on the sphere the all points are oscillating in the same phase and therefore, it will form a spherical wavefront.

Similarly line source, it will emit a cylindrical wavefront. Extended source extended plane source will extend a plane wavefront. I repeat, wavefront is locus of points which oscillate in same phase. Now, suppose we launch a plane wave on a convex lens. Usually plane waves are drawn, usually plane waves are represented by these planes and they propagate in this direction.

Now, here since our paper is in two-dimension, therefore, let us represent these planes with a straight line, if you take a cross section of a plane you will get a straight line and let us assume that this is plane wavefront which is falling on the convex lens. Now, these wavefronts will come and the center portion of this wavefront will see the lens surface first because there is a curvature on the lens surface, the central portion is bulging out.

Therefore, the plane wavefront which is approaching towards the lens it will see the central portion of the lens first, and then it will the central portion of the wavefront will start traveling within the lens medium. While the extremities, the extremities of the wavefront will see the medium of the lens a bit later. In addition, the central portion of the lens is thicker as compared to the extremities.

And this is why the central portion of the wavefront will see more lens material as compared to the wings or edges of the wavefront and we know that the lens is kept in air and lens is made up of glass which has a refractive index which is larger than that of the air. You know that refractive index n is defined by c by v, where c is the speed of light in vacuum while v is the speed of light in the medium.

Now, you know that n for the glass is larger than that of air, therefore, the velocity of the wavefront within the lens would be smaller. Since central part of the wavefront is staying for longer duration within the lens, therefore, it would be delayed as compared to the extremity of the wavefront. And therefore, this the central part this part it would be delayed and this part will be ahead in time.

Central part is staying longer in the lens because lens, the thickness of the lens is larger while at the tip of the lenses, the thickness of the lens is smaller and therefore, the part of the wavefront which is going through the tip of the or the thinner portion of the lens. It will stay for a shorter duration within the lens medium.

And therefore, although it would be delayed, but the relative delay between the central portion of the wavefront and the edge of the wavefront, the upper and lower portion of the wavefront the relative delay would be different. The central portion would be delayed more and therefore, at the output the wavefront will look like this, something like this.

You see here that there is a difference here, this difference is because of the thickness of the lens, the varying thickness of the lens instead I should say. And at the center the lens is thicker, therefore, the central portion got delayed more, at the extremities the lens is a bit thinner therefore, the delay is less at the extremity of the wavefront at the top and bottom portion of the wavefront are less delayed as compared to the central portion.

And this is why we see this type of curvature at the output in the wavefront. Due to this curvature the wavefront propagates and get focused here and this is the same distance as was observed in the ray theory description here in the left most figure and this point is called your focal point. Now, this explanation falls in the domain of wave theory.

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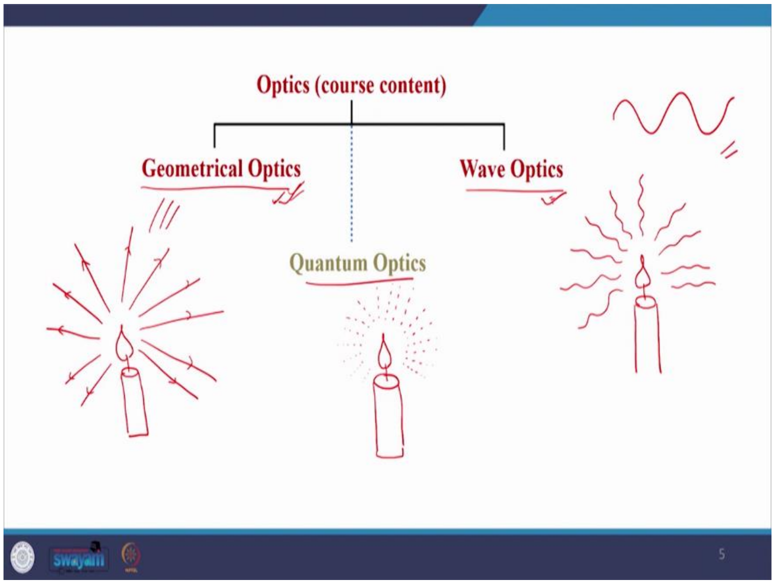

Now, coming to the content of this course the content is divided in two parts. The first part is geometrical optics and the second is wave optics. And now I hope that you understand why this differentiation is because in geometrical optics, we apply ray theory and in wave optics, we apply wave theory which is well explained in the previous slide.

The part, I again repeat, of optics which can easily be explained using ray theory, it falls in the category of geometrical optics, while the part of the optics, which can be explained through wave theory, it falls in the category of wave optics. Therefore, the optics can majorly be defined in these two parts geometrical optics and the wave optics. And the course is also divided in these two categories all the content of the course.

Therefore, the first part of the course falls in the category of geometrical optics while the second part in wave optics. But apart from these two categories, there exists a third one, which is called quantum optics. In quantum optics we quantize the light. To understand the differences, let us suppose that we have a candle.

Now, if you want to understand the emission of light in this through this candle then there are several ways the first way or the first method is this ray, geometrical optics and in geometrical optics if you want to understand the emission of light from the candle then just draw these rays then in geometrical optics the emission of light from the candle can be understood through these ray picture.

There is a candle and the candle is emitting light rays and this such a description falls again in the category of geometrical optics. And while in the wave optics we know that a wave is nothing but a disturbance and if we hold a rope and start waving our hand up and down, then it will create a sinusoidal like pattern and this is the typical representation for a wave. A sinusoidal pattern is a typical representation of a wave but generally any disturbance can be defined like a wave.

And if you want to understand the same phenomena of light emission in the wave optics then again let us draw this candle and then here we say that the waves are emitting it is a rough description although, still okay. The emission here is explained through this wave picture which is nothing but a wavy line.

But what about quantum optics as I said in quantum optics we discretize the light, it means the light wave is no more continuous you cannot draw a continuous line be it a straight or wavy. Therefore, in this description we can draw this broken line, it represents it symbolizes quantization or discreteness. But the course Applied Optics it covers only geometrical optics and wave optics, we will not discuss quantum optics in this course.

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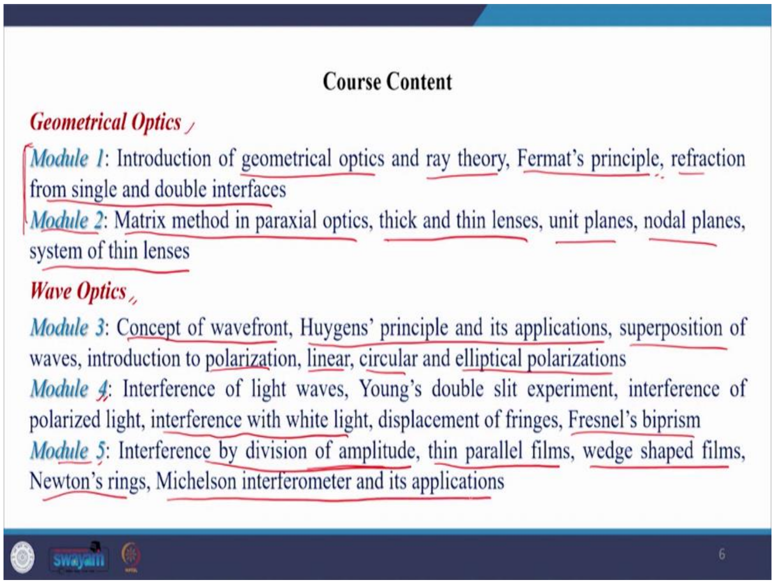

Now, with this let us go to the course content as I said before the course is divided in two parts geometrical optics and wave optics and in total there are 12 modules. This is a 12 weeks long course and therefore, there are 12 modules. In geometrical optics, we have 2 module while in wave optics, we have 10 modules.

In the first module, I will introduce you to the geometrical optics and the ray theory, then Fermat's principle will be introduced and using this Fermat's principle we will try to understand the phenomena of refraction, reflection, total internal reflection we will derive Snell's law using Fermat's principal and using this principle we will try to understand refraction from single and double interfaces.

We will take curve interfaces and on this curve interfaces we will launch rays and we will try to understand its refraction. Now, in module two, we will talk about matrix method in paraxial optics. Then, we will derive the lens formula for thick and thin lenses we will also derive the expression for the focal length for both thick and thin lenses.

And thereafter, principle planes would be introduced wherein we will talk about unit planes and nodal planes and at last we will study system of thin lenses wherein we will put instead of one we will analyze two lenses when they are placed together with a certain separation between them. And in this topic, we will also derive a focal length for this combination of the lens system.

After this we will move to the wave optics part, wherein first of all we will be introduced to the concept of wavefront then we will talk about Huygens principle and its application which would be followed by superposition principle and introduction to the polarization. And in polarization we will talk about linearly polarized light, circularly polarized light and elliptically polarized light. In module four interference would be introduced, wherein we will talk about the famous historical Young's double slit experiment.

And in Young's double slit experiment, we will also learn the role of polarized light, what role polarization plays, how would it affect the fringes or fringe formation, fringe visibility, this all would be discussed in module four. Apart from this, we will also learn interference with the white light. We will see that if in Young's double slit experiment, what will happen if we cover one of the slits with thin transparent film.

And then, we will also talk about Fresnel's biprism experiment. In module five, we will continue with interference but here we will talk about interference by division of amplitude here because in module four whatever interference was studied it falls in the category of division of wavefront here we will talk about division of amplitude wherein we will talk about thin parallel films, wedge shaped films, Newton's ring and famous Michelson interferometer and its application.

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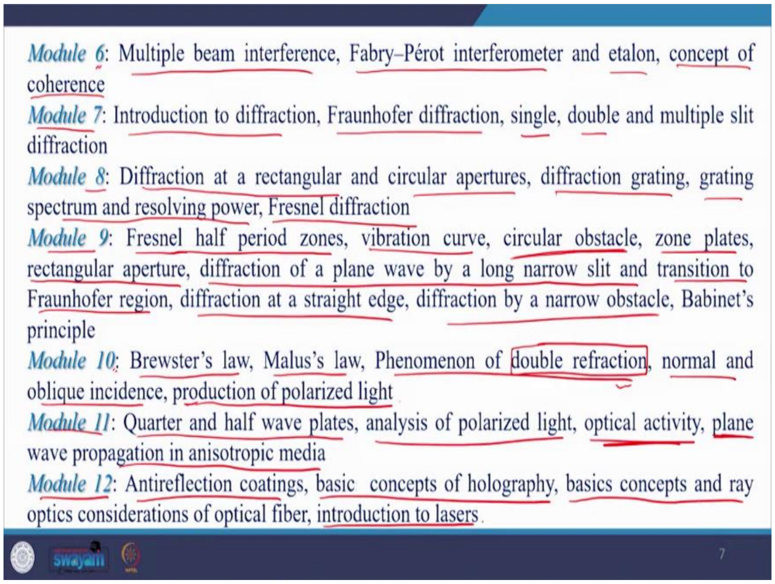

We will continue with interference in module six as well, and in module six, we will see interference with multiple beam that will be followed by Fabry-Perot interferometer and etalon and then the concept of coherence would be introduced which is a very important part. With module six, we will finish the interference and module seven will start diffraction. In module seven, you will be introduced to diffraction and we know that diffraction is of two kinds the first is called Fraunhofer diffraction second is called Fresnel diffraction.

In module seven, we would be focused with Fraunhofer diffraction, wherein we will talk about single double and multiple slit diffraction pattern. In module eight, we will talk diffraction at a rectangular and circular aperture, then diffraction grating which would be followed by grating spectrum and resolving power. And at the end, we will be introduced with Fresnel diffraction.

In module nine, you will continue with a Fresnel diffraction and here we will learn Fresnel half, learn about Fresnel half period zones, vibration curve, diffraction through circular obstacle, then the concept of zone plates would be introduced, then diffraction through rectangular aperture would be talked about, then diffraction of a plane wave by long narrow slit and transmission to the Fraunhofer region, then diffraction at the straight edge, diffraction by a narrow obstacle and at last Babinet's principle.

In module 10, we will be introduced with Brewster's law, Malus law, phenomenon of double refraction, normal and oblique incidence and production of polarized light. In this module, you can see that, that this phenomena of double refraction is something which is very new, which you must have not heard up till your intermediate classes. And in module 11, quarter and half wave plates will be introduced.

And then using these wave plates, we will learn how to analyze a polarized light if a light is given to us, then how to know what is the state of polarization of this light, this would be covered in module 11. Then we will talk about optical activity and then a theoretical foundation would be introduced for wave propagation in anisotropic media. The mediums can be categorized in two categories, one is called isotropic media and another is called anisotropic media.

In anisotropic medium, optical properties are direction dependent, while in isotropic medium optical properties are direction independent. In the last module, we will talk about the applications of what we studied till module 11. The first application is antireflecting coating that would be followed by holography.

Then we will be introduced with the basic concepts and ray optics consideration of optical fibers. And at last you all would be introduced to lasers. This is the whole syllabus, 12 week long syllabus of this course on Applied Optics.

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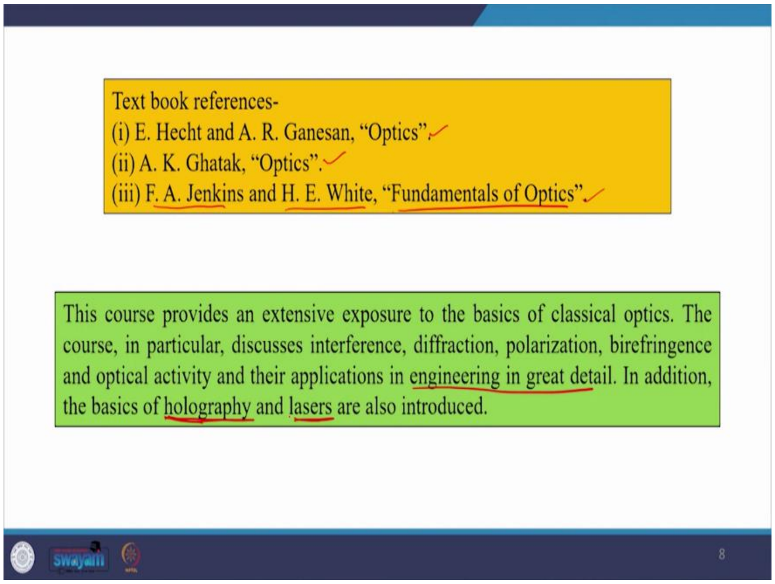

As a reference book, I would be majorly following optics by E. Hecht and A. R. Ganesan and optics by A. K. Ghatak, off and on, I would also be resorting on fundamentals of optics by F. A. Jenkins and H. E. White. I hope that this course would introduce you to the basic concepts of optics, it will not only give you the exposure to the ray optics, which is geometrical optics, but it will also go deep into the wave optics.

And then there in the wave optics, you will learn about the very important phenomena of interference, diffraction, then you will be introduced with polarization, birefringence, optical activity, and there so many applications. And these applications are important not only to the scientists, but also for the engineers.

In addition to these a very new concept of holography will also be introduced to you in this course and at last we will also cover lasers. With this introduction, I end my today's lecture, hope to see you in the next class, thank you for joining me.