Applied Optics
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Module 3
Lecture 11
Concept of Wavefront, Huygens' Principle – I

Hello everyone, welcome to my class. Today we will start wave optics. Till now, we have covered module number 1 and module number 2. In these 2 modules, we talked about geometrical optics.

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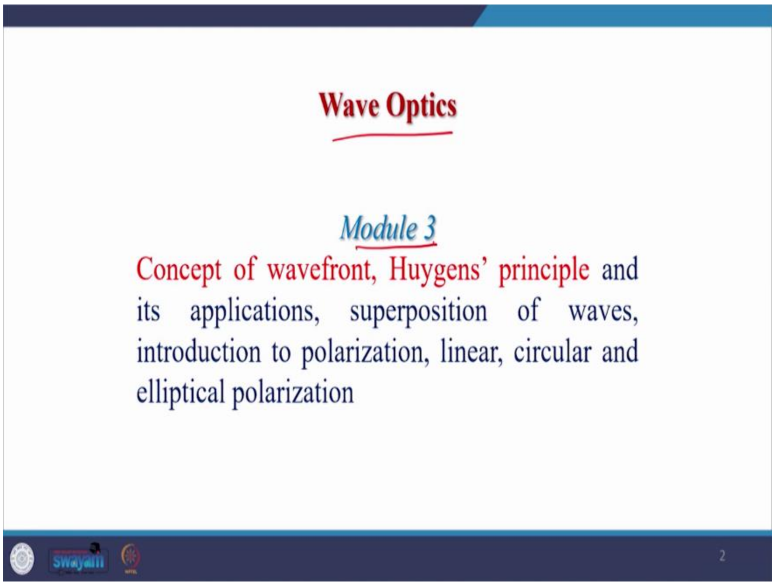

Now onwards, we are moving in the second part of the course, which is wave optics. And in wave optics, there are 10 modules starting from module number 3. So, today, we will start module 3, and within module 3, we have several topics which will be covered during next few lectures.

In module 3, we will talk about concept of wavefronts, and then we will talk about Huygens' principle, and its application, which would be followed by the introduction of superposition principle. And then, we will learn about polarization, wherein we will talk about different kinds of polarization, such as linear polarization, circular polarization. Today, we will start with the concept of wave front, and Huygens' principle. But before that, we will talk a bit about history of optics, or history of light, which people discovered from time to time.

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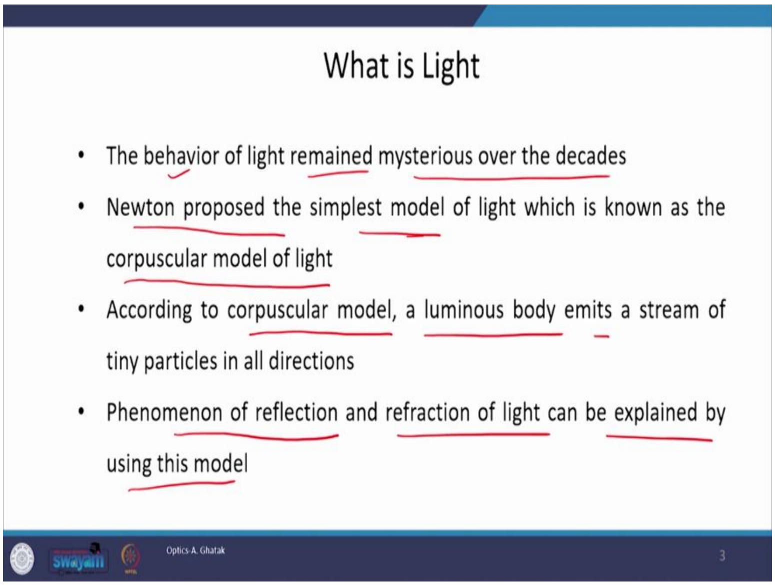

Now, the behaviour of light remains mysterious over decades. Sometimes, people were saying that light behave like a particle. And Newton gave corpuscular theory where he told that, from the light source, light comes in form of small particles. And then Huygens told, no, it is not in the form of particle itself, in form of waves and so on and so forth. There were several models, we will just go briefly through them. Then Newton proposed the simplest model. And in this model, as I told, he proposed corpuscular nature of the light, and this model is called corpuscular model of light.

And according to this corpuscular model, a luminous body emits a stream of tiny particles in all directions. The phenomena of reflection, and refraction of light can be explained using this model. This model successfully explained refraction of light, as well as reflection of light. But it could not explain several other phenomena. And what are those phenomena? These were diffraction, this corpuscular theory failed to explain these phenomena.

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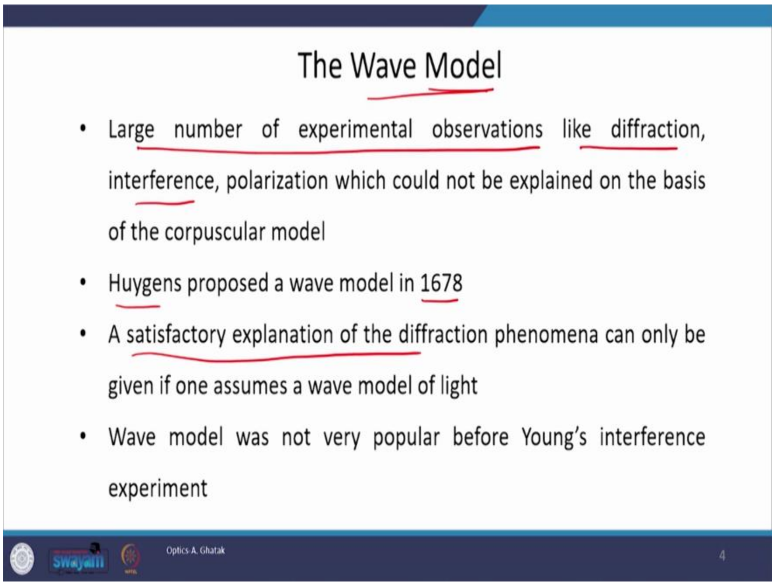

Now, a large number of experimental observations like diffraction, interference, polarization, these things could not be explained on the basis of corpuscular model. And therefore, people thought of a new model, which we call wave model, and this model was proposed by Christian Huygens, and this model was proposed in 1678. A satisfactory explanation of diffraction phenomena can only be given if one assumes a wave model of light. The wave model which was proposed by Huygens was not very popular before Young's interference experiment.

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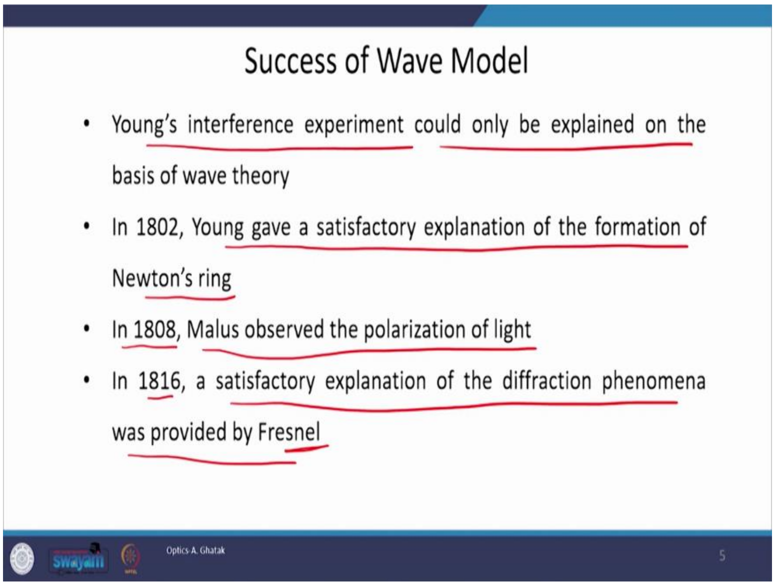

Now, Young's interference experiment could only be explained on the basis of wave theory. This interference experiment could not be explained using corpuscular theory, or using geometrical optics. In 1802, Young gave a satisfactory explanation of the formation of Newton’s ring. Right after this in 1808, Malus observed the polarization of light. All these things were explained using the wave model. And in 1816, a satisfactory explanation of diffraction phenomena was provided by Fresnel. These wrote the success story of wave model.

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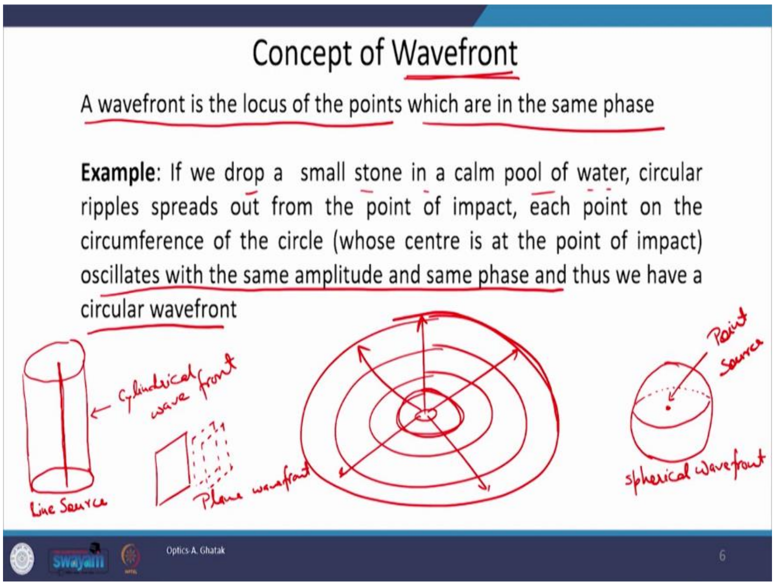

Now, once we know that wave model is very successful, then we must know what are the building blocks of wave model. But before starting wave model, we must understand a few preliminary definitions. The basic definition which come in the domain of wave model is wave front. Therefore, in this slide we will learn what a wavefront is?

A very standard definition of wavefront is that, a wavefront is the locus of points which are in the same phase. And a very good example to understand the concept of wavefront is a water body. Take a pebble and drop it in the pond, then what will happen? The pebble will go down, and it will strike with the upper surface of the water, and then from the point of impact a wave will get generated, a wave will generate from the point of impact, and it will propagate radially outward.

Then this type of wave will be observed, you must have seen in the pond that a concentric wave start to propagate outward from the point of impact of the pebble. This is the direction of the propagation, these arrows represent the direction of the propagation. And this is what is written in this example, if we drop a small stone in a calm pool of water, circular ripples spread out from the point of impact, and these are these ripples, these circles are the ripples.

And each point on the circumference of the circle, now, if we consider a particular circle, then each point on this oscillates with the same amplitude and same phase, this is very important point. Each point on this circle oscillate with the same amplitude, and with the same phase.

And therefore, this fits with the definition of wavefront, and we call it a circular wavefront. Because all the points on the circle, they simultaneously go up and they go down. This simultaneous motion means they are in the phase, and once they are in the phase all the points which are moving in the same phase form a locus, which locus? and this locus is our circle. And therefore, the wavefront in this particular case is circular, let us repeat the definition of wave front.

A wavefront is the locus of points which are in the same phase, and we see that in the case of water. As soon as we drop a pebble, circular ripples generate, these ripples propagate radially outward and on a particular circle all the points oscillate with the same amplitude and phase. And therefore, this wavefront is a circular wavefront, and they satisfy the criteria of the wavefront, and this is one of the examples.

But all the wavefronts are not circular, if you take a line so, this is the example of mechanical wave in the optical domain, if you take a point source then what will happen? A point source will radiate in all possible direction, if there is a point source, a small light source and it will radiate, it will emit light in all possible direction.

And therefore, if you form, or if you consider the locus of points which are oscillating in the same phase then it will form a sphere, you will see that the locus of points which are oscillating in the same phase would be sphere in case of point source. The centre, this is our point source, and the locus of points which are oscillating are moving in the same phase is a sphere. Therefore, in case of point source we have spherical wavefront.

Now, instead of point let us pick a line source. This red line is suppose to our line source, which have almost 0 width, and it is extending from it is a very long in length, and let us call it a line source. What would be the shape of wavefront in case of line source? It can easily be guessed and the wavefront which this line source will emit would be in the form of a cylinder. Therefore, line source emits a cylindrical wavefront.

Similarly, if we have suppose a source, which is in 2D, and it is extending till infinity in both these 2 direction, then it will emit a plane wavefront. Suppose this is your source, then it will emit a wavefront which would look like this. And this is called plane wavefront. An extended source emits a plane wavefront, the source which is in the form of plane will emit a plane wavefront, these are the few examples of the different kinds of wavefronts.

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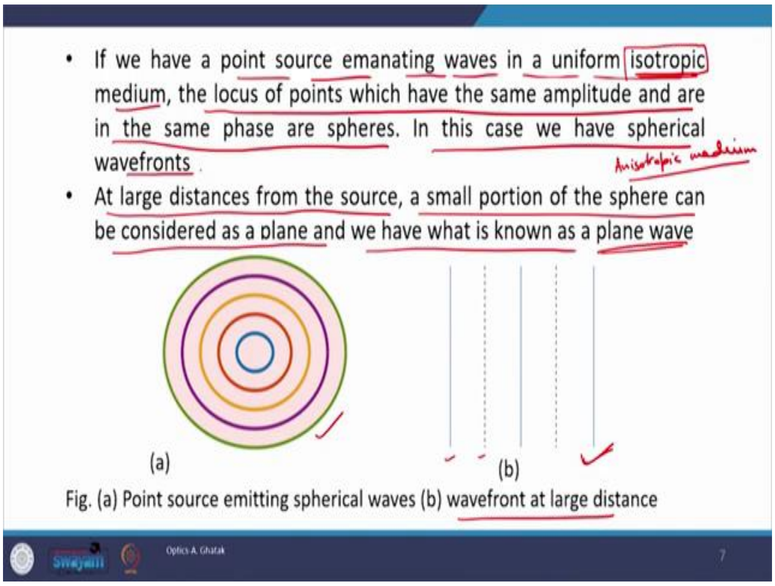

Fig. (a) Point source emitting spherical waves (b) wavefront at large distance

And now, if we have a point source emanating waves in a uniform isotropic medium, then the locus of points which have the same amplitude, and are in the same phase are spheres. And in this case, we have a spherical wavefront, and this is what we discussed. Now, a very new word which appears here in this statement is isotropic medium, what is isotropicity?

Isotropic media means, the medium whose properties are independent of the direction, a media which exhibit same properties in all the directions. And if a medium exhibits different property in different direction, then such a medium is called anisotropic medium, the word is anisotropic. If a medium has different properties in different direction, than this medium is called anisotropic medium, while the medium is exhibit same property in all the direction, it is called isotropic medium.

Now, moving to the next point, suppose we have a point source which is emanating a spherical wavefront, and we let this wavefront propagate through a very long distance, then what will happen? If you take a small portion of this sphere then it will look like a plane. Therefore, at a larger distance we can treat a circular, or spherical wavefront as a plane wavefront, and this is what it is written here. At large distances from the source a small portion of the sphere can be consider as a plane, and we have what is known as plane waves, or plane wavefront. Where can we get such kind of wavefront? How to realize it?

The sun which is very far from us, we can treat it as a point source, and since it is a spherical in nature, the original sun is a big object and it is a spherical in nature, we can assume that it is emanating a spherical wavefront. The wavefront, which is coming or traveling towards us, it travels a very long distance while coming to us. And therefore, we can treat this wavefront as a plane wave.

Now, these are the examples of a spherical waves, and these are schematically drawn here, and the wavefront at a large distance you will see that it can be treated as plane wave. And that continuous and dashed line means, crest and trough of the waves, here they are represented by continuous and dashed lines respectively.

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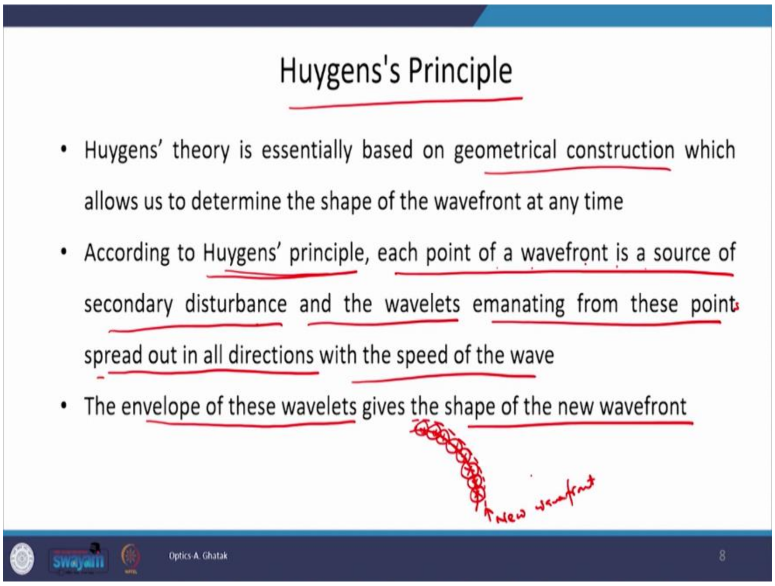

Now, coming to the Huygens's principle, this Huygens theory is essentially based on geometrical construction, which allows us to determine the shape of the wavefront at any time. The basic Huygens's principle we have already studied in our junior classes, and we know that suppose we have a point source and then it is emanating a wavefront, then each point on this wavefront will work as a secondary source, and these secondary sources again emit a spherical wavefront, and then you draw envelop over the secondary wavefront, or secondary wavelets, and this envelop forms the new wavefront, and this is how the waves propagate, this is what we have studied in our junior classes.

And let us see what exactly Huygens says on wavefronts and its propagation. Huygens's principle says that each point of a wavefront is a source of secondary disturbances, suppose this is a part of the wavefront then each point which is on this wavefront it works as a secondary source or secondary disturbance. And then a sphere, a spherical wavefront can easily be drawn starting from these point sources, and these new wavefronts are called wavelets. Now, let us repeat each point of a wavefront is a source of secondary disturbance, and the wavelets emanating from these points spread out in all directions.

And what would be this speed of the spreading, speed of propagation? This would be equal to the speed of the wave. Here each point on the wavefront work as a secondary source. And from these secondary source, secondary wavelets or wavelets get emanated, and they propagates with the speed of the wave. And then we draw envelop on these wavelets, and then we draw an envelope and this envelope gives the shape of the new wavefront, this will be your new position of the wavefront, or new wavefront and this is how the wavefront propagate.

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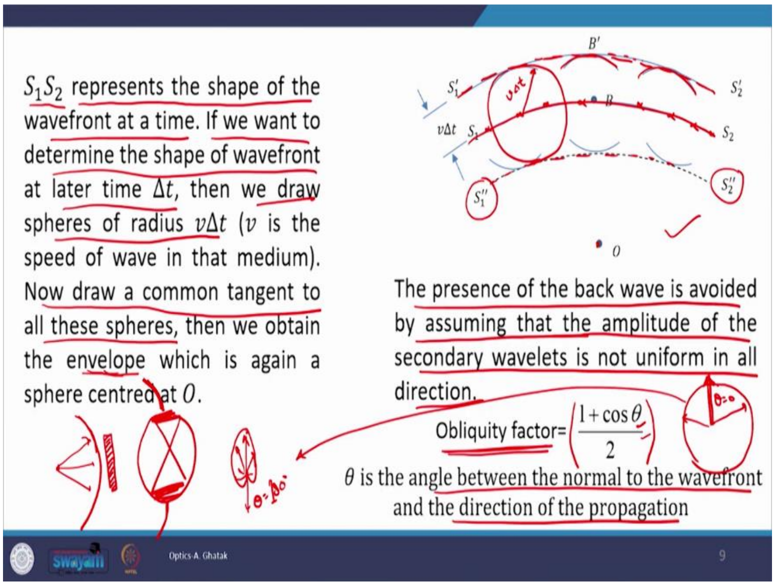

And this is what is drawn here in this figure is schematically. In this diagram, S_1, S_2 this is a part of a spherical wavefront, this is what is written here S_1, S_2 represents the shape of the wavefront at a time. If we want to determine the shape of the wavefront at a later time Δt, then what we will have to do? Then we draw a sphere of radius $v \times \Delta t$, where v is the speed of the wave in that medium. And if you want to know what would be the position of the wavefront after a time Δt , then we will have to draw a radius, draw a sphere of radius $v \times \Delta t$, from each point of the wavefront S_1, S_2. There are many points here on the wavefront, and we will have to draw a sphere of radius $v \times \Delta t$.

And suppose we draw one such sphere like this, and the radius of the sphere is $v \times \Delta t$. And this way we will have to repeat it many times. Once such a sphere is drawn, then next what we will do? We will draw a common tangent to all these spheres, once a common tangent of, now these are the spheres, the part of the spheres and this is the common tangent. S'_1, S'_2 is the common tangent, and once the common tangent is drawn then this common tangent or the envelop gives a new position of the wavefront. And this wavefront would again be in form of a sphere, and it would be cantered at the original origin O.

But you see that, in this figure we only draw envelope in the forward direction, the same envelope can also be drawn in the backward direction, and if you draw the envelope in the backward direction, then you will get a curve $S"_1$, $S"_2$ but no one talks about it.

Huygens said that wave does not propagate backward. He just avoided this wave. And this is one of the drawbacks of Huygens theory, and the presence of the back wave is avoided by assuming that the amplitude of the secondary wavelet is not uniform in all the direction. Huygens just said that the backward propagation is not possible.

Later obliquity factor was introduced. And it was Fresnel who introduce the obliquity factor, and what does obliquity factor does? The obliquity factor is nothing but an expression which is (1+cosθ)/2, and θ is the angle between the normal to the wavefront, and the direction of propagation.

Suppose a wavefront is going in x direction, and the normal is pointing in other direction, then θ is the angle between the two. Now, this θ, if we consider the forward direction then this θ would be 0, and this obliquity factor would be equal to 1, it means in the forward direction the total amplitude of the light will propagate.

Obliquity factor is nothing but it is a multiplication factor which goes with the amplitude of the wave, and in the forward direction when θ is equal to 0, you can say that the wave is propagating with its full amplitude. Suppose this is a point on the wavefront, and then this is the secondary wavelets which are emanating from the wave, and this is the direction of the propagation. Then in this direction of the propagation θ is equal to 0, but, if you increase θ, then what will happen? The amplitude will decay down as per this obliquity factor. If you increase θ, then the value of obliquity factor will reduce down from 1.

And therefore, instead of the circle, you will get this, something like this, the intensity would be maximum in the forward direction, and then it will reduce down. And here you will get 0, exactly at 0 degree you will backward in this direction, where θ is equal to 180 degree then, obliquity factor would be equal to 0.

This means, as long as we are looking in the forward direction, we will have maximum amplitude. And if we start to increase a spread of θ, then amplitude of the wave will reduce. And it will keep reducing and in the backward direction, since obliquity factor is 0, there would not be any amplitude. And this way we can say that the light will not go in the backward direction.

One more assumption which was made by Fresnel was that, suppose there is a point source and this is the wavefront, the part of the spherical wavefront which is propagating in right hand direction. And suppose we put a stopper here, an obstacle, then what it is supposed is that we will get a part of the wavefront here, and part of the wavefront here, and you will not get anything in the shadow region.

What Huygens said is that, as long as a part of the space is enveloped by the wavefront, we will have light there, or we will have nonzero amplitude there. And if we cover a part of the wavefront, then there should not be any light in that portion, since this portion is not enveloped by the wavefront.

But what is found is that apart from the portion of his space, where there is a wavefront, where there is light, but light was also found in the shadow region. Some light was there in this part, and some light was there in this part, this is exactly what diffraction is. This is exactly the diffraction, there is a light in the shadow part, and the presence of light in the shadow part is the phenomenon of diffraction, and this cannot be explained using Huygens principle.

Later, Fresnel came into the picture, and he modified Huygens' principle and he said that the wavefront they can also interfere. Once we incorporate this addition into the Huygens's principle, then this principle can explain interference and diffraction. And this modified principle is called Huygens-Fresnel principle. And this is all far today, and thank you very much for listening me. See you in the next class.