Spectroscopic Techniques for Pharmaceutical & Biopharmaceutical Industries

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Lecture 2

Introduction to Spectroscopy II

Hello students, welcome to second lecture of the course. In the last lecture we discussed about what is the content of this course and we also discussed about what kind of questions we are going to ask and what kind of questions we are going to discuss.

As I told you that this course consists of two parts; one is your theory of the spectroscopy or principles of the spectroscopy and second part deals with the applications. applications will include The application in chemistry application in biochemistry and application in medicine. So in this lecture I will focus on basics of the spectroscopy.

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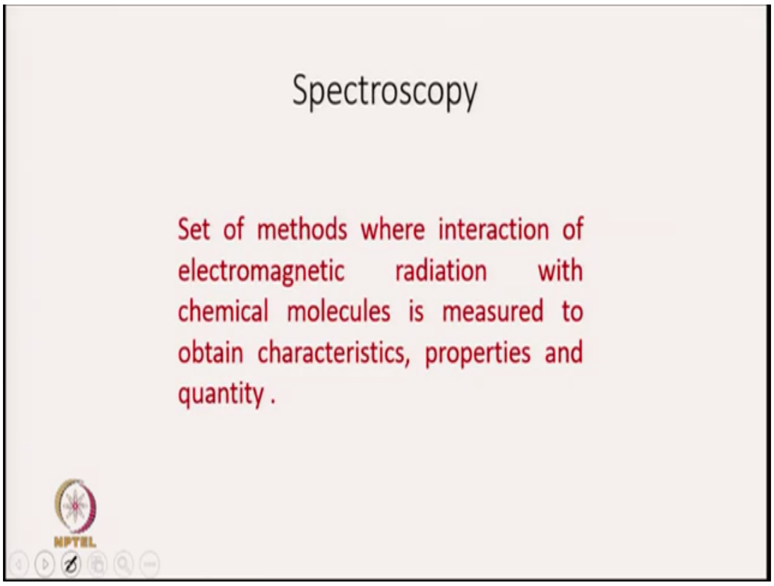

So as I discussed last time spectroscopy is set of methods where interaction of electromagnetic radiation with chemical molecules is measured to obtain characteristics, properties and quantity, characteristics, properties and quantity.

So there are two important point one is electromagnetic radiation and its interaction with chemical molecule. So first we will discuss about what is this electromagnetic radiation?

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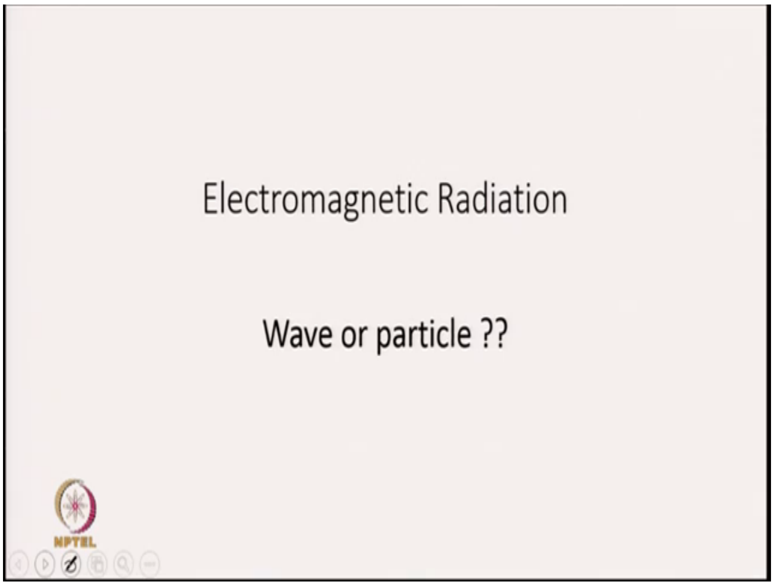

So, first question comes is, whether this electromagnetic radiation is a wave or particle? To understand this, we need to understand the difference between wave or particle.

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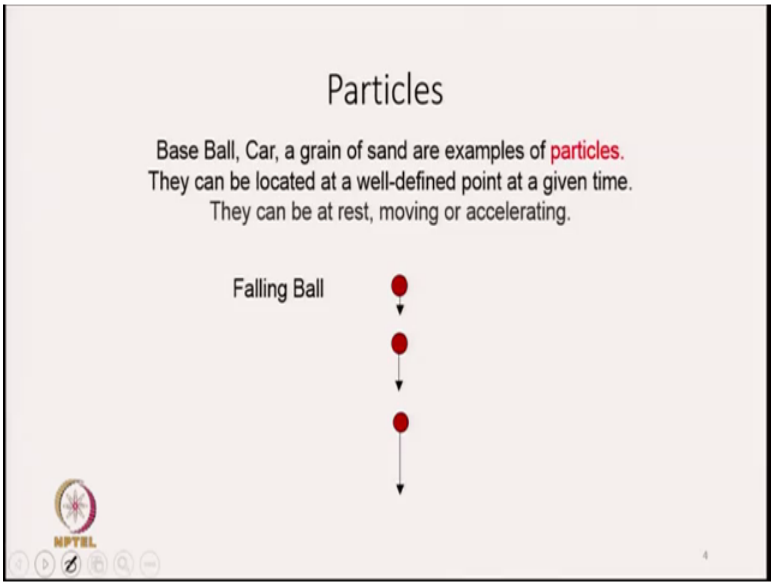

So particles like baseball, car, a grain of sand or this pen can be located at a well-defined point at a given time. So particles can be located at a well-defined point at a given time, so at a particular point I can say this pen is here.

They can be at rest, so for Example, this pen can be at rest or this pen can be moving or accelerating. Ball is an example of particle and you can say that initially this ball is at this position and now it is started falling and at certain time it will be at this position at other time it will be at this position. So with time it is changing the location but at a certain time its location is well defined and that is how we define particle.

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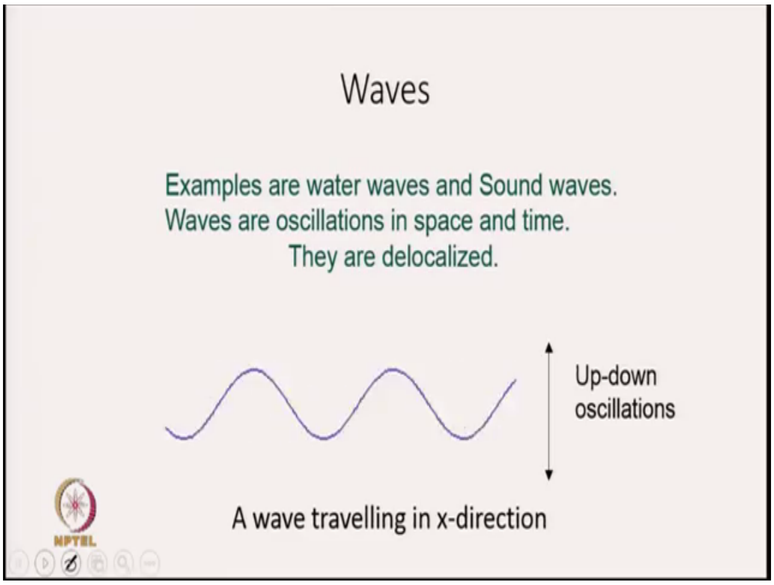

Now, what are the waves? You must have seen water waves and sound waves. Waves are basically oscillation in space and time . They are delocalized. They cannot be localized. So you can see here that with time your wave is moving. So this is a wave travelling in the x direction and there is up and down oscillation. So you can see there is up and down oscillation. This is the way a wave is representing.

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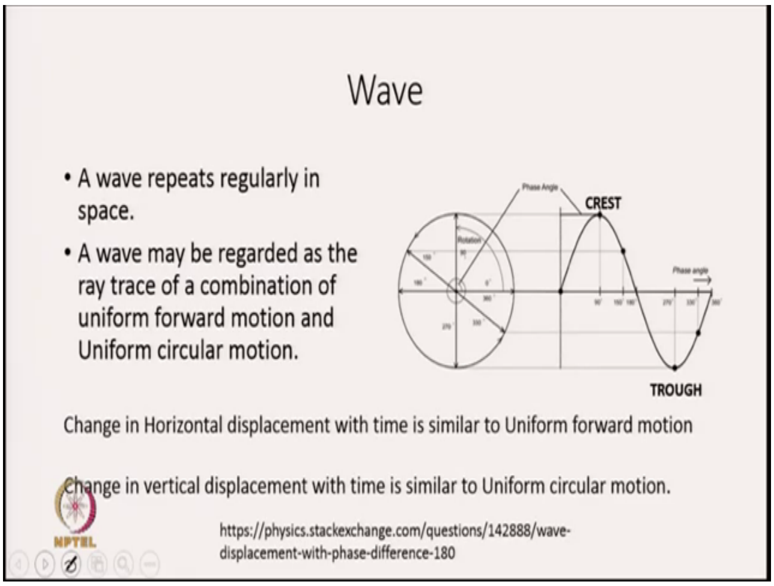

A wave repeats regularly in space, so this is important point about wave that wave repeats regularly in a space. Wave may be regarded as rate race of combination of uniform forward motion and uniform circular motion.

So now look at this wave, suppose this is a point, here with time it will move and it can come at this point. So displacement in x direction reminds us of a uniform forward motion but displacement around y axis, this vertical axis can be regarded as a uniform circular motion.

See how you can represent a vertical displacement with time as a uniform circular motion. So suppose a point on the wave is here at time t is equal to 00. That can be represented as a point at this position.

Now what we are looking at is as the point moves can we represent the displacement, vertical displacement with time by a circular motion. So now look at this, what we are comparing is, y displacement, a displacement in Y axis and displacement in Y axis with rotation.

So now you suppose you are here vertical displacement is 00 and if you are at this point vertical displacement is also 00 during the rotation. Particle goes to here and when it is here, there is a maximum displacement and that corresponds to circular rotation by 90 degree. Circular rotation by 90 degree.

So when a point reaches to this position with time then this can be represented by a circular motion of 150 degree. Circular motion of 150 degree. When you are here this is your Y displacement is 00 and that corresponds to a rotation by 180 degree or when you are here and this corresponds to 270 degree rotation.

270-degree rotation and again here your vertical displacement is maximum in –Y direction and same is the case this point. Now when this point reaches at this position this is corresponding to 330 degree rotation and if it comes to this position then you are basically have done one whole rotation.

So going from this position to this position corresponds to one cycle of the rotation. So change in horizontal displacement with time is similar to uniform forward motion, whereas the change in vertical displacement with time is similar to uniform circular motion. Uniform circular motion. So wave is a combination of uniform forward motion and uniform circular motion.

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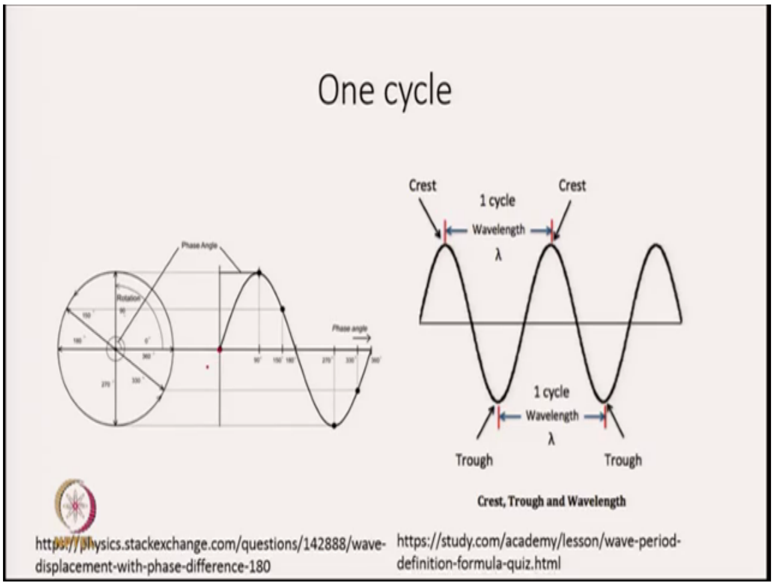

Now, let us think of what do we mean by one cycle? Just I discuss that when you are at this position, your point is at this position it corresponds to 00 degree it corresponds to 00 degree of rotation, when you at this position then it corresponds to 90 degree of rotation, when you are at this position it corresponds to 150 degree of rotation.

When you are at this position this corresponds to 180 degree position and if you are at this position this corresponds to 270 degree of rotation and if you are at this position this corresponds to 330 degree of rotation and if you are a this position this corresponds to 360 degree of rotation. 360 degree of rotation.

So from this to this place corresponds to one cycle of rotation. Corresponds to one cycle. Corresponds to one cycle. Now there is another way to define cycle. If I start with this point it means I am starting at at this position or crest of the wave.

So if I start at this position then if I go round and come back to again to this position, so what you are going is, you have started with maximum displacement in Y direction, you are coming back to maximum displacement in Y direction that also constitute one cycle it means that crest to crest point moving from one crest to subsequent crest consist of one cycle.

Similarly if you start at this point and come back, take a rotation and come back to the maximum displacement in -Y direction then that also constitute one cycle and so trough to trough consist of trough to trough corresponds to one cycle. Corresponds to one cycle.

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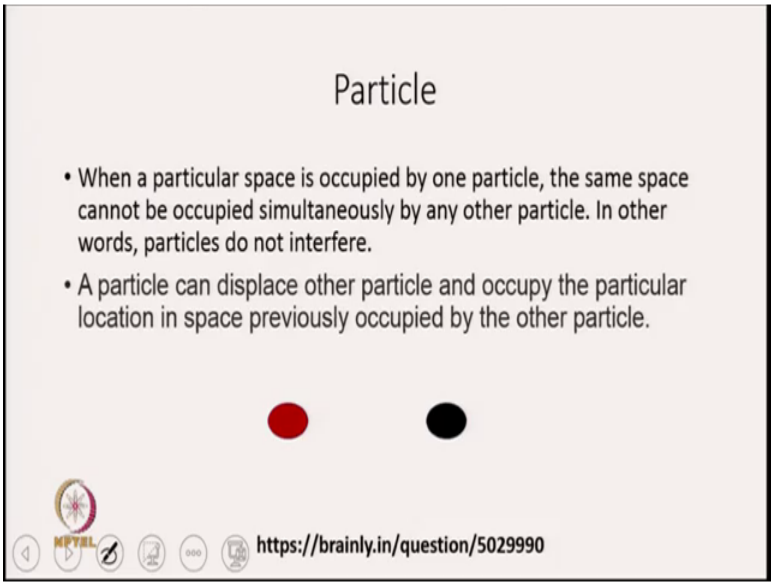

Now let us come back to particle. When a particular space is occupied by one particle, the same space cannot be occupied simultaneously by any other particle. In other words, particles do not interfere.

So suppose there is one particle and there is a second particle if this comes, this cannot occupy the position taken by this particle. This can only occupy this position if this is displaced from its earlier position.

So this is example so there is a black particle and there is a red particle it has a fixed position. Now, suppose this comes in this direction and tries to occupy this space then that can be only done by displacing this red particle.

So a particle can displace other particle and occupy the particular location in a space previously occupied by the other particle. So you can see that, now, black particle is occupying the position of the red particle but it has to displace the red particle. So when a particular space is occupied by one particle a same space cannot be occupied simultaneously by any other particle. It can do that by displacing the other particle.

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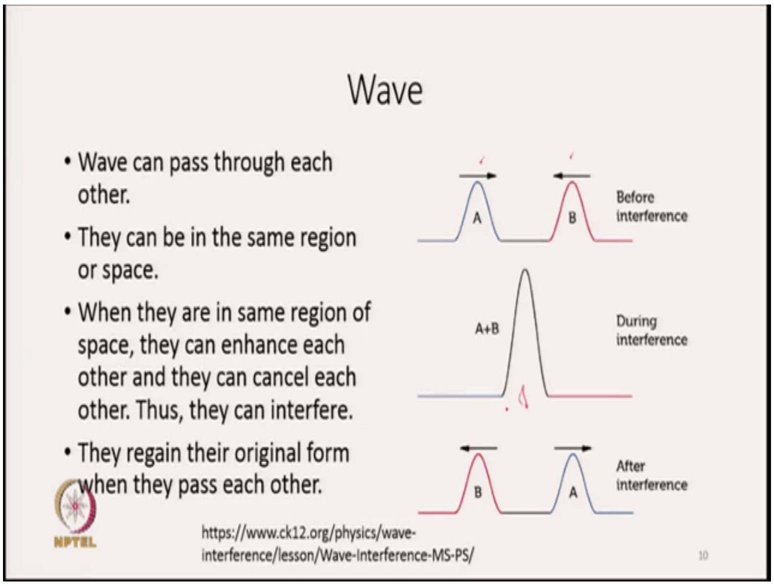

So what about wave? Wave can pass through each other. So here are two waves, A and B moving in opposite direction. Moving in opposite direction, at this time they can be at the same region or same space.

They can be in the same region or at same space. When they are in same region or a space, they can do that by enhancing each other or canceling each other. In this case, two waves are enhancing each other and that means they are interfering with each other.

When they interfere, they can enhance, when they enhance that is called constructive interference and when they cancel that is called destructive interference. Now, if we go further ahead in the time, what will happen that B will go in this direction, A will go in this direction.

So what is happening, that now B is at this position and A is in this position. So they regain their original form when they pass each other. They regain their original form when they pass each other. So this is a difference between wave and particle.

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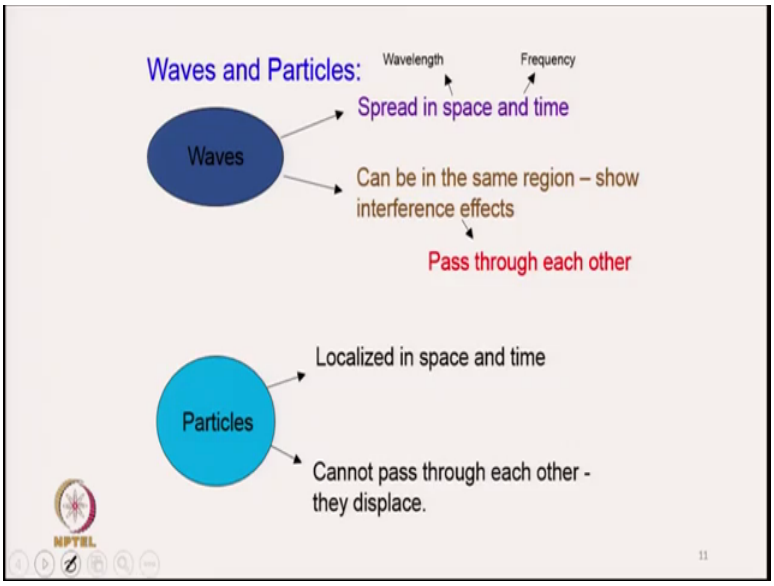

So this is a nut cell what we can say, the waves are spread in space and time and they can be in the same region and so they will show interference effect. Whereas, particles are localized in a space and time and cannot pass through each other they displace.

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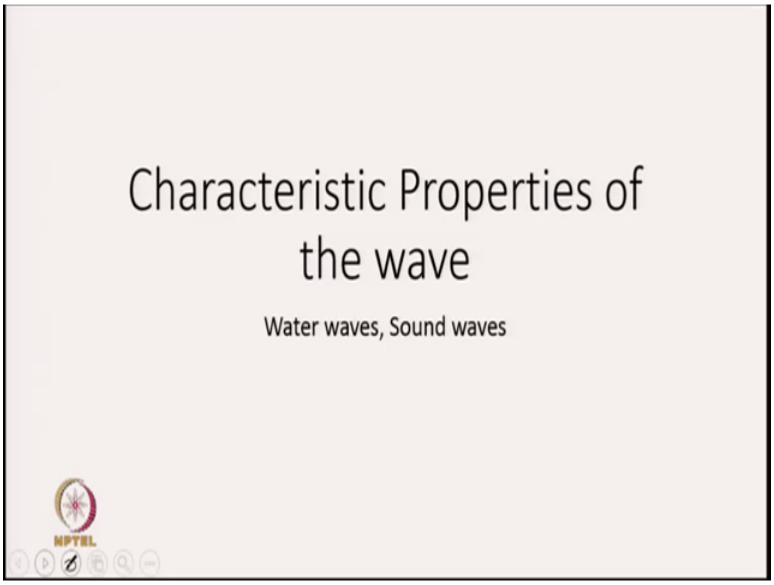

Now, let us think of what are the characteristic properties of the wave. Particle we know (()) (13:35) what particle what, let us look at what are characteristic properties of the wave. Examples are water wave or sound wave.

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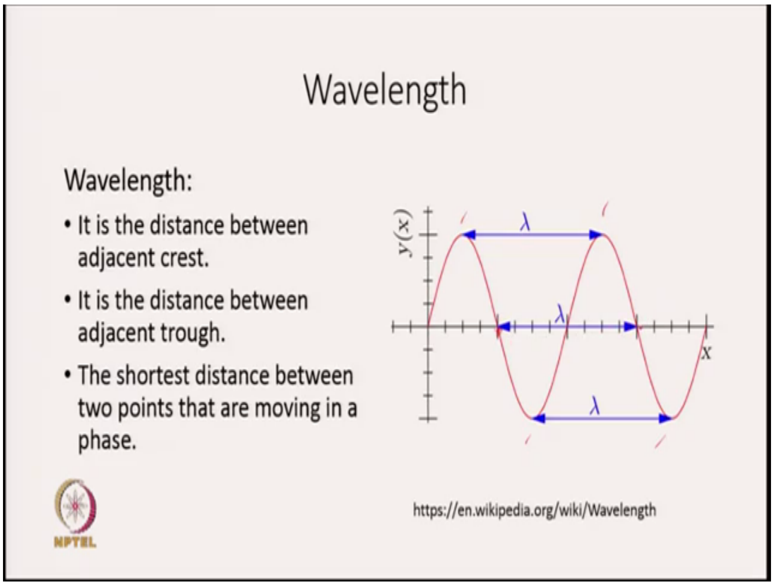

So one of the very important property of waves is wavelength and it is basically a distance between two adjacent crest. Two adjacent crest or it is a distance between two adjacent trough or it is a distance between this place and this place.

So basically when they complete one cycle, the distance in x direction what they cover is called Wavelength. A shortest distance between two points that are moving in a phase or that are in same phase.

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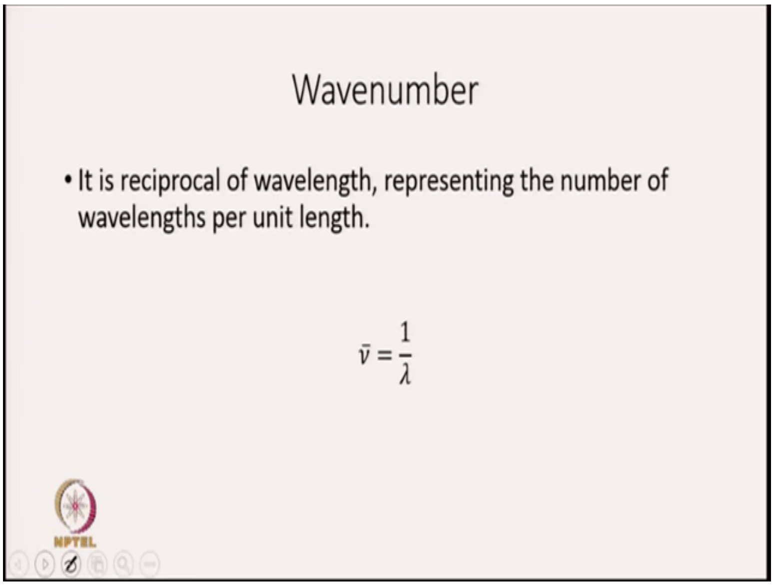

The wave number is basically reciprocal of wave length and that represent number of wave length per unit length. So there is a relationship between new bar which is known as wave number and lambda which is a wave length. The relation is new bar is equal to one by lambda.

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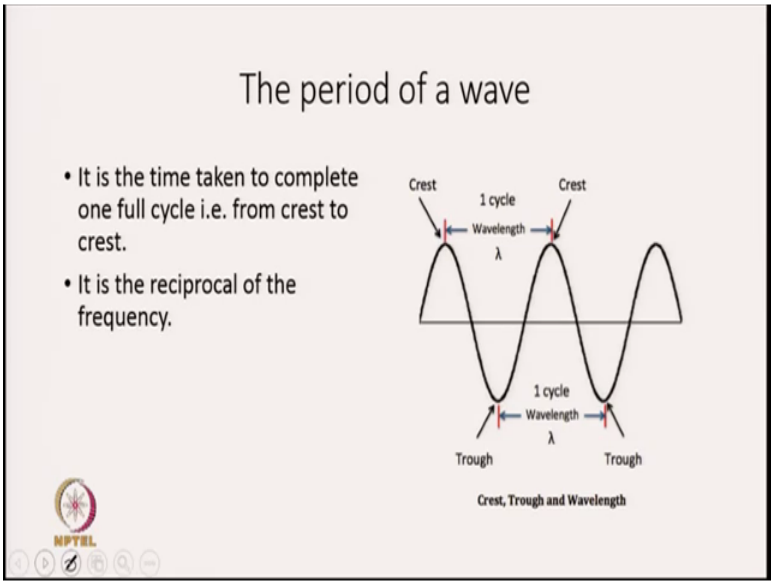

Now, what is period of wave? It is a basically, time taken to complete one full cycle. So time it takes to go from one crest to another crest adjacent. We are certainly talking about adjacent crest or it is a time taken to go from one trough to another adjacent trough and it is the reciprocal of frequency, I will talk about frequency soon.

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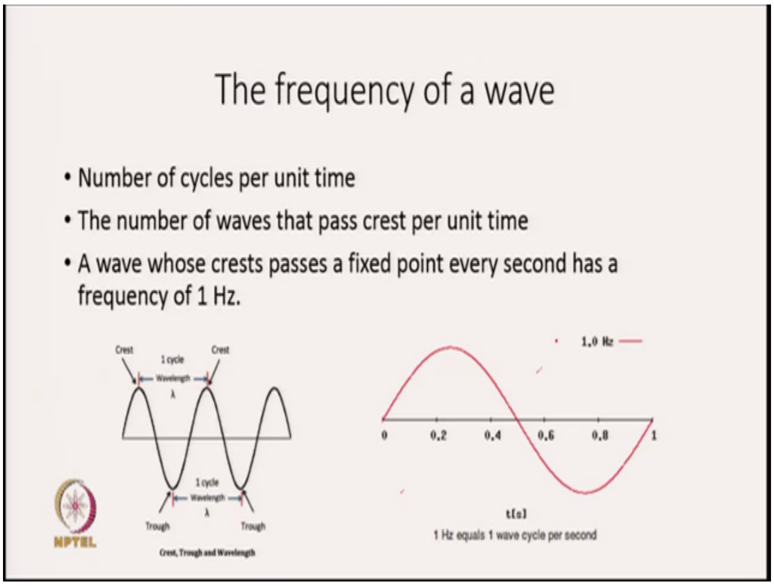

What is frequency? It is number of cycles per unit time. Number of cycles per unit time. So suppose in one second a wave completes one cycle then the frequency of that wave will be

1Hz. Frequency of that wave is 1Hz. For example, you see this case in one second it is completing one complete cycle and that is why this wave has this wave has frequency of 1Hz.

So if suppose crest to crest movement which consist of one cycle happens in x second then frequency is one by x, frequency is one by x. So frequency is basically the number of waves that pass crest per unit time or a wave whose crest passes a fix point every second has a frequency of 1Hz.

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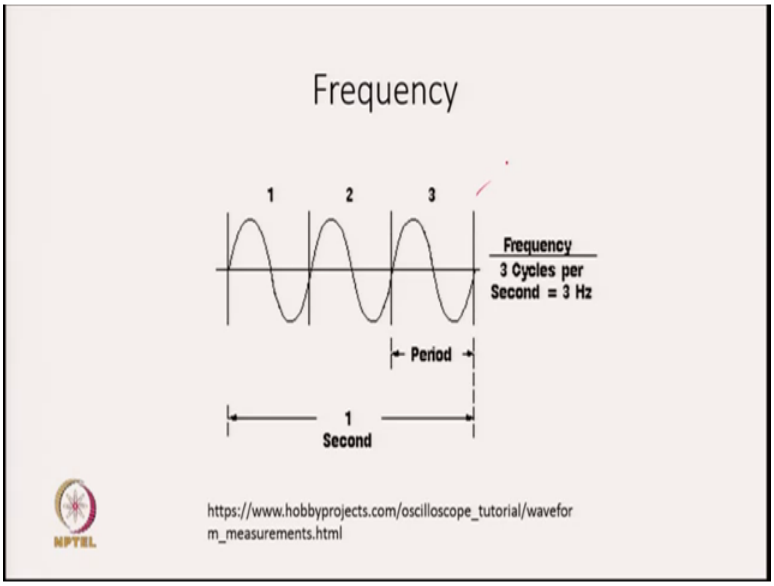

Now, look at this example, what here shows you that the wave completes three cycle in one second. Three cycle in one second and what does that mean is it's frequency is 3Hz. It's frequency is 3Hz.

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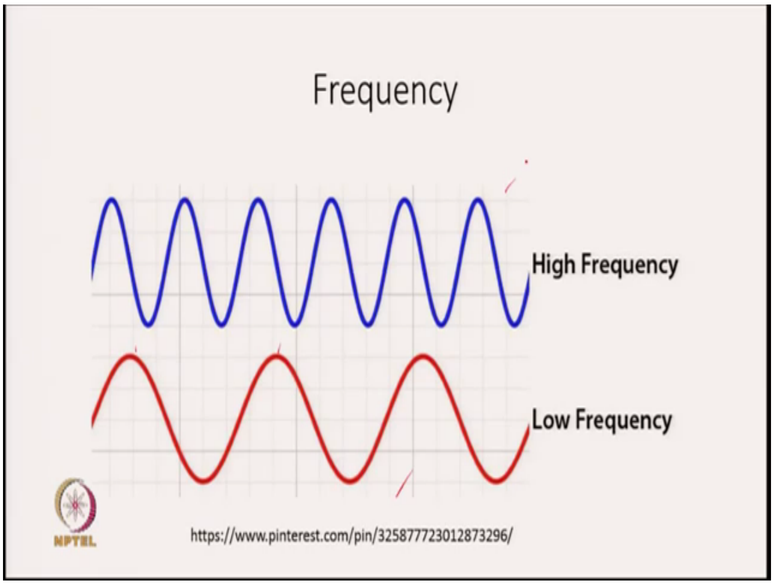

Now, just by looking at wave you can tell whether that is of high frequency or low frequency. Now, you can see here that if you go from crest to crest for this upper wave it takes less time compare to the time it takes to go from one crest to another crest in the lower curve and what does that mean is during one second the upper one, upper wave will complete more cycle compare to the lower wave and that is why the upper wave is of higher frequency in comparison to lower wave.

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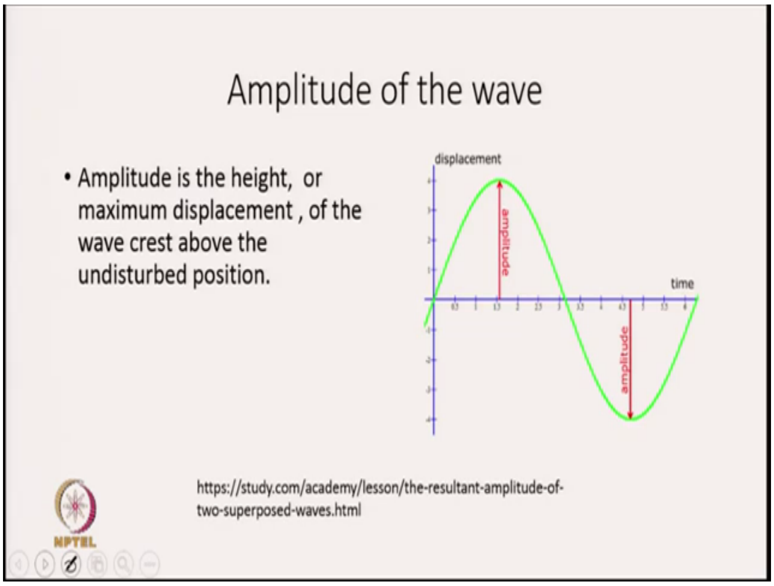

Now, next property, amplitude of the wave. amplitude is the height or maximum displacement in Y direction of the wave crest above the undisturbed position. When Y is 00. When Y is 00.

So it is displacement from Y is equal to 00. It is displacement from Y is equal to 00. So Y is 00 at this position and you can say this is the maximum displacement of the wave and so your amplitude is basically a maximum displacement of the wave from the undisturbed position.

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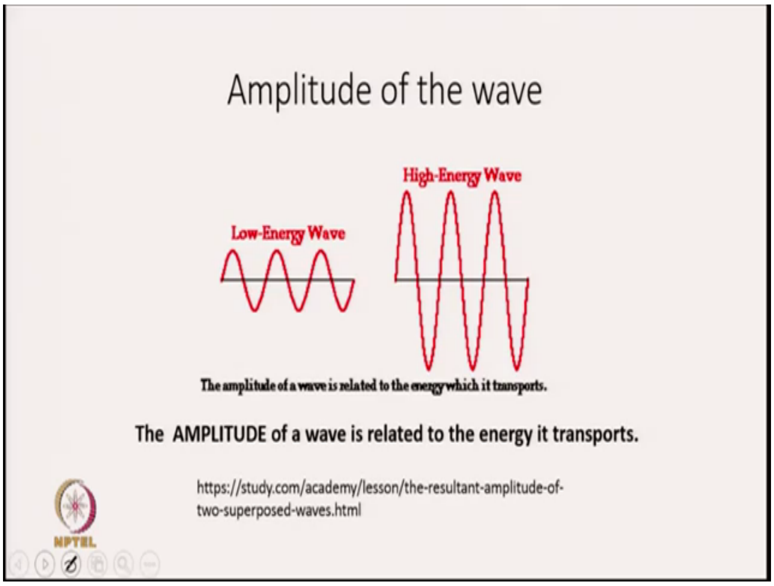

Amplitude of the wave can also tell you about the energy it transport. The energy it transport. So amplitude of a wave is related to the energy it transport if amplitude is small what does that it mean is you have a low energy wave, if amplitude is high then you are dealing with high energy wave.

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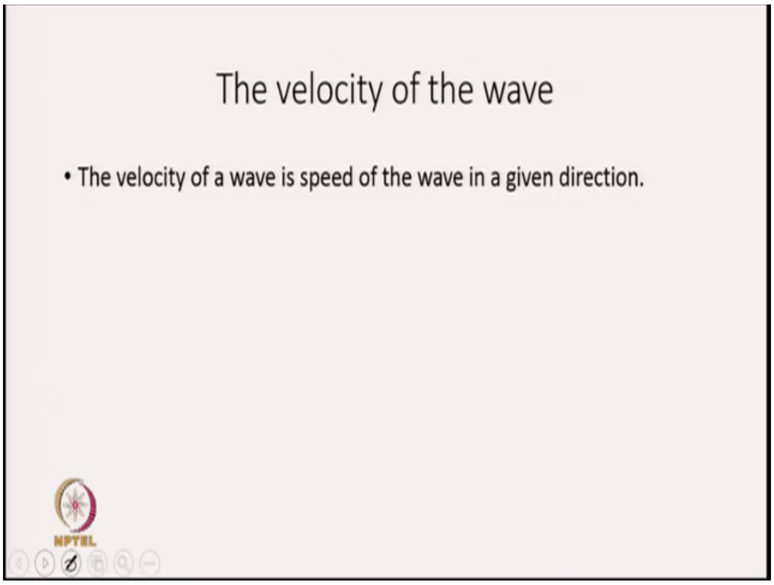

Now, next property is velocity of the wave and velocity of the wave is speed of the wave in a given direction. So velocities has two component, one is speed and another is direction and so velocity of wave is speed of the wave in a given direction.

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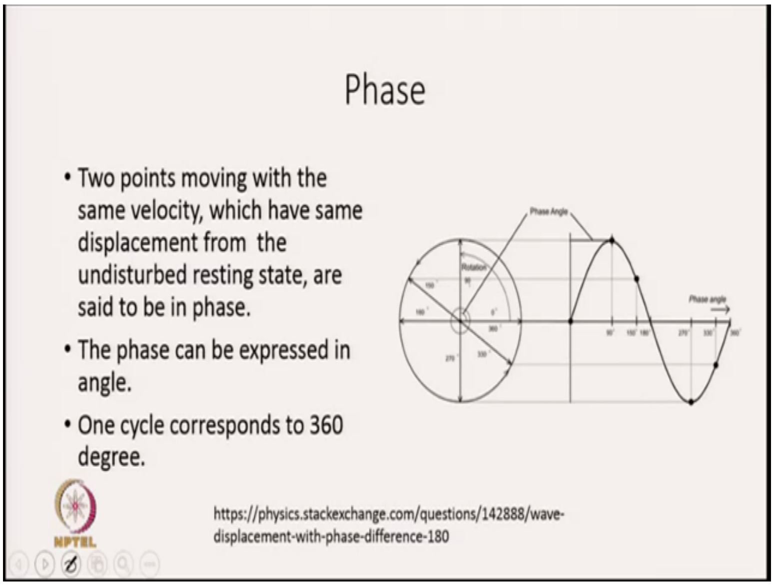

Next, very important property is phase is phase. So just we discussed about that wave motion or path of a wave can be compared with the circular motion if this take into account vertical displacement with time.

So same thing is here, so we just told that this point we just discussed that this point corresponds to 00 degree rotation in a circular motion and so phase is 00 degree for this point. For this point.

If you go to this position which is the crest of the wave, this corresponds to 90 degree rotation, 90 degree rotation from the undisturbed position and so phase of this crest or phase of the point at crest is equal to 90 degree.

Similarly this position corresponds to phase of 150 degree, this position corresponds to phase of 180 degree and this position corresponds to phase of 270 degree, this position corresponds to 330 degree and this position corresponds to 360 degree. So two points moving with the same velocity which have same displacement from the undisturbed resting state are said to be in phase.

What does that mean is this point and this point have same phase have same phase because 360 degree is basically 00 degree. Here, this point and this point if you compare between this point and this point although vertical displacement is although vertical displacement is 00 still they are not in phase because particle displacement or particle velocity direction is not the same particle velocity direction is not the same.

For example, if you take this particle this is going towards this way and this particle is going towards this way. So they are not in phase. In fact they are out in phase. They are 180 degree apart 180 degree apart. So it is not only amplitude, direction of path also matters direction of path also matters.

So two points moving with same velocity which has same displacement from undisturbed resting state are said to be in phase. A phase can be expressed in angle and we have just seen that that this corresponds to 00, this corresponds to 180 degree phase and this correspond to 360 degree and one whole cycle corresponds to 360 degree.

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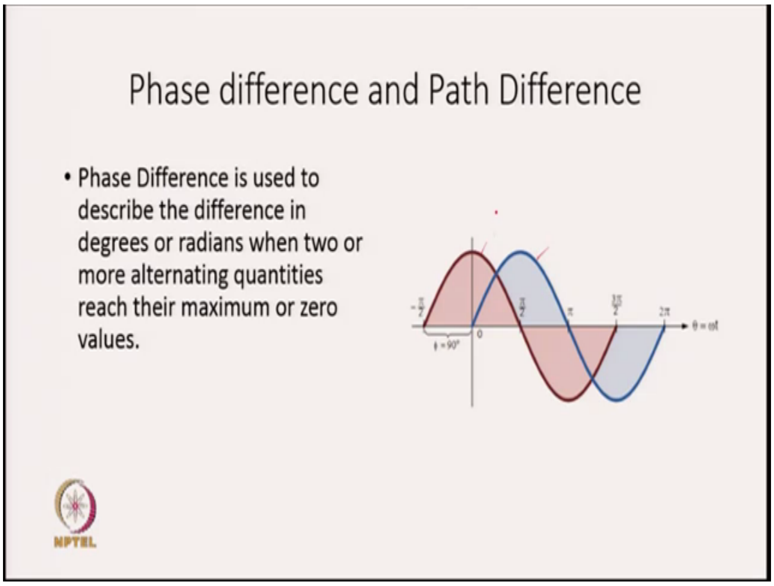

Now, let us think of what is phase difference, what is path difference? So consider two waves, which are shown here one by blue and one by this red one. Now what is the phase difference? Phase difference is basically used to describe the difference in degrees or difference in degrees or radiance when two or more alternating quantities reached their maximum or 00 value.

So what I mean by that this are the two waves they reach maximum at this two position between these two a difference of phase between this two points is called phase difference between two waves.

So now you see this, this corresponds to 00 degree and this corresponds to 90 degree phase, so difference between this two phase is 90 degree. So you can compare between two crests, you can compare between two troughs or you can compare their the displacement, vertical displacement is 00.

So can compare between this and this also and difference in phase corresponds to your phase difference. For example, in this case the phase is 00 here and phase is 90 degree for this wave and so the difference between this two crest is 90 degree and so phase difference is 90 degree.

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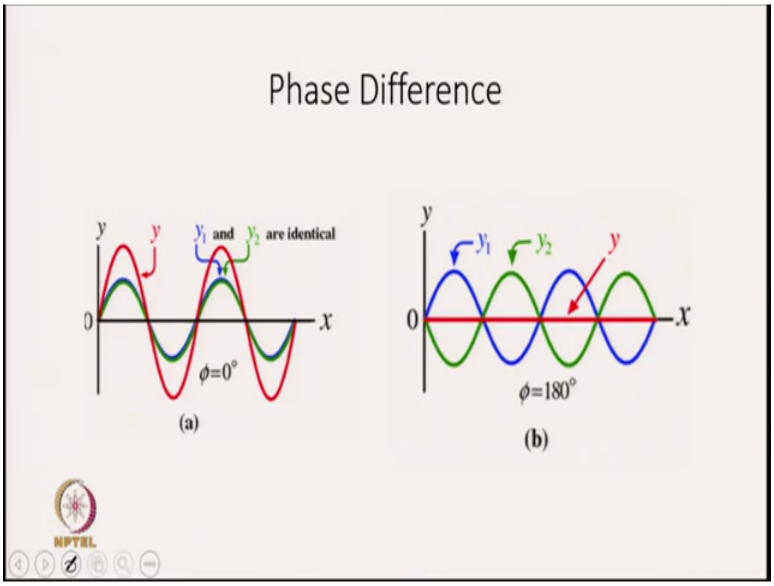

Now, let us again think about other cases, so here three waves are given, wave y, wave y1 and wave y2. Now, you see Y1 and y 2 are almost identical. They are identical, they have same phase, they have same amplitude.

Whereas, this y differs from y1 and y2 in that that amplitude differs but their crest are at the same phase their crest are at the same phase. So phase difference between y and y 1 and y2 is 00 and so phase difference is even a 0.

So y, the phase difference between y and y1 and y2 is 0. Whereas, in this case amplitude of y 1 and y2 is same but their phase differs their phase differs. So this corresponds to 90 degree whereas for this it corresponds to 270 degree and so difference between your y 1 and y2 is 180 degree 180 degree. So phase difference between y 1 and Y2 is 180 degree.

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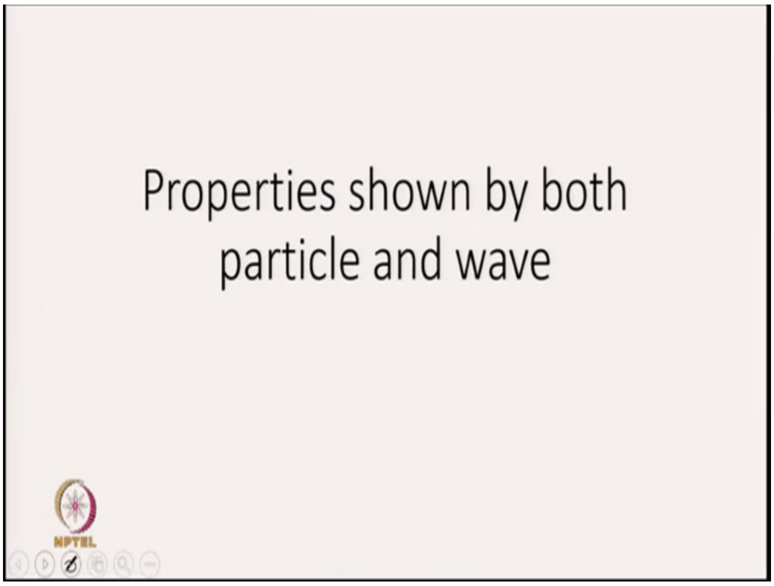

Now, now we know particles and waves. A basic difference between particle and waves we know. Now, we will discuss about properties shown by both particle and wave. So there are some property which are shown by both particles and waves. What are those properties?

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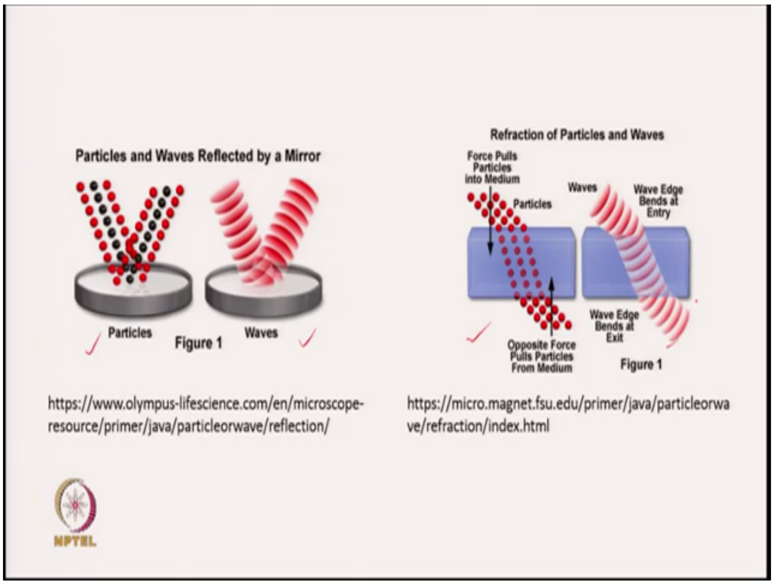

So reflection can happen with both particles and waves and you can see here this is your reflection of particles and this is reflection of waves. Similarly refraction can be shown by both particles and wave and here is the example, so forces pulls particle into medium here opposite force pulls particle from medium and this is the wave.

So wave is bends at entry and wave is bends at exit. So both particles and waves show refraction property.

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Till now we discussed, What are the properties which are shown by particles or waves. Particles and waves. Now, we will discuss about what are the properties which is shown by which are shown by wave alone wave alone.

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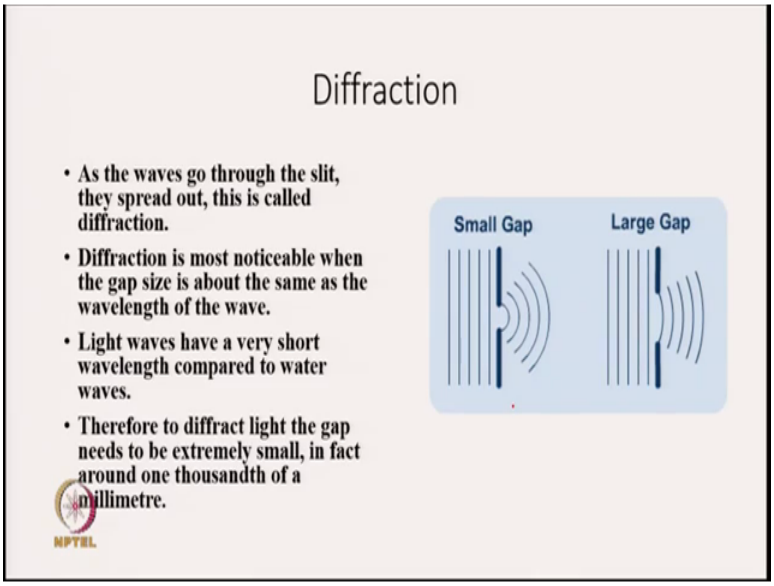

So one of the property which is shown by wave alone is diffraction. diffraction and here you see this is a diffraction so if you pass monochromatic light through a hole you will see a diffraction pattern. So as the waves go through the slit they spread out and this is called diffraction.

So you can see this is a diffraction. Diffraction is most noticeable when the gap size is about the same as the wavelength of the wave. So here you can see it quite clearly, in this case you will not see it quite clearly because there is a large gap or there is large hole.

There is a large hole. Gap size is high gap size is high. The diffraction is most noticeable when the gap size is about the same as the wavelength of the wave. Light waves have a very short wavelength compare to water waves. Therefore, to diffract light gap missed to be extremely small infact around 1000 of a millimeter.

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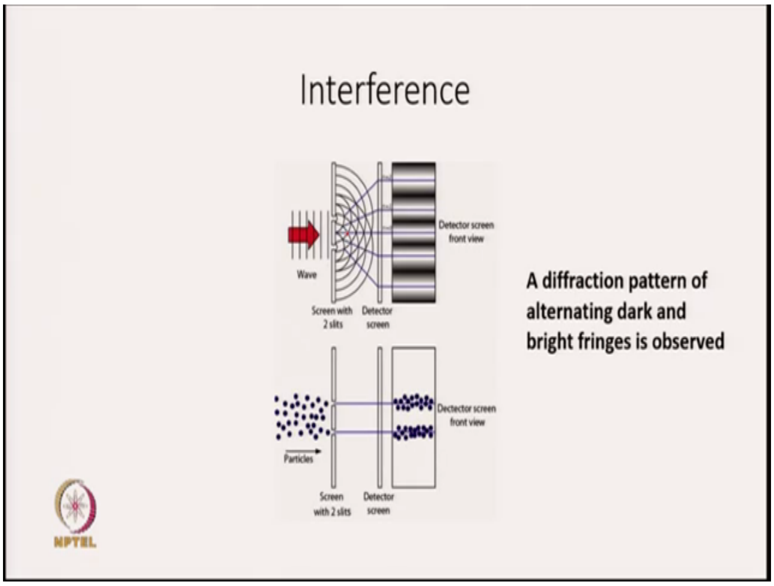

Now, the second property which is shown by the wave is interference. interference thsee are not sound like the particle. So what happens is, that if you take a monochromatic wave and then you passed through this two slit pass through your two slits.

What will happen is they will form what is known as interference pattern. If you observe them on a screen and what you are going to see is a diffraction pattern of alternating dark and bright fringes.

Dark and bright fringes. If it is a particle, a big particle what you are going to see is something like that. Two spots. Something like that. So in case of wave you will see a diffraction pattern of alternating dark and bright fringes.

So these are two very important properties of waves which are not observed for big particles. Which are not observed for big particles. So to prove that whether electromagnetic radiation acts like a particle or acts like a wave, you need to do an experiment to see whether electromagnetic radiation undergo your interference or diffraction.

If you can show that it undergoes interference or diffraction you can speculate okay your electromagnetic radiation is a wave. If it does not show interference or diffraction pattern what does that mean is your electromagnetic radiation behaves as a particle behaves as a particle.

So now, think about why this alternating diffraction pattern of diffraction pattern of alternating dark and bright fringes is observed.

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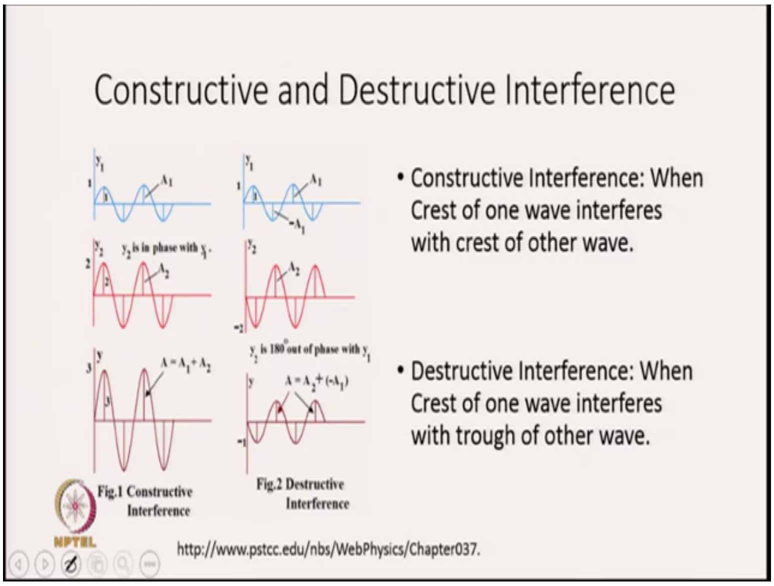

So think of there are two waves in same phasey 1 and y2 are in same phase. What they are of different amplitude. So if they are in the same place, when they are in the same place what will happen that they will add to each other or they will enhance each other and it will lead to constructive interference and you will get this kind of wave this kind of wave.

But if you tit two waves which are not of the same phase or you can say they are 180 degree out of phase, what does that mean, the position of crest of one wave coincide with position of trough of another wave theny 1 is 180 degree out of phase with y2.

So y2 andy 1 phase difference is 180 degree. In that case you will get a destructive interference and your amplitude will be simply a2 minus a1. So when two waves are at the same place constructive interference can happen and that will happen when crest of one wave interferes with crest of other wave. On other hand when crest of one wave interferes with trough of other wave then you have a destructive interference. You have a destructive interference.

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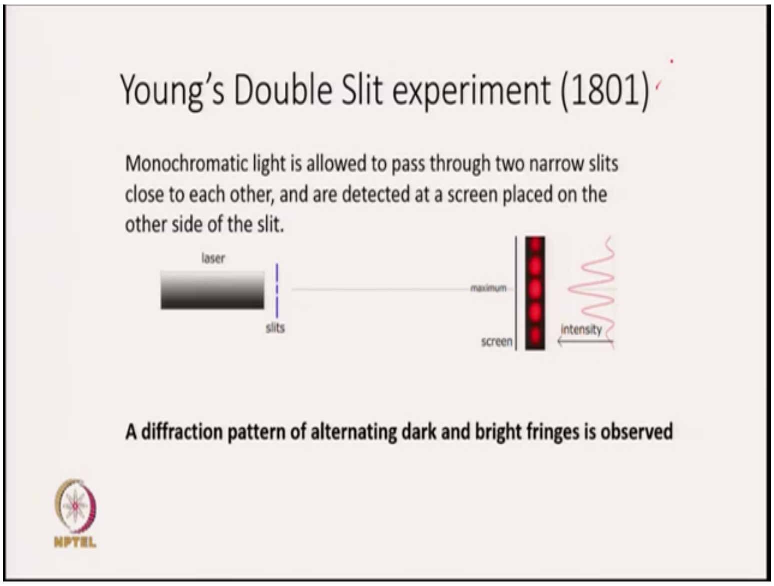

So now we will look at whether electromagnetic radiation is a wave or a particle. Scientists started this quite long before and the first experiment was done by Young and that is famously called 'Young's double slit experiment' and this was carried out in 1801.

So what he did is, he passed monochromatic light through two narrow slit widths closed to each other as given in this figure and it is detected at a screen paste on the other side of the slit.

So it is detected on this screen and what he got is a diffraction pattern of alternating dark and bright fringes and that is only possible with wave. So electromagnetic radiation acts like a wave acts like a wave

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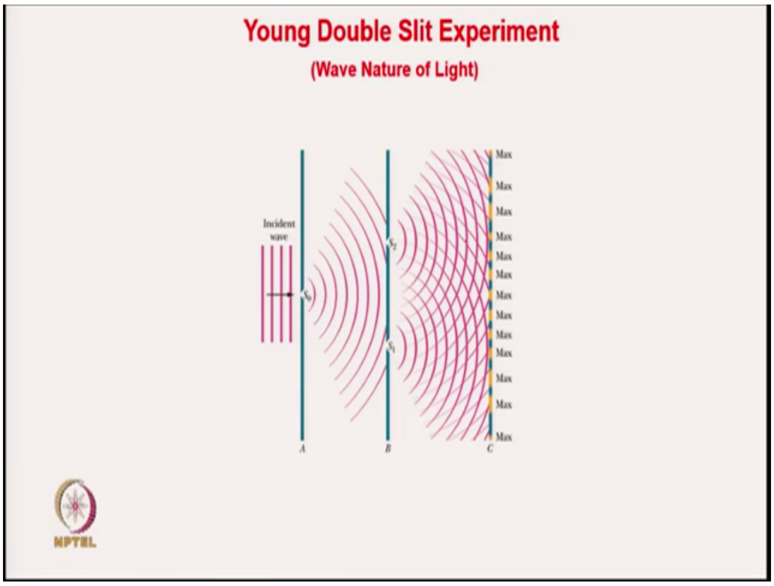

And similar kind of explanation you can give. Now this is if it goes through one slit then there is like a spread of the wave, if it goes through two slit then there are a lot of places where two waves are at the same position, you can see these are the places. If this two waves are in phase then you have maxima, when they are out of phase when they are 180 degree phase apart then there is a minima.

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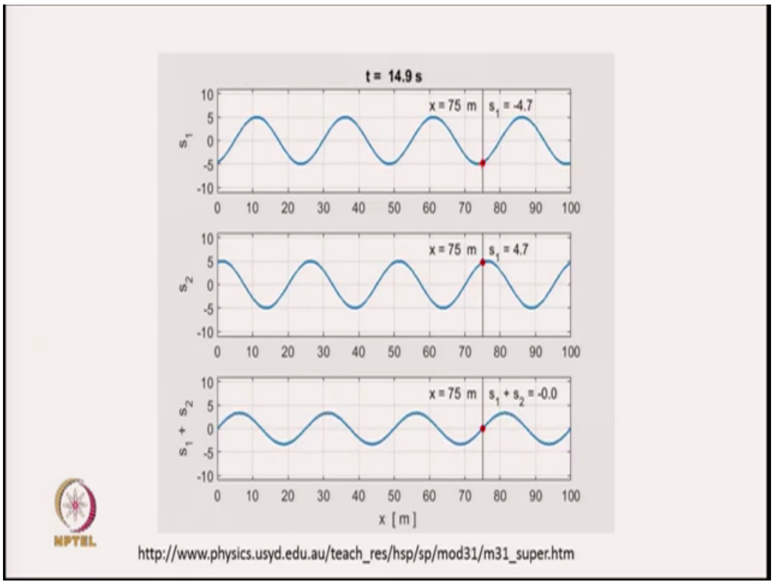

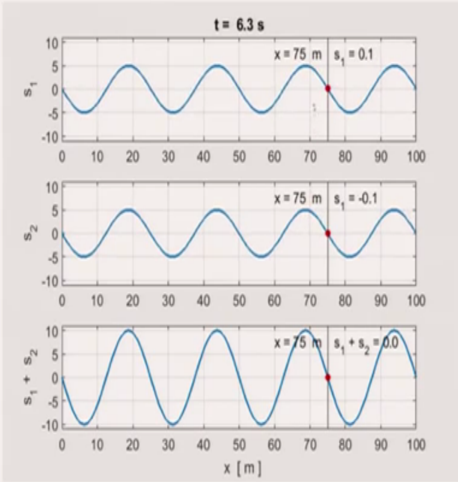

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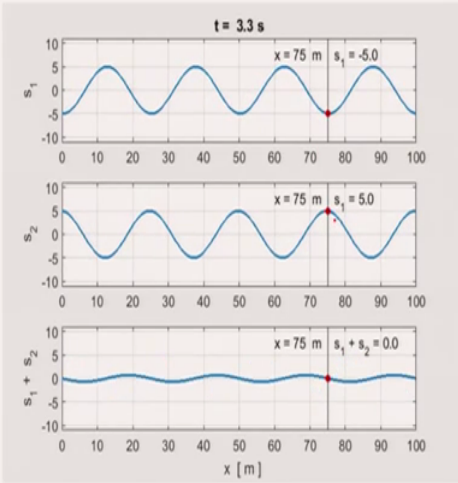

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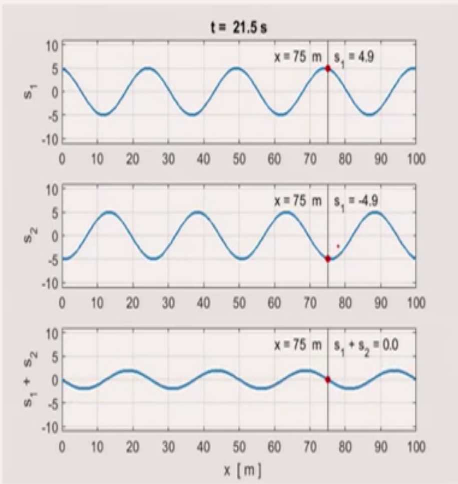

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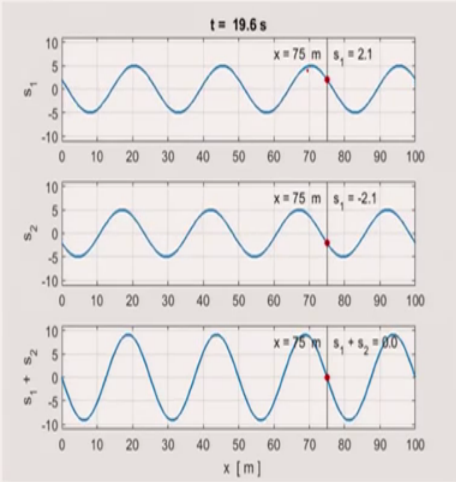

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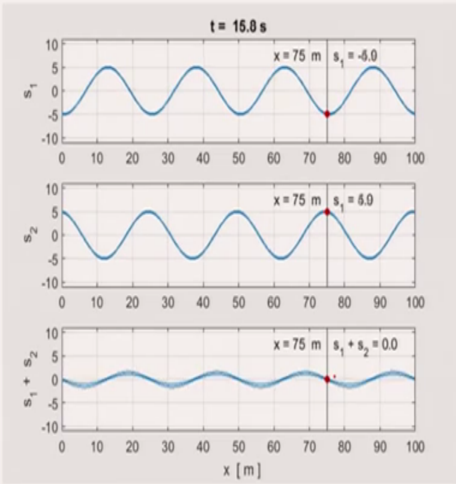

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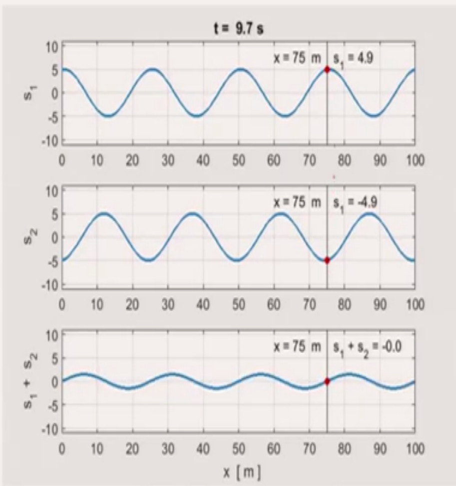

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There is a minima and you can see here this are the two waves. This is your composite wave. So you see here, so let us see this is now at maxima, so here you see crest and trough interfere and so you got 0. Now let us see, so again trough and crest you see 0. Now, let us wait. This is moving towards crest, trough, again 0.

So when trough crest interfere again it is going to 0. Now, you see this two, at the same that is maxima. That is a maxima.

So when crest and crest interfere then you have a constructive interference and when crest and trough two waves interfere then you have destructive interference. So it was proved that electromagnetic radiation acts like a wave.

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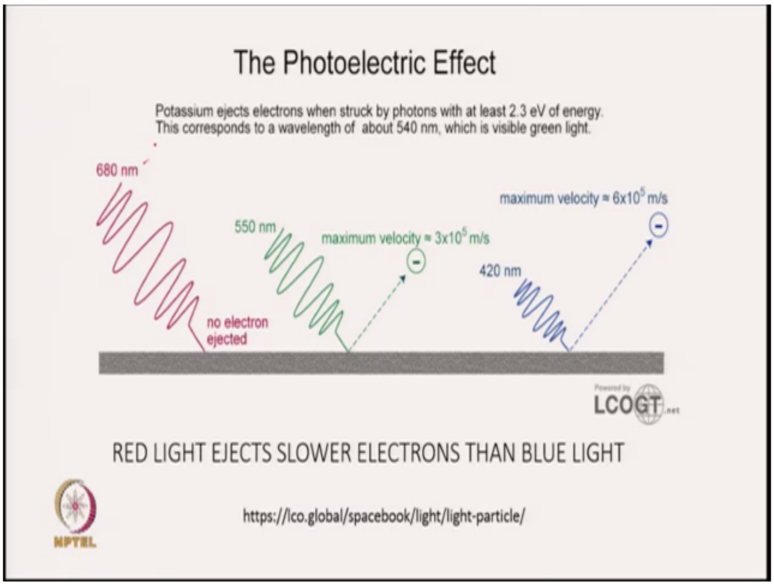

But there was another experiment which is known as photoelectric effect. In this experiment what scientists observed is that potassium ejects electrons when instruct by photons with at least 2.3 electron Volt of energy and this corresponds to wave length of about 514nanometer, which is visible green light.

So when you bombard the potassium surface with 680 nanometer, 680 nanometer light, what will happen is no electron is ejected. When you bombard with 550 nanometer, 550 nanometer light, electron will be ejected and its maximum velocity is 3 into 10 to the power 5 meter per second, when it is bombarded with 420 nanometer blue light, electron ejected with higher velocity.

So red light ejects slower electron than blue light and if you go much reder then, for example, 680 nanometer, it will not even eject electron.

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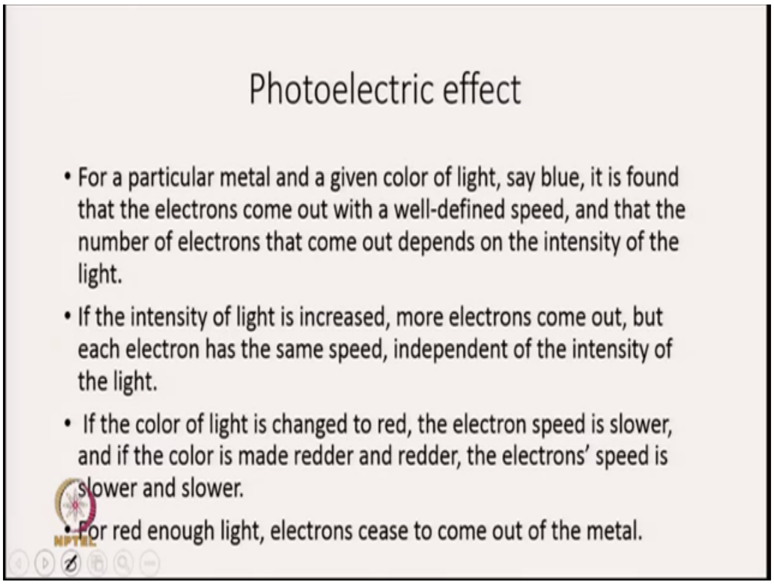

So the observations are or observations were, for a particular metal and a given colour of lights, a blue, it was found that the electrons come out with well-defined speed and that the number of electrons that come out depends on the intensity of the light.

If intensity of light is increased more electrons come out but each electron has the same speed. So electron speed does not change with intensity of light. It is basically independent of the intensity of light.

This is basically in contrast to if you consider a light as a wave. The other observations were, if the colour of light is changed to red, electron speed slower and if the colour is made reder and reder the electron speed is slower and slower. A red enough light electrons cease to come out of the matter. So these are the observations when potassium metal is hit by photon.

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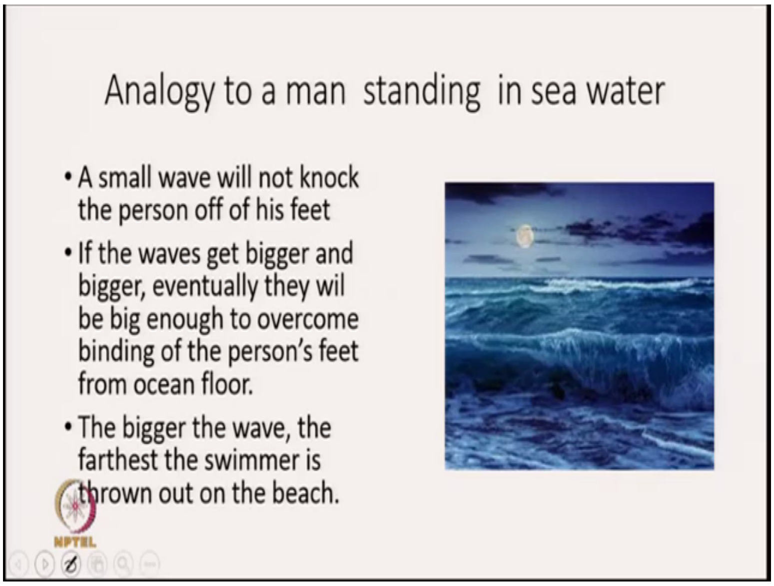

Now, think of that if a man is standing in a sea water. So it is facing waves, am I right it is facing waves. So if, so you can make analogy to what will happen, when your the metal, potassium metal is with hit with a wave okay.

So what happens, if you are standing near a sea water, a small wave will not knock you off your feet right off your feet. So a small wave will come and you are standing. You are simply standing.

But if suppose waves get bigger and bigger eventually they will be big enough to overcome your binding, your feet's binding to ocean floor and what will happen that way you will be thrown out on the beach.

You will be thrown out on the beach. So smaller wave may not knock you off your feet but a bigger wave can knock you off the feet. This is opposite to what was shown in photoelectric effect. If you increased the intensity it is not going to affect the velocity. It is not going to affect the velocity. So what we mean by, by analogy to a man standing against a wave, you can think of if light behaves as a wave.

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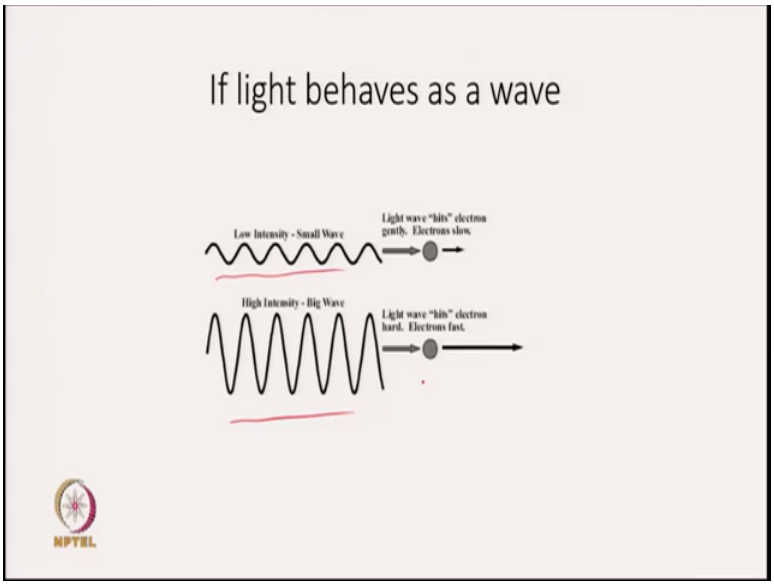

So what will happen, so low intensity small wave will hit electron gently and so electron will move slowly. Whereas, if there is a high intensity wave, which is a big wave, if it hits electron, it will hit electron hard and so velocity of electron increased.

Velocity of electron so increase. What you have seen that in Photoelectric Effect the velocity is independent of intensity of the light. Intensity of light so what does that mean is that particularly in this case electromagnetic radiation or light is not behaving as a wave. It is basically behaving as a particle.

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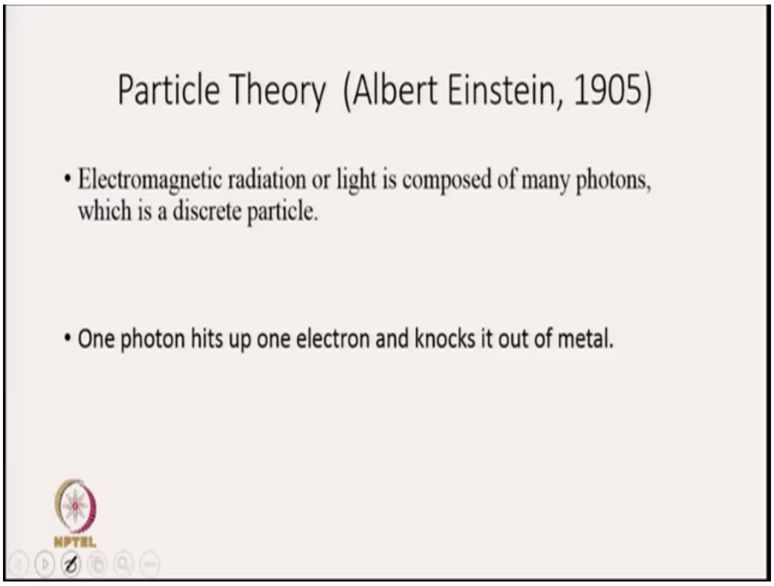

So based on this experiment Albert Einstein in 1905 proposed the this theory that electromagnetic radiation or light is composed of many photons which is a discreet particle. So he told that, apart from wave electromagnetic radiation can also act as a discreet particle or bunch of discreet particles and then he went on to explain this Photoelectric Effect what he told that one photon will hit one electron and knock it out of the matter and if you increased the intensity what you are doing is, you are increasing the number of photons. So as the number of photons increases, number of electron, electrons knocked out will also increase.

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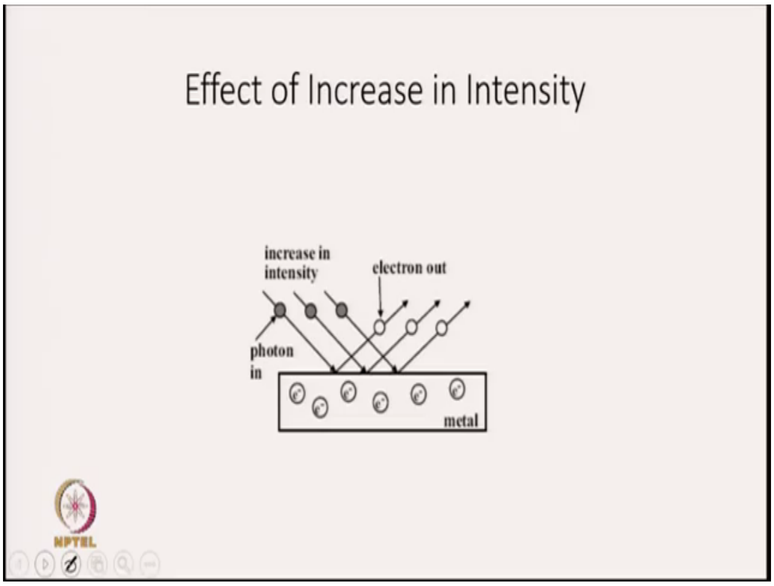

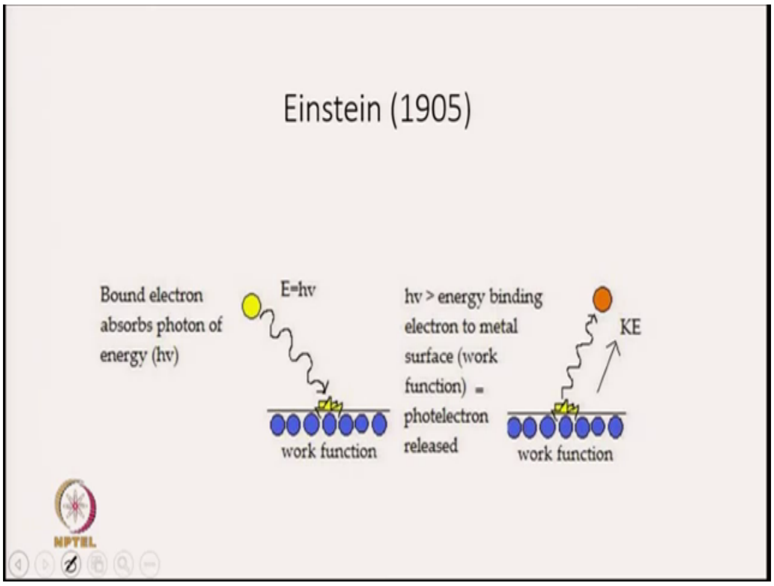

So number of electron knocked out will also increase and this is shown here that if you increase the intensity of the light more number of electrons will be out. Now, let us think of why, if you put photon of reder frequency, why some time electron will not knock out? It is because, it requires energy greater than it requires energy greater than binding energy of electron to metal.

So if energy of photon is not good enough or not greater than binding energy of electrons to metal your electron will not move out. Electron will not move out and this energy, binding of electron to metal is known as work function. So if energy of photon is higher than work function then only electron will be imitate.

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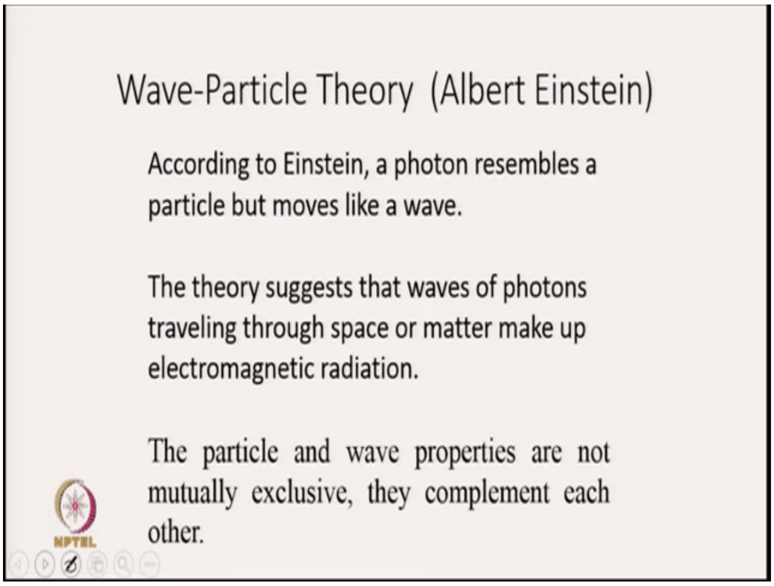

So based on this, your wave particle theory is proposed by Albert Einstein is tells you that a photon resembles a particle but moves like a wave. The theory also suggests that waves of photons travelling through a space of matter a makeup, your auto magnetic radiation.

A particle and wave properties are not mutually exclusive. They complement each other. They complement each other. So your electromagnetic radiation has dual property or light has dual property. It will some time behave as a particle or some time behave as a wave and it is not mutually exclusive thing.

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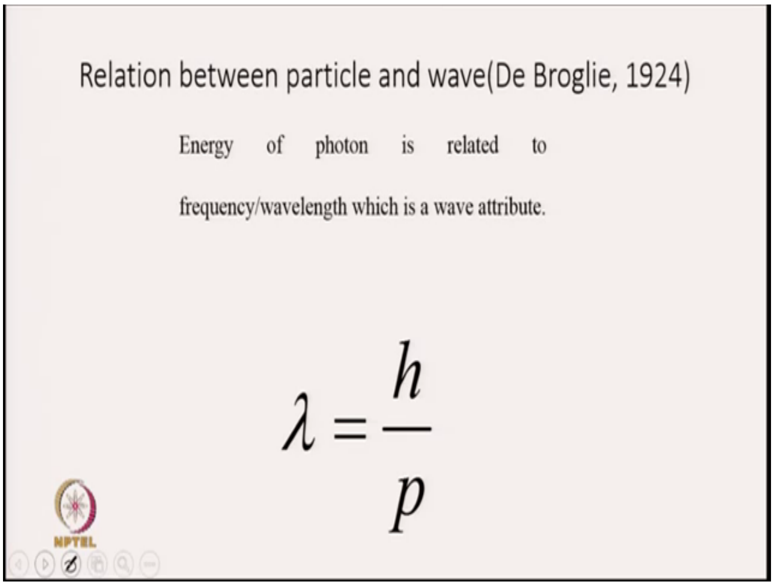

Infact De Broglie in 1924 proposed the relationship between particle and a wave. He told that energy of photon is related to frequency wave length, which is wave attribute and the relation he gave is lambda is equal to h by p. lambda is equal to h by p, where h is Plank's constant, p is the momentum of the particle.

Momentum of photon and lambda is wave length of your light. Now, what are the different, now we understand what is electromagnetic radiation, it is your, it has dual property now we will look at some important properties of light.

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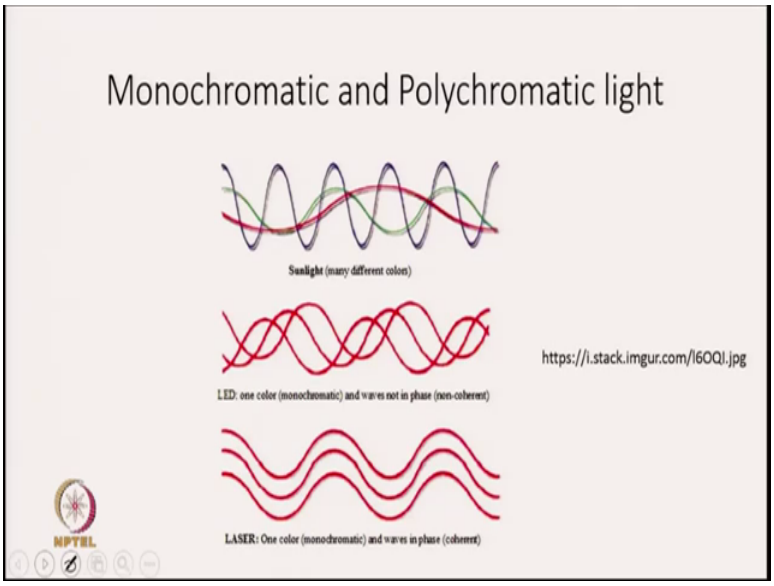

What is the difference between Monochromatic and Polychromatic light? So some lights are monochromatic and some lights are polychromatic. So if you look at the rays from the sun, it is here Polychromatic light. It means it is a combination of different wavelengths of light or it is a combinations of waves of different wavelengths.

Whereas, a light from the lent or light from a leser is example of monochromatic light. It consist of wave, it consist of waves of same wavelength. It consist of waves of same wavelength.

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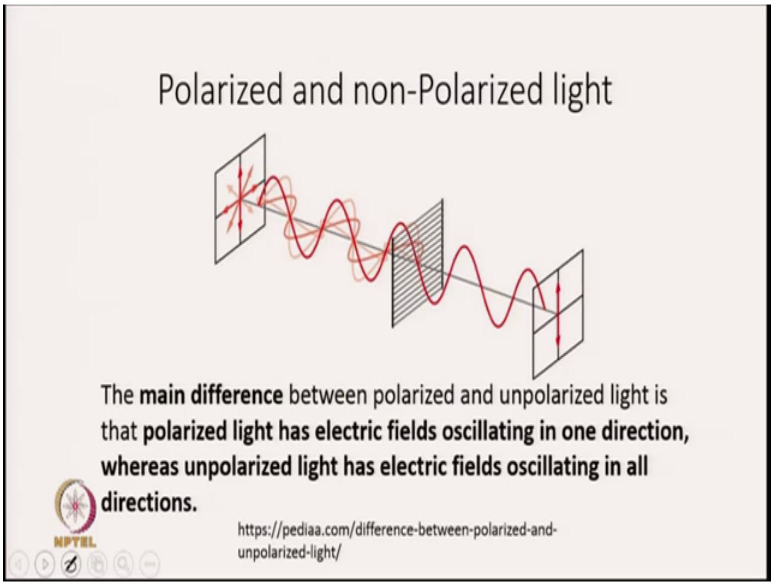

Now, there is a difference between the another type of properties is polarized and non-polarized light. What we mean by polarized light is, polarized light has electric fields oscillating in one direction.

Whereas, unpolarized light has electric field oscillating in all direction. So now you see that this wave has electric field oscillating in this direction. Y direction and so this is example of Polarized light.

Whereas, if you see this light it is a combination of different Polarized light or you can say it is unpolarized light, because in this your electric field is oscillating in different direction. Almost every direction. Almost every direction.

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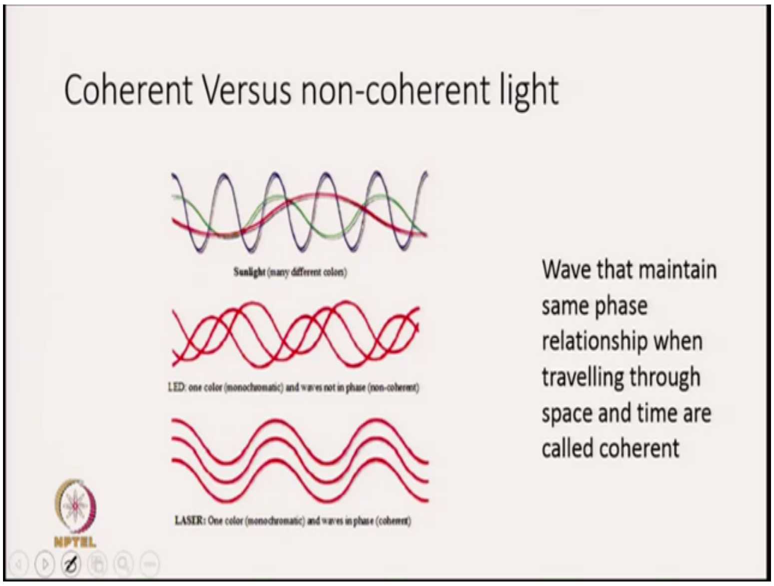

The next properties is Coherent verses Non Coherent light. So we just discussed there sunlight is a Polychromatic light. Now, let us compare between the light from the lead source or light from a laser.

So in the light obtain from the lead, a phase difference, there is a phase difference between different waves although they have same wavelength. Although they have same wavelength. That combination of waves is called Non Coherent light. So this is your Non Coherent light.

So in Non Coherent light, waves are not in phase. Whereas, in Coherent lights waves are in phase waves are in phase. So wave that maintain, waves that maintain same phase relation when travelling through a space and time are called Coherent waves.

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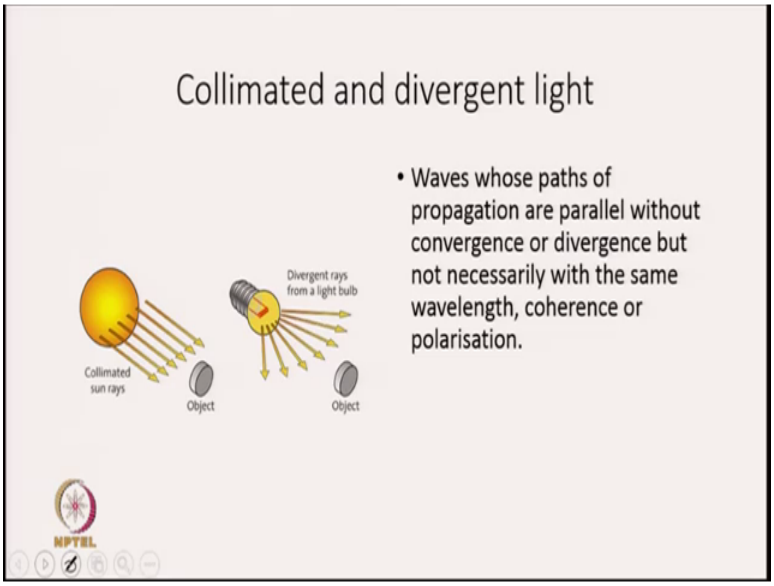

Next property of light is Collimated and Divergent light. Collimated and Divergent light. See in Collimated light path of propagation of different waves are parallel to each other. You can see that this waves are parallel to each other.

It does not mean this waves are of same wavelength. This may not be of same wavelength, they may not be Coherent, they may not be Polarized; but their wave pass a propagation are parallel.

So this is light from your Sun. Whereas, light from an electric bulb is Divergent, because the light which is coming out from a bulb the path of propagation for the waves are not parallel. So you can see these are the Divergent.

So these are four different properties of light and I hope that you will be, you will now be able to understand this things. So these are about the light. So we have seen that electromagnetic radiation or light behaves as a wave and particles.

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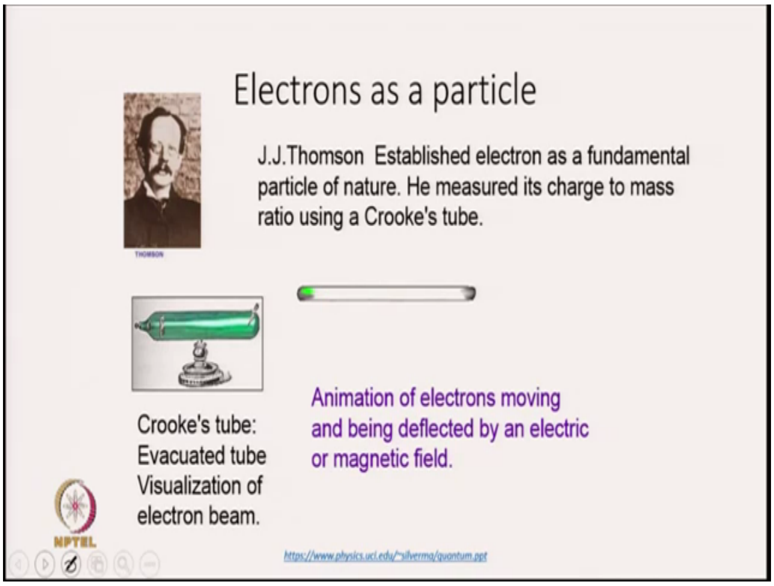

Now, we will discuss about particles. Particles such as electrons or baseball. Electrons or baseball. Now, electrons behaves as a particle and that was first established by J.J.Thomson and he established electron as a fundamental particle of the nature.

Fundamental particle of the nature and he visualized the electron beam in a crook's tube and this is the animation so you can see that there is a deflection by an electric or magnetic field.

Based on that he proposed that electrons behaves as a particle. Electrons behaves as a particle.

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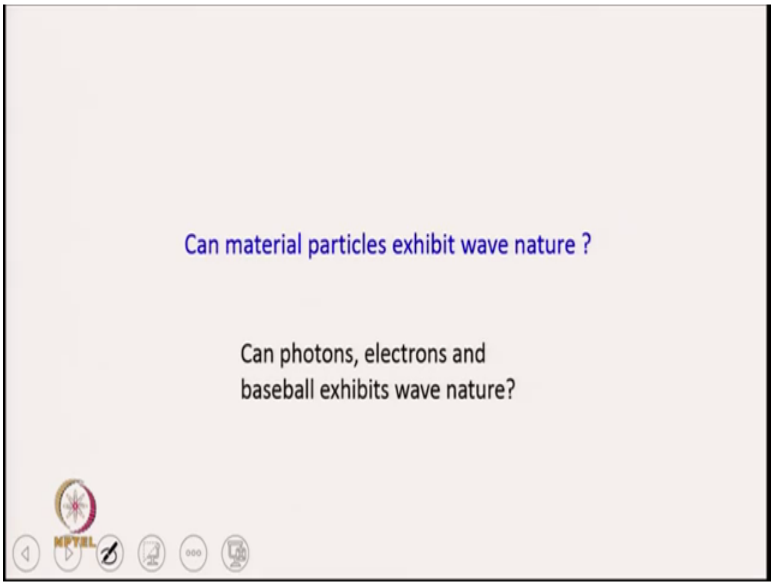

Now, the second question was, can material particle exhibit wave nature or can photon electrons and baseball exhibits wave nature.

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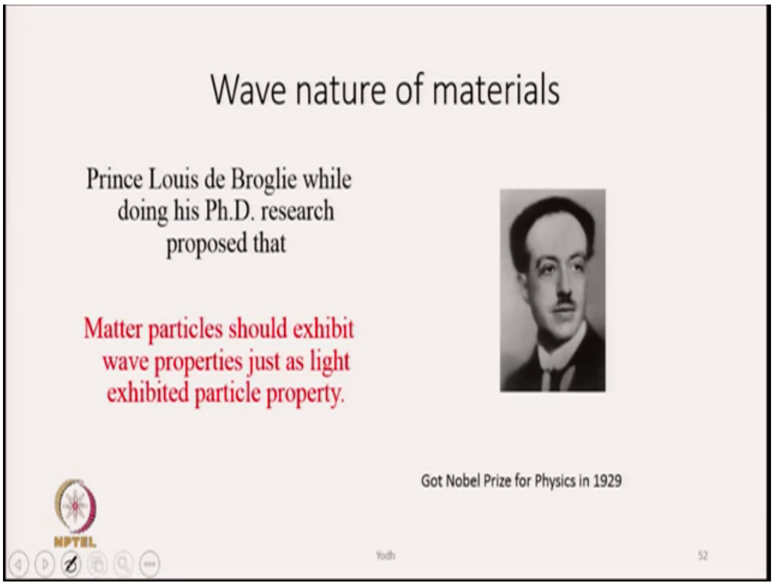

So wave nature of material is first proposed by de Broglie. He got Nobel prize for physics at 1929. He proposed that matter particles should exhibit wave property just as light exhibited particle property

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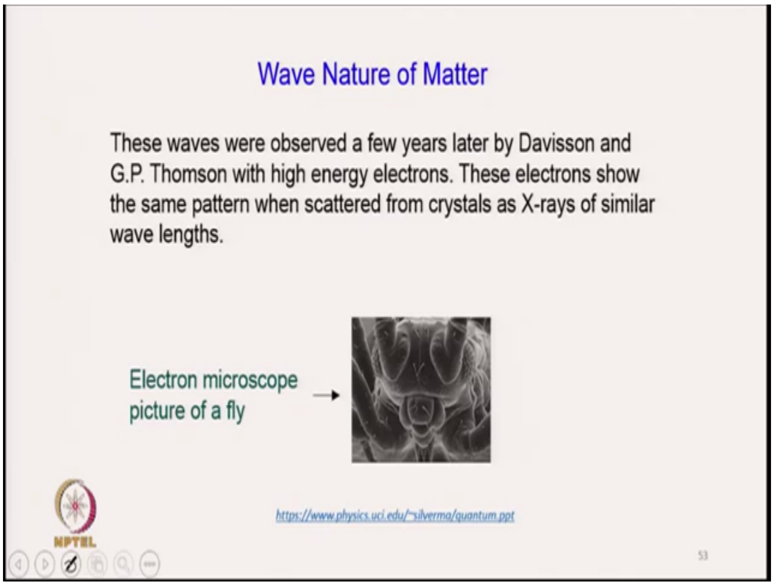

And this was first experimentally verified by Davsson and G.P.Thomson with high energy electron and they showed that electrons also show diffraction pattern. Electrons show diffraction pattern which is the property of wave. So they were able to show that matters can also behave as a material or electron can behave as your wave. Particles.

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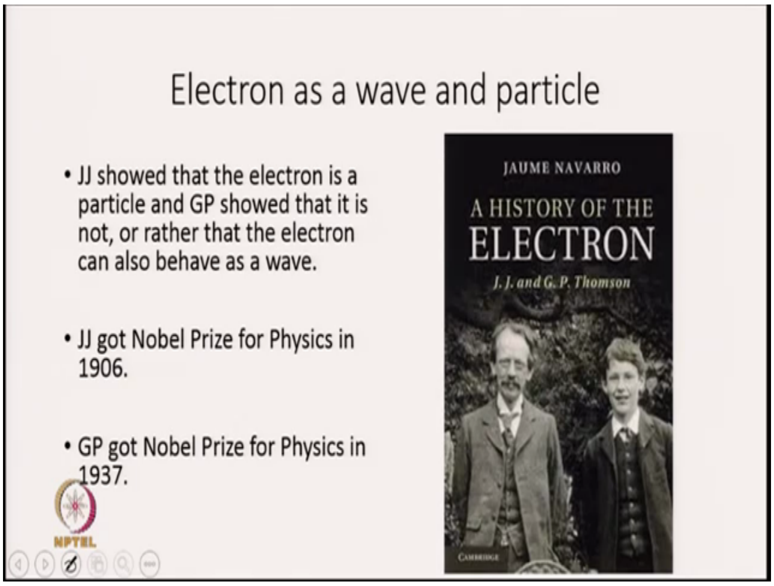

So electron as a wave or electron as a particle. Interesting that J.J.Thomson told that an electron is a particle whereas, his son told that or showed that it is not or rather electron can also behave as a wave.

Electron not only shows particle behavior it also shows wave property and both father and son dual got Nobel prize. J.J.Thomson got Nobel prize for physics in 1906 whereas, G.P.Thomson got Nobel prize for physics in 1937.

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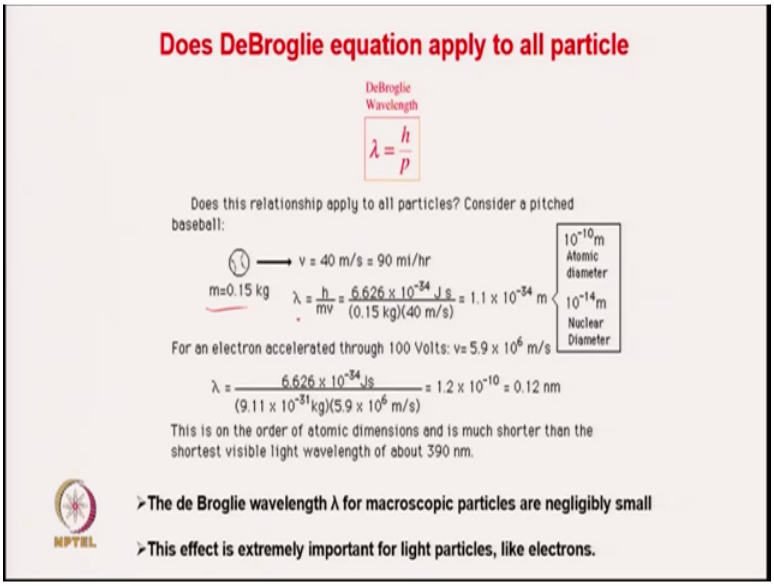

Now, question is can or does De Broglie equation apply to all particles. So let us calculate lambda for your baseball. So if mass of baseball is taken as 0.15 kg and if lambda is calculated when V is 40 meter per second then lambda come lambda or baseball comes out to be 1.1 into 10 to the power minus 34 meter.

Whereas, when electron is accelerated to 100 volt the lambda comes out to be 0.12 nanometer. So now you can see the difference between lambda, the lambda of electron is 0.12 nanometer, where lambda of your baseball is 1.1 into 10 to the power minus 34 meter.

What that mean is De Broglie wavelength for macroscopic particle are negligibly small and this effect is extremely important only light particles like electrons, because this is the 0.12 nanometer is of the order of atomic dimension. Whereas, 1.1 into 10 to the power minus 34 meter is negligibly small.

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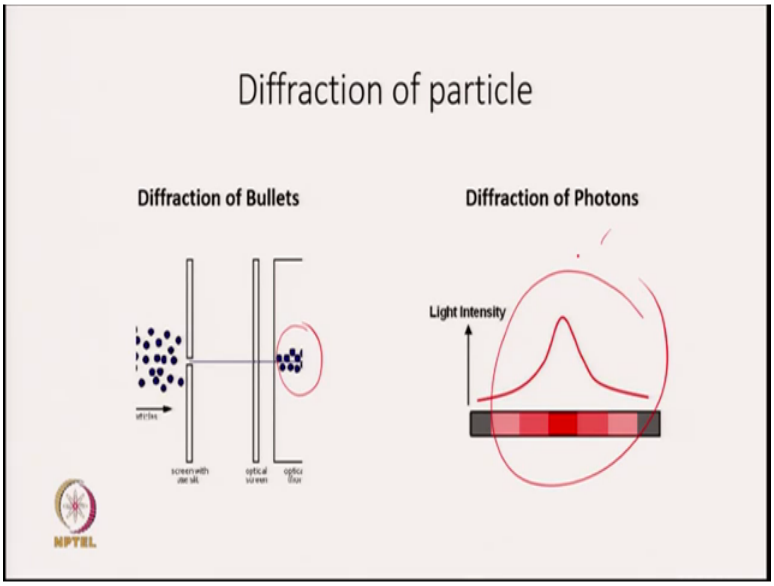

So if you take bigger particle like bullets and you try to see diffraction will not see the diffraction pattern but if you take photons or electrons you will see a diffraction pattern. You will see a diffraction pattern. What does that mean is your small particles behaves as a wave whereas bullets or bigger particle does not behave as a wave.

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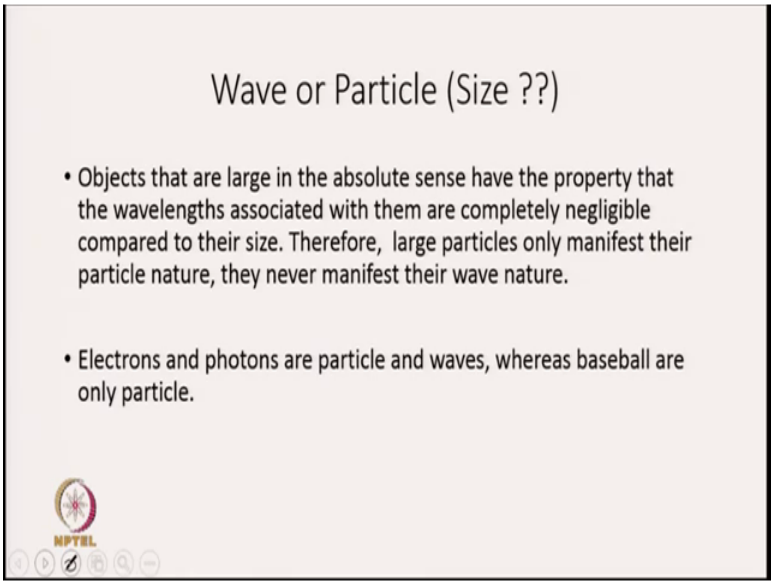

So wave or particle property of a material will depend on size. Objects that are larger in the absolute sense have the property that the wave length is associated with them are completely negligible compare to their size.

Therefore large particles only manifest their particle nature never manifest their wave nature. So macroscopic particle never manifest their wave nature. Whereas, electrons and photons who are very small they can behave as both particle and waves. Whereas, baseball will only behave as particle.

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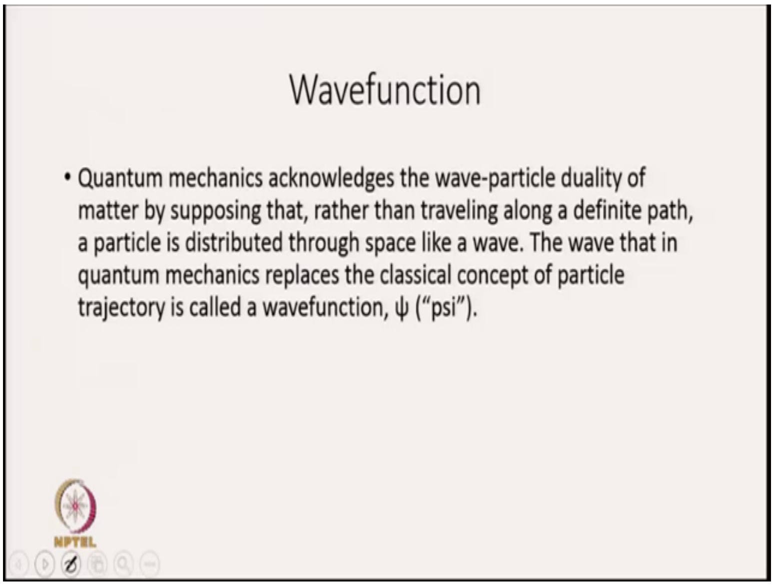

Now, quantum mechanics acknowledge the wave particle duality of matter. So we will discuss about quantum mechanics in the next class but what quantum mechanics does it, it acknowledges the wave- particle duality of matter by supposing that rather than travelling along a definite path, a particle is distributed through a space like a wave. The wave that in quantum mechanics replaces the classical concept of particle trajectory is called a wave function.

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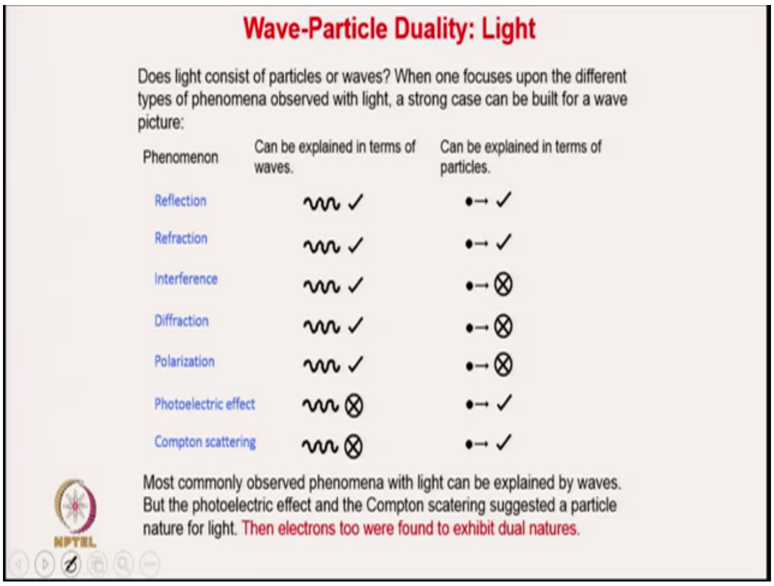

So I will leave here because time is complete. In summary, your light behaves as both wave and particle. In some of the properties, some of the property exhibited by light can be explained by taking either wave nature of the light or particle nature of the light. For example, reflection and reflection, refraction.

Whereas, interference, diffraction and Polarization can be explained on the basis of wave nature of the light. Whereas, Photoelectric Effect and compton scattering which I did not discussed can be explained on the basis of particle nature of the light. Particle nature of the light. So, and again second important thing is electrons too were found to exhibit with dual nature.

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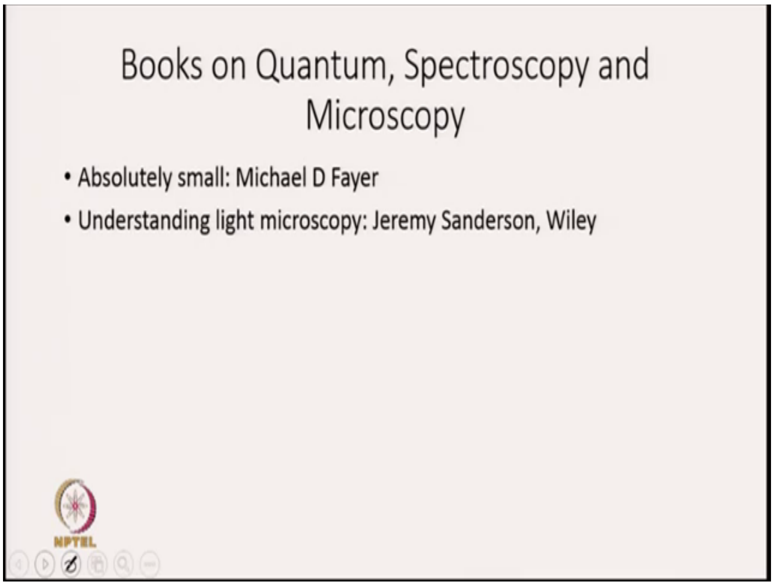

The books which I am referring is absolutely small by Michael D Fayer and understanding light microscopy by Jeremy Sanderson and this is from Wiley publication. This is from Wiley publication and

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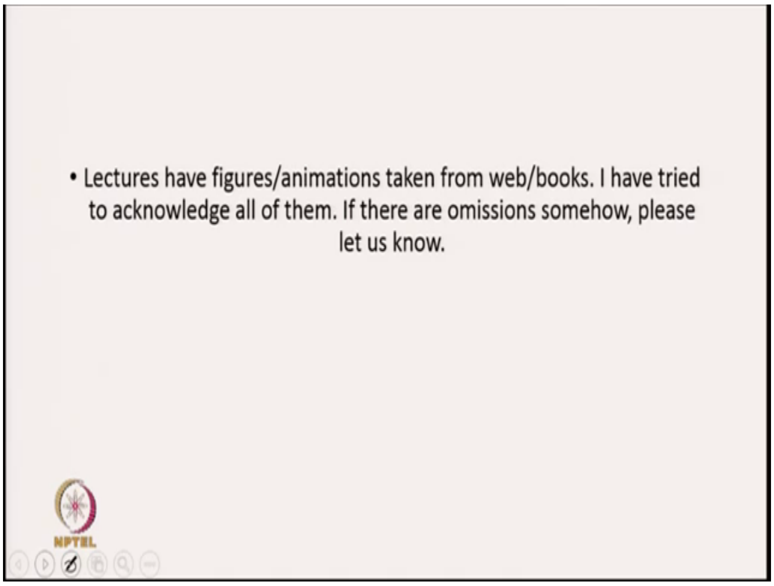

I am also referring to other quantum books, other quantum books, lectures have figure animation taken from different books or web. I have tried acknowledge all of them. But if there is a missing, let us now, we will try to acknowledge everyone and thank you for listening. See you in the next lecture. Thank you.