Physics – I Oscillations and Waves
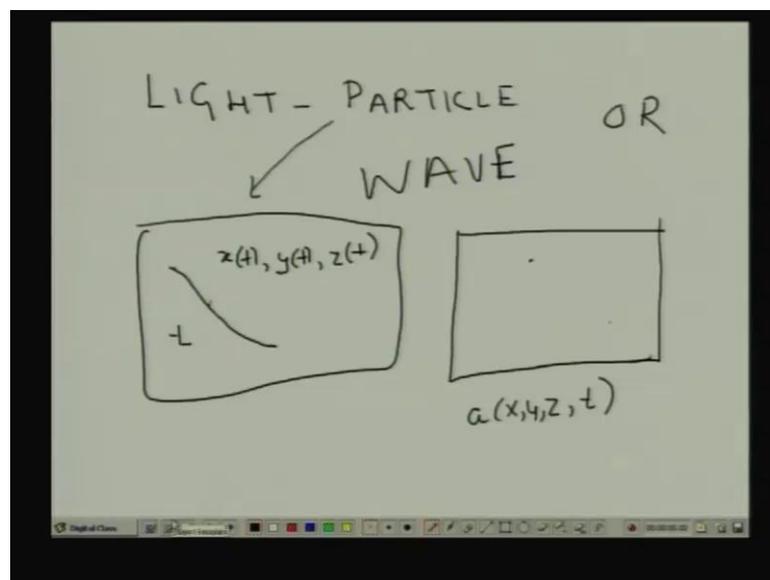**Prof. S. Bharadwaj**
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Lecture - 09
Electromagnetic Waves -I

Good morning. We shall discuss lecture magnetic waves in today's lecture. Let us, start our discussion with the question. Is light particle or a wave?

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Now, let us so is light particle or wave? In order to address this question, we should first be clear as to what we mean by a particle and what we mean by a wave? How are these 2 different? So, a particle as we have, we know a particle, is something which occupies a, which you can find at a point at a given time. So, to describe the position of a particle you need in 3 dimensions, you need 3 coordinates x y and z.

So, if you specify the x y and z corresponding to a particle, you have told precisely where the particle is. So, once you have specified the position you know exactly where the particle is and the particle is there and nowhere else. And if you specify xy and z as a function of time you then, have specified the complete trajectory of the particle. So, now, once you done this you know exactly how the particle moves as a function of time.

And at any given time you expect to find the particle only at 1 point. Now, unlike this, this was a particle. So, this is a particle: a particle is to be found at a given, at a particular

position at even at a given time and nowhere else. Unlike this, a wave and we have discussed a plane sinusoidal plane wave. A wave fills the whole of space. So, you have a quantity a, which is a function of x, y, z and time.

So, at any given time instant you could ask the question what is the value of a here or what is the value of a here and a is something which is distributed over the whole of space at any given instant of time. It could have value 0 somewhere or it could have a finite value somewhere, never the less it is defined everywhere to the whole of space at a given instant of time. And as time involves, as time progresses this the dependence on x, y, z changes.

So, it is there defined over the whole of space and you can ask the question; what is the value of a here? What is the value of a here? What is the value of a here at different positions at the same time? So, the wave is something which is extended which exists over the whole of space. A particle is something which is has a unique point at a given time it exists only at 1 point.

So, this is one of the main differences between a wave and a particle. Now, let us ask the question is light a wave or is light a particle?

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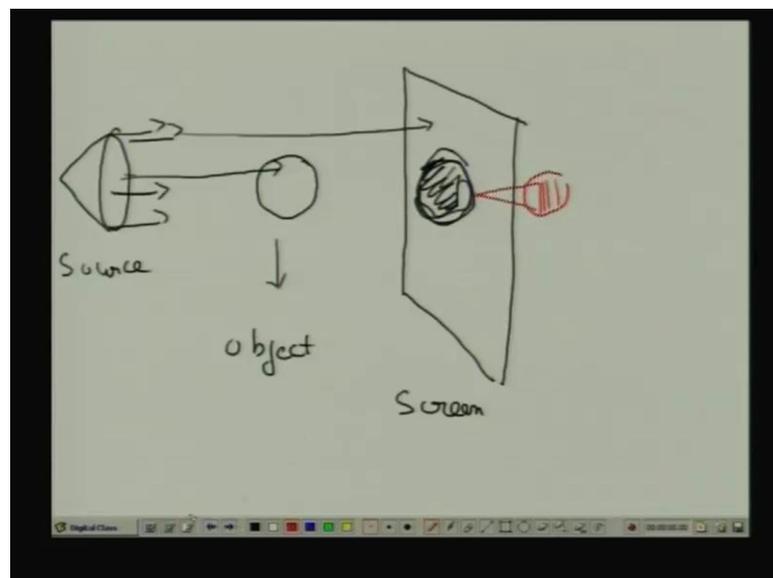
Now, consider a situation where you have a light source. So, you have a source of light, which emits out light. So, the light comes like this. And you put an object in the path of the light. So, this the light and then you have a screen over here. The question is what will happen in this situation? So, I have a light source which emits out light. The light

comes from this source, this is my source. And I have an abstraction and object over here. And this is my screen and light comes from the source and falls on the screen. Now, the question is what do we see? So, this is situation that we have encountered quite often and what we know, is what we absorb in such a situation is that on the screen.

You will get a dark patch, which is the image of the object as and the rest of the screen is illuminated. Now, if you try to model this situation. So, let us try to make up a simple model by which we can understand this situation. And the simplest possible model would be, that light comes out from the source as some. So, light is some particles which come out from the source.

Particles which impinge upon this object which, encounter the object do not pass through. Particles which do not encounter the object pass through. So, the part of the screen, a part of the screen is illuminated and another part of the screen has no light falling on it. And the particle having no light falling on it you see the shadow. And you can this is a, this the predictions of this model correspond to what you actually observe.

So, you have the corpuscular on the particle theory of light which was in vogue and Newton's time. So, you could start of by saying that light is a particle. But if you look closely at the shadow. So, if you look very closely at the shadow, at shadows in general you will find. So, if you look at a shadow in the vicinity of the edge of the shadow, you will find bands of bright and dark lines.

So, somewhere over here in the vicinity of the shadow you will find something which looks like this. There will be bands of bright and dark lines. And these lines are prominent if you have an object which is quite small, how small we shall discuss as we go along in course. Such a thing will be hard to see in this particular situation, but there are situations where at the edge of shadows you will find bands of bright and dark lights.

There are situation there is another possible situation let me, explain that to you. Suppose, you take two of your fingers and put them very close to each other and look at the sky in the day time when the sky is illuminated by sunlight. You will notice, very fine bands of, very fine bands of bright and dark in the space between these 2 fingers. You have to make sure of the fingers are very close together, but there is still a gap a very small gap.

You can then, notice a very fine set of bright and dark lines which go through your which in the gap which exists between the 2 fingers. There are many experiments, like the Newton's ring and so forth. All of which cannot be explained. So, this bright and dark bands at the edge of the shadow which I just talked about these the bright and dark bands which you get if you look at the small gap between your fingers.

Newton's rings which you can absorb in the physics laboratory and a large variety of such observations cannot be explained unless you postulate that light is a wave. It is now, well known that light is an electromagnetic wave and in today's lecture we are going to deal a little with little bit with what we mean by electromagnetic waves. To be more precise we are going to ask the question how these waves are produced, what are the equations governing these waves etcetera.

So, let to give a little bit of so, we can start off this question of electromagnetic waves, the issue of electromagnetic waves by again asking the question. So, the question that we are going to start with is. So, let us take up a question and the question that we are going to start out discussion with is as follows.

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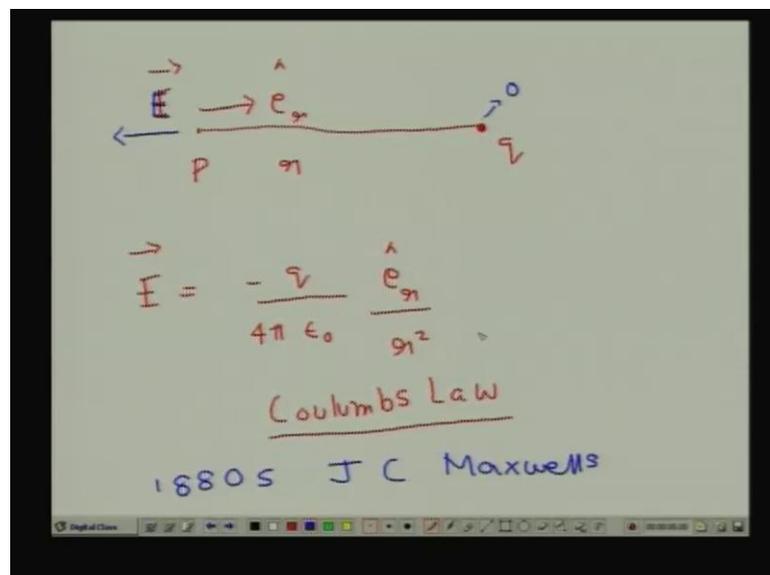
The situation that we are going to discuss as follows there is a charge q located over here. And there is a point p a distance r away from the charge. So, we have a charge q and there is a point p a distance r away from the charge. Let us, ask the question what is the electric field at this point p that is produced by the charge q over here. So, we would like to calculate the electric field at this point. And we all know, that you can apply

Coulomb's law to the situation. Coulomb's law tells us at the electric field at the point p there is minus q divided by 4 pi epsilon into e cap or divided by r square. So, this is Coulomb's law: the law of electrostatics which is familiar to all of us.

And Coulomb's law tells us that if I have charge q at rest over here the lifted feel it produces at a point p which is a distance or a way his given by minus q by 4 pi epsilon naught e cap r: e cap r is the unit vector which points from the point where you wish to calculate the electric field to the position of the charge. So, e cap r is a unit vector pointing from the point p to the positional charge.

So, the electric field is in the direction of e cap r, but it is has a minus sign. So, it is actually opposite we directed divided by r square. So, the lifted filed falls of s 1 by r square. So, you essentially have an electric field which points like this and it falls off this is the electric field e. So, let me overwrite with blue this is electric field e and it points away from the charge and it falls of as 1 by r square.

So, this is Coulomb's law it tells us the electric field at this point p. And Coulomb's law is quite well known. So, I am sure all of you know all about it. Unfortunately, Coulomb's law is not precisely valid. In the 1880s. So, in 1880s let me put down the year roughly 1880s. Somewhere 1880s a British scientist J C James Clerk Maxwell proposed certain changes in the loss which govern the electric field and which the so, the changes also employee modifications of the Coolum law, Coulomb's law.

So, these modifications proposed by James Clerk Maxwell in the 1880s had profound implications for the electric field and the magnetic field produced by charges. And the electromagnetic waves, is a consequence of these changes proposed by Maxwell. The changes proposed by Maxwell go by the name the final equations proposed by Maxwell. Which were proposed by Maxwell go by the name of Maxwell's equations.

In this course, we shall not be discussing Maxwell's equations. We shall discuss the consequences of Maxwell's equation, to the problem which we are now studying that is the electric field produced by a charge. So, let us now address the same question what is the electric field produced at this point p by the charge q taking into account the modifications of the loss of electricity at magnetism proposed by James Clerk Maxwell.

Well so, the law proposes certain modifications and the first the 1 of the big consequences 1 of the also a problem of the Coulomb's law. We all know, that no signal

can propagate faster than the speed of light. Now, Coulomb's law if you look at Coulomb's law. So, let us look at Coulomb's law: Coulomb's law tells us, that the electric field here depends on the distance to the charge and it is directed away from the charge.

Now, let us consider a situation where I move the charge a little bit. So, if I move the charge from here to here there would be a change in the electric field at this point. And Coulomb's law tells us, how to calculate the new electric field and the change in the electric field would occur instantaneously it would occur at the same instant of time that you move the charge from here to here.

So, Coulomb according if Coulomb's law were strictly correct. Then, the electric field here would change the moment you move the charge over here. Now, this would be against the accepted fact against the hypothesis that no signal can be propagated fast than the speed of light. And it is now, an absorb fact that you cannot actually propagate send any signal faster than the speed of light.

So, if you cannot send if you if. So, the fact that you cannot send signals faster than the speed of light and Coulomb's law or in disagreement with each other. So, you have to either abandon this hypothesis that you cannot send a signal faster than the speed of light. Or you have to abandon Coulomb's law. And it is so, happens that the modifications proposed by James Clerk Maxwell lead to a modification of Coulomb's law which taken which incorporate the fact that, you cannot send a signal faster than the speed of light.

So, let us now write down the modified electric field. So, let me again draw the picture first and then, write down the modification that occurs in the electric filed.

So, the picture is that i have a charge over here the charge is q and we want to calculate the electric field over here at the point p which is a distance or a way. So, let me write down straight away the electric field at the point p, at a time t. Let us, produce by the charge q. So, the electric field is given by minus q by 4 pi epsilon naught we now, have e cap r prime by r prime square plus r prime by cd by dt e cap r prime by r prime square plus 1 by c square d square by dt square e cap r prime.

So, this is the expression for the electric field at the point p as predicted by Maxwell's equations. Let me, now explain to you the various terms in this expression. The first thing which you notice, is that instead of the distance r to the charge we now, have a new symbol r prime. So, we have this quantity r prime which is different from r. Now, as I just told you a signal cannot propagate instantaneously from the charge to the point p where I want to calculate the electric field.

So, now if you want to calculate the electric field at the time t, at the time instant t at this point. The electric field at time instant t should not depend on the position of the charge at the same instant of time it cannot because, that violates that is contradictory to the fact that a signal, no signal can propagate faster than the speed of light than a fix speed which is the speed of light.

So, the electric field here at a this point p at a time t should depend on the position of the charge not at the same time, but add some earlier time. And you have to look, at the position of the charge. So, you have to go back in time by the amount light of time light

takes to propagate from the charge to this point where I want to calculate the electric field. For example: we know, that the sun is at a distance of 1.5 into 10 to the power 11 meters.

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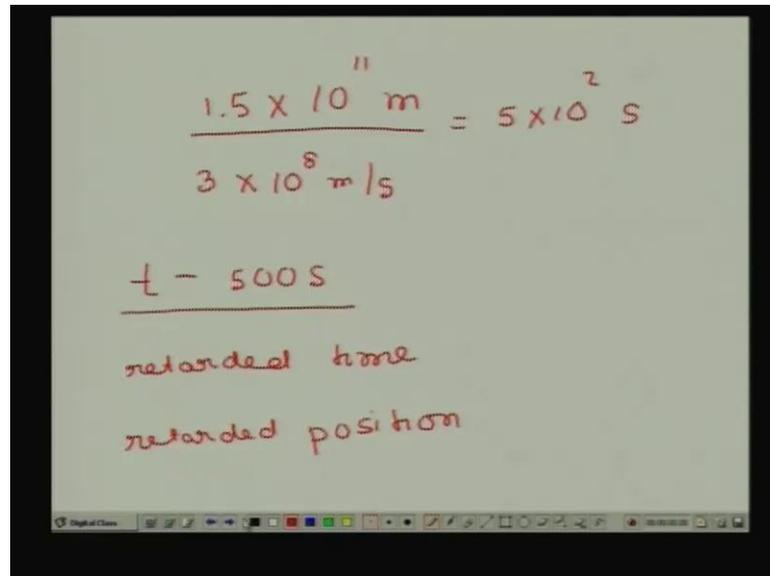
So, the sun let us just do and estimate the distance to the sun is 1.5 into 10 to the power 11 meters and if there is some electrical, some electron on the sun does something funny just move around. Then, it will take a time, it will take the time is divided by see the speed of light which is 3 into 10 to the power 8 meters per second which gives us 0.5 into 10 to the power 3 or 5 into 10 to the power 2 500 seconds.

So, if you are interested in the electric field produced by some electrons on the sun and we are interested in the field measured on earth by that. So, the electrons are on the sun and we are measuring the field of the earth. So, if I measure the electric field on the earth. Now I should look, I should be looking at I should be concerned with the position of the electrons not at the same instant, but at an instant which is 500 seconds earlier.

So, the electric field here due to electrons on the sun will depend on the position of the electrons on the sun 500 seconds earlier. So, you should be looking at. So, if I want to calculate the electric field at a time t on earth you should be looking at the positions of the sun of the electrons on the sun at a time 5 minus t minus 500 seconds. And this is what is called retarded time and the positions of the electrons at this retarded time at the time instant in the past when, the signal left the electrons is called the retarded position.

So, the thing to bear in mind is that r prime refers to the retarded position of the charge. It is not the charge, the position of the charge at the same instant of time which you wish to calculate the electric field here. But it is the position of the charge at a previous instant of time which takes into account the fact that light takes a finite time to propagate from the charge.

The signal takes a provided time to propagate from the charge to the point where you wish to calculate the electric field cannot propagate instantaneously. So, r prime is the retarded position. So, the electric field over here depends on the retarded potion of the charge. The simplest thing, which you could do this would be to modify Coulomb's law. So, has to incorporate the fact that signals cannot propagate instantaneously.

Then, replace the position r and the unit vector e cap r with reference to the retarded position e r prime and the first term in the expression over here is precisely this. So, the first term over here is just the Coulomb's law where the position of the charge has been replaced by the retarded position of the charge r prime.

But this is not the only modification that occurs in the expression for the electric field there are two more terms which occur. So, let us look at the 1 more terms. So, I have we have 1 more term here and 1 more term here. And both of these are new things which come about because, of the modifications in the laws of electricity and magnificent proposed by JC Maxwell which are incorporated in the Maxwell's equations.

Now, you should note that these 2 new terms come into the picture only if the charge is moving they involve time derivatives of the position of the charge and the unit vector to the position retarded position of the charge. So, you have time derivatives and these time derivatives are nonzero, these time derivative and this time derivative they are nonzero only when, the charge is moving.

So, you have these modifications of Coulomb's law which come up when, the charge is moving. Now, let us look at these new terms 1 by 1. So, the second term has the first time derivative of the position. So, it is a effectively of time derivative of the Coulomb's law which comes over here and you have to multiplied by r by c. So, this has the same dimension as this term and you have the time derivative of the position. So, this term comes into the picture the movement you have a moving charge.

So, if you had a charge moving with a uniform velocity, uniform speed then, you would have a contribution from the second term. Whereas, the third term would contribute only if you had accelerations because, it involve the second derivative of the quantities which referred to the position of the charge and this will be nonzero only if the charge is accelerating.

So, the. So, the first new term arises if the charge is moving also, if it accelerates for the second charge is non zero only for a charge which is accelerating. A charge which is not accelerating and moving with the uniform speed, will have only a conflation from this and this not from this. Now, radiation is something which can is an electric radiation is an electromagnetic effect.

So, it is a effect of electricity and magnetism which can propagate over large distances. Another point which I forgot to mention earlier, is that the modifications of the loss of electricity and magnetism proposed by Maxwell. So, these new equations of electricity and magnetism by proposed by Maxwell. Had another very profound implication they showed that electricity and magnetism are manifestations of the same underline quantity.

So, the you now have an unified theory of electromagnetism. They are not distinct phenomenon, electricity and magnetism or essentially manifestations of the same phenomena of the same thing called electromagnetism they are not distinct. And it is a unification that you have and Maxwell's equations they this unifications essentially, follows from Maxwell's equation.

So, Maxwell showed effectively that they are the same electricity and magnetism are just two aspects of the same thing. And the magnetic field predicted by Maxwell's equations let me also write it down here.
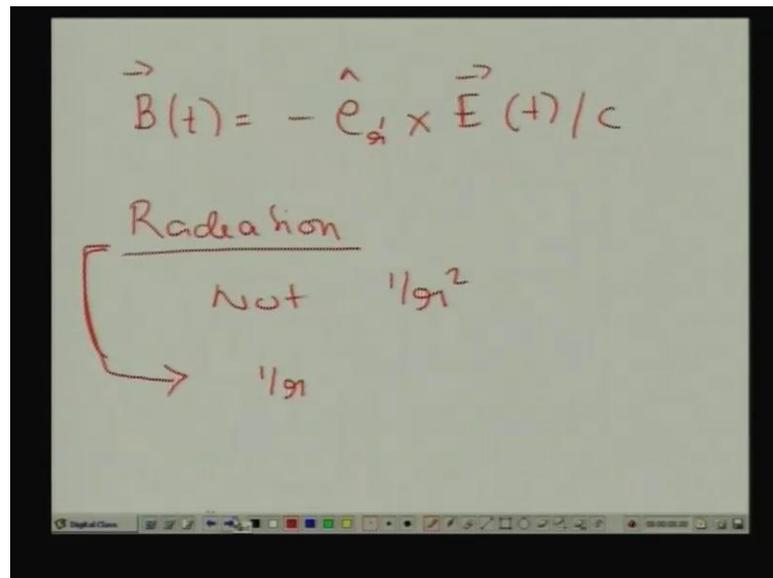
So, the Maxwell's equation also predicts a magnetic field which is given by B which is at the point is minus e r prime cross Et by c. This is something i should have mentioned earlier I forgot to mention it. So, Maxwell's equation predict that the electric field here you to a charge here is given by this expression and the electric and the magnetic field at this point is given by this expression.

So, the magnetic field is the unit vector to the retarded potion of the charge cross the electric field divided by c with the minus sign. So, if you wish to calculate the electric and the magnetic fields at this point due to the charge over here. So, you have to you can calculate the electric field from this expression and you can calculate the magnetic field by taking the cross product of the unit vector towards the retarded position of the charge with the electric field.

So, the electric field and the retarded potion of the charge together determine the magnetic field also. So, once you know this you can essentially determine the magnetic field also at this point. Now, view a discussing the electric field in some detail and I told you that this term is the same Coulomb's law with retardation take in into account this term arises when, the particle is has a velocity and this term arises when, the particle has an acceleration.

Now, radiation the phenomena of radiation, in the phenomena of radiation you have charges at rate distances influencing charges, other charges at charges influencing.

So, you have 2 charges at get distances influencing each other. We could go back to the situation of the sun charges on the sun, charges which are moving around on the sun produce electromagnetic radiation which we see here. So, charges moving around the sun, on the sun influence charges on the earth and the light that we see is essentially this. So, there are charges inside my eyes which get influenced by charges moving around of the sun and this is the how we see essentially, how we see the light from the sun.

So, this the whole thing. So, radiation is something which can propagate over large distances in influenced which over large distances. So, we have to see terms in this expression for the electric field, which will be significant even at large distances. The Coulomb's law notice, falls of in the predicts at the electric field will fall off as 1 by r. Now, this is not the term which leads to radiation.

So, radiation does not arise from these 1 by r square depends. So, radiation is not the 1 by r square part of the electric field. Radiation arises from any 1 by r dependent term if it all it is there in the electric field. So, if I had a 1 by r dependent term in the electric field this would we something which falls of considerably slower than the 1 by r square term in the electric field and this is the term which is responsible for radiations.

So, if I had a 1 by r term in the electric field this would be the term, which would be responsible for radiation. If I did not have such a term there would be no radiation. And the reason why, we can associate this with radiation we shall be cleared in the next class when, we discuss the power which is radiated. So, the question is under what situation will there be a 1 by r term in this expression for the electric field.

1 by r square term does not contribute to radiation. And it is clear that the Coulomb's law predicts only a 1 by r square term. You can easily verify, that if I differentiate this expression for this expression over here. So, here I have the unit vector to the retarded position divided by r square, if I differentiate this with respect to time and then, multiply by r the retarded position distance by c. This again is of order, this again is of order 1 by r square and this does not contribute to radiation.

So, it is only this term over here which has a 1 by r which can have a 1 by r dependence and it is this which gives rise to radiation. And this term has a nonzero value only when, the particle is accelerating because, it has a second derivative with respect to time. So, the point is that you have radiation only when you have an accelerating particle. So, let

us now look at this term which is responsible which can give rise to a 1 by r term which is what we call radiation.

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Let us, look at this term in some more detail. So, the term we had over then is d square dt square of the unit vector to the retarded position of the charge particle. So, to let me draw the picture again this is the charge particle this is the point where we wish to calculate the electric field. And we have to calculate, the retarded the second derivative of the unit vector to the retarded position of the particle.

Now, we could this can be written as d by dt square by r square by r right. So, this could be written that side I had the correct thing. So, this can be written as a second time derivative of the vector to the retarded position of the particle divided by the magnitude of that r prime. Now, this evaluating this expression in general is a little complicated. And the complication arises because, of the following when the particle moves from here to here.

Let say, then you have to also change the expression for the retarded time. Because, the retarded time depends on the distance to the particle. So, you have to take it to account the change in the retarded time when, if the particle moves from here to here. The distance to the particle from p has changed and that will affect the retarded time and the retarded position both simultaneously.

Now, you could make a simplification if you assume that the motion of the particle of the charge particle is restricted to a small region over here. Such that, the dimension of this

region that this region inside which the particle moves is much smaller in extend compared to the distance r. So, we are interested in calculating the electric field here.

So, we are going to make a simplifying assumption we are going to assume that this distance r is much larger than the distance over which the charge particle move. The charge particle moves only over a small extend. For example: going back to the electron on the sun, the electron on the sun does motions on the surface of the sun. The radius of the sun is ten to the power 8 meters and the electron on the surface of the sun.

Let us, assume that does not go all the way around the sun is does motions, which are restricted to a part of the surface of the sun. So, the distance to the sun is 10 to the power 11 meters. So, the assumption that the extend of motion of the electron is much smaller than the distance from the earth to the sun is quite valid. So, this is the an example of the assumption which I am going to make.

So, we are going to assume that the charge particle moves around does accelerations, but the motion is restricted to a very small region. Then, the point where you want to calculate the electric field is much further away than this extend. In this assumption, you can hold the retarded time you can calculate the retarded time using this fixed distance on and this simplifies matters quite to bit.

So, when you want to calculate the electric field at a time t over here the retarded time that you use is t minus r by c. Where r is now the distance to the centre of this region. You do not take it to account the fact that the charge particle moves around within this region, which will change the expression for the retarded time that is neglected because, it is a very small change. And we are going to use this expression t minus r by c for the retarded time here note r is the distance from the point p to the centre of the region inside which the particle moves around.

So, with this simplification further this is 1 of the simplifications further, we are going to assume that when you differentiate this twice. So, you are going to we have to differentiate this expression twice. If you differentiate the denominator twice you will get a term which falls off as 1 by r square which is not that term of interest. So, the term we are interested in is going to be where, you differentiate the numerator twice or you differentiate the numerator and the denominator once.

Well the term that we get finally, is approximately the acceleration. If we differentiate the position vector twice you get the acceleration divided by r. And we are again going to assume, that as the particle moves around in the denominator you can replace r prime by the position to the centre of this region over here. So, it is the retarded acceleration it is the acceleration at the time t minus r by c.

Now, if the charge particle moves in the direction of this line of sight, it does not change the unit vector. There is a change in the unit vector to the charge particle; to the retarded position of the charge particle only if the charge particle accelerates the direction perpendicular to the line sight an acceleration over here. In this direction, an acceleration in this direction will not cause any change in this term.

So, this does not contribute. So, we have to look at only the acceleration perpendicular to the line of sight perpendicular. So, it is only this acceleration which contributes to this term it is the only this acceleration we changes the unit vector. So, if this my unit vector the particle moves from here to here there is no change in the unit vector. The unit vector changes only if the particle moves from here to here.

So, it is only the perpendicular component of the acceleration, perpendicular to the line of sight component of the acceleration which produces any effect on this term. So, it is only this that has to be taken into account and if I put this back into this expression we then have the 1 by part, 1 by r part of this electric field that is the part which we call radiation.

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So, let we write down the 1 by r part of the electric field. So, we have Et is equal to minus q by 4 pi epsilon not c square r into a perpendicular t minus r by c . So, let me again recapitulate what we have done. I told you right in the beginning, that the modifications of the law of electricity and magnetism proposed my James Clerk Maxwell. If you incorporate those, the electric field due to a charge is given by this expression over here.

When, you are interested in radiation you have to isolate the part of the electric field which falls of as 1 by r as you move away from the charge. The part which falls of as 1 by r square or a larger power of r does not contribute to radiation. So, we have seen that it is only the last the third term here which contributes to radiation. So, radiation occurs only when the particle is accelerating.

We calculated this term under the simplifying assumption that, the particle's motion is restricted over a very small region. In this assumption we then, calculated this second derivative of the unit vector and putting it back into the expression we obtained the electric field produced by the charge accelerating particle to be this. So, this the radiation part of the electric field which corresponds to radiation.

Let me, summarize this again. So, there is a point p here there is a charge which is accelerating in this direction. And we would like to calculate, the electric field produced by this charge accelerating in this direction the charge has got a magnitude q accelerating in this direction a. We would like to calculate the electric field produced by this over here. So, if you wish to calculate the electric field produced by this accelerating charge at this point. You have to first take the component of the acceleration, perpendicular to the line of sight.

So, this is the direction perpendicular to the line of sight. So, you have to take the component of the acceleration perpendicular to the line of sight which is this. So, the electric over here is equal to minus q by 4 pi epsilon not c square r into the component of the acceleration in this direction. So, let me in this direction over here. So, the electric field over here will be parallel to this and there is a minus sign. So, it will be directed opposite.

So, this is what the electric field is going to look like. It is the it is parallel to the component of the acceleration perpendicular to the line of sight. It is directed in the opposite direction and it has a magnitude given by the expression over here. You could

also write this Et is equal to minus q by 4 pi epsilon not c square r a perpendicular t minus r by c into sin theta.

Where, theta is the angle between the line of sight and the direction line of sight is here and the direction of the acceleration. So, you could also write the electric field as minus q by 4 pi epsilon not c square r into the perpendicular component of to the acceleration. There is no need to put the perpendicular component anymore into the retarded acceleration into sign theta. Where, theta is the angle between the direction of the acceleration and the line of sight.

So, in the past say past few minutes of this lecture I have told you how to calculate the part of the electric field which corresponds to radiation. We have I have told you how to calculate this from an accelerating charge. Let me, now take up for discussion of practical application of this. So, let me show you the situation which is the practical application of this.

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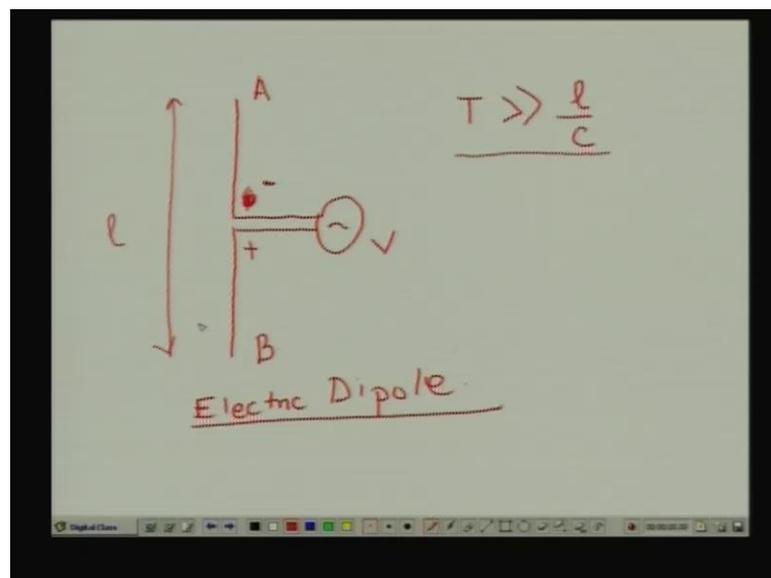
We have two metal wires: 1 like this and 1 like this let us call this A and B these 2, But can think of it as 1 single metal rod which has been cut in the middle. These 2 parts of the rod are connected to a voltage generator. So, I have 2 metal rods you can think of it a line this. So, can think of it a there are 2 metal rods: 1 is A, 1 is B. And the tips of these the 2 tips which are near each other or connected to wires and these wires are fed into a voltage generator.

So, this voltage generator produces a time dependant voltage. So, alternating voltage so, let us consider a situation where at a given instant of time this is positive and this is negative. And ask the question what will happen? So, if I have a positive voltage here to this end of the rod metallic rod then, all the positive charge will accumulate at the other tip and the negative charge will rush over here.

Similarly, the negative charge over here on this rod will accumulate on the tip over here and the positive charge will rushed onto the other end. So, if I apply a voltage like this there cannot be a voltage gradient across inside the metallic wire on the surface. So, the charges will go to the tip. So, when I put a positive voltage here there be a positive charge accumulated at this tip.

If I put a negative voltage here there will be a negative charge accumulated on this tip. Now, the voltage source is varying with time. So, if I have a voltage source varying with time then, after sometime this will become negative and this will become positive. When, this becomes negative. So, now, it was a earlier positive, it has now become negative. Then, the positive charges from here will rush on to the other wire other end and the negative charges from here will rush here.

So, you have the charges the essentially the electrons will jump back and forth between these 2 watts. And if the electrons jump back and forth between these two rods through this because, of this voltage oscillating voltage you will have positive and negative charges alternatively accumulated over here. So, this you will have charges, accelerated charges going back and forth in this direction.

So, if this has a length l you can think these two metal rods as a single metal rod of length l and you have charges accelerating back and forth that two ends between the 2 ends of this metal rod. So, you a situation where you have charges accelerating in this direction in the direction of this rod. Now, if you are interested in the electric field pattern at a large distance from this arrangement over here then, you can think a.

So, that is the first thing. And if it takes for the charges to move, from 1 end of the rod to others. So, the time skill at which the charges are moving back and forth. If that time is much larger than, the time it takes for light to propagate this distance. So, if the time skill over at which the charges are moving back and forth is much larger than the time it takes for light to propagate across this rod. If this condition is satisfied then, far away from this contraption we can think of this as a as an oscillating dipole.

So, this is what is called an electric under these conditions this is what is called an electric dipole oscillator and you can think of this as an oscillating dipole. So, this kind of an oscillating dipole. So, inside this oscillating dipole I have charges accelerating back and forth. And this kind of an oscillating dipole, where you have these charges oscillating back and forth will produce electromagnetic radiation, if will produce a radiating electric field.

So, the radiating electric field they will also in addition to the radiating electric field, there will also be a magnetic field. There will be a magnetic field given by this expression because, of the accelerating charges. So, this kind of an oscillating electric dipole, the radiation it produces is called as the electric dipole radiation is very common in a large number of technological applications.

So, whenever this 1 of the simplest mechanisms to produce electromagnetic radiation. And not only, that much of the radiation produced in nature is occurs through electric dipole radiation. And in the class we shall discuss the electric dipole radiation, the radiation produced by such an apparatus somewhat more detail.