Introduction to Electromagnetism
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Lecture - 64
Radiation from an accelerating charge I

This is the final lecture on this introduction to electromagnetic theory course. You have learnt in this course about electrostatics, about magnitude statics. Then we came to the dynamics part and you learnt how electric and magnetic fields can give raise to each other, when they change with time. We have also learnt how they sustain each other and give raise to disturbance that can radiated, that can propagate, and that is called radiation. No course on e m theory is going to complete until we see how this radiation arises. So, in this final lecture I am just going to give you a qualitative description of how you electromagnetic radiation arises. You have all heard in your eleventh twelfth grade, in particular in connection with Bohr's model, that any accelerating charge radiates. And therefore, in Bohr's model, an atom would be unstable, if that charge moving in the orbit radiated, because it is accelerating.

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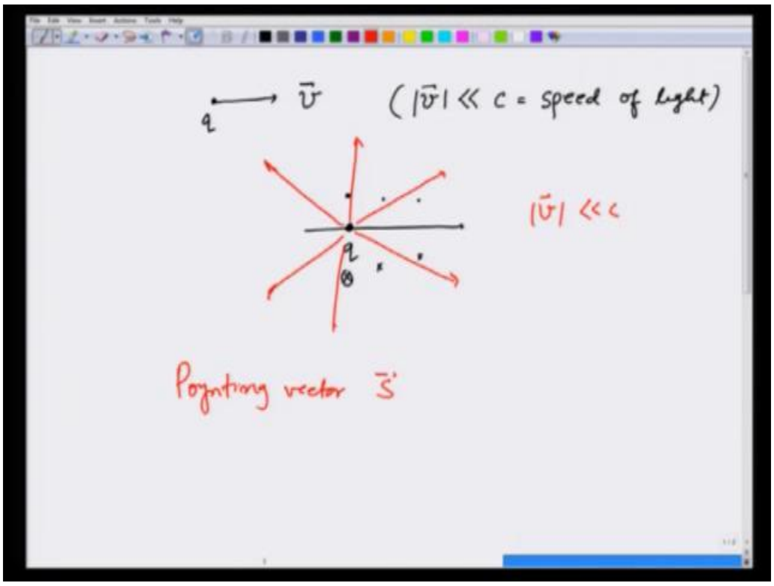

So, what I want to show in this lecture is, how acceleration of charge least radiation. To start with let see y and non accelerating charge should not radiate. So, let us look at a charge q point charge q moving with constant velocity v, which is such, I am going to focus this lecture on magnitude of v being much less than c which is the speed of light.

In one of the previous lectures, or assignments, you have seen that a moving charge create a magnetic field around it. So, this charge q which we take to be positive. Suppose it is moving the right direction, it will have a b filled which is coming out on top and going in the bottom, and as you go away field magnitude become smaller, none the less this is what it is. And to good approximation I can take the e field to be being readily out, if this is for v magnitude you much less than c. So, that what you notice is that ,the pointing vector s, is such that it does not take the power away and therefore, does not reradiate. There is another very cute way of looking at it and that is this.

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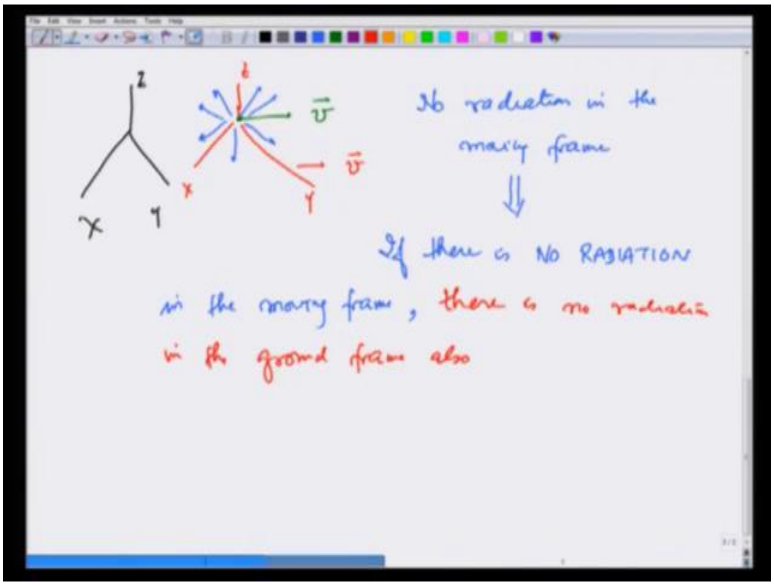

If this charge is moving with velocity, constant velocity v, let us attach a frame to this charge. Let me make a frame by as red line x y z, and this frame therefore, is also moving with constant velocity v, and here is my ground frame. So, with respect to this ground frame is frame is moving with velocity v. However, in this red frame which is moving frame a charge at rest, and therefore, the electric field due to the this charge is going to be radially outward, and there is no magnetic field, and therefore, no radiation. So, let us write this no radiation in the moving frame; however, this frame is moving with respect to the ground frame with a constant velocity, and therefore, it is an inertial frame ,and the physics in the two frame has to be therefore the same, and this therefore, this implies, if there is no radiation in the moving frame. This implies there is no radiation in the ground frame also. Thus charged moving with constant speed does not reradiate.

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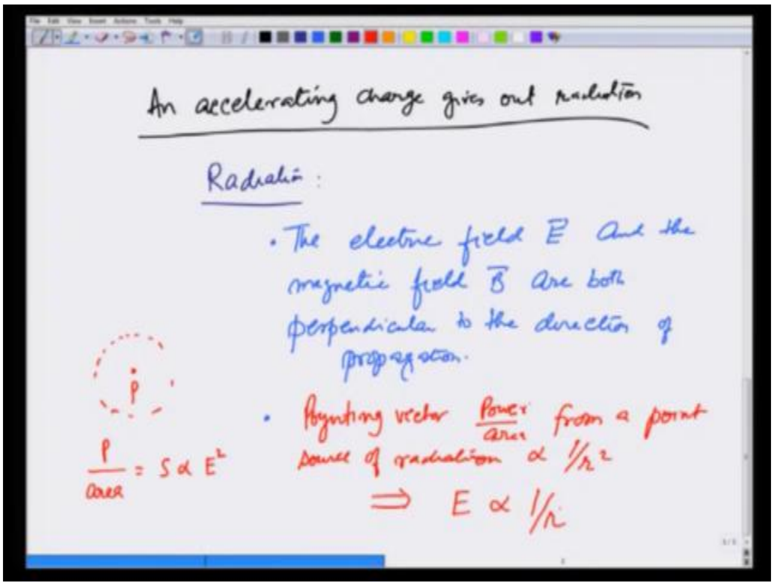

Let us now show how an accelerating charge would give out radiation. So, now, what we want to show is, an accelerating charge gives out radiation. If you continue doing physics or an advanced course in electromagnetic theory, you will see a mathematical radiate derivation of this through potential and all that. Here is the description is going to be very qualitative. So, let us for this understand to key properties that I am going to use of radiation. In a radiation, the electric field e and the magnetic field b are both perpendicular to the direction of propagation.

We have seen that in the past two lectures. Number two, if there is a point charge radiating; suppose with power p. As you go farther and farther away, the same power start going to a larger and larger area, and power per unit area is nothing, but the pointing vector, which is the proportional to e square. So, the pointing vector, or power per unit area form a point source of radiation, is proportional to 1 over r square, where r is the distance from the point source. And this implies that the e field is proportional to 1 over r. Let us see pictorially, if I have a point's source, let us make it with green out here, then at a distance r. If the radiation is going out this way, I would have an e field, either going as shown here or go into the paper.

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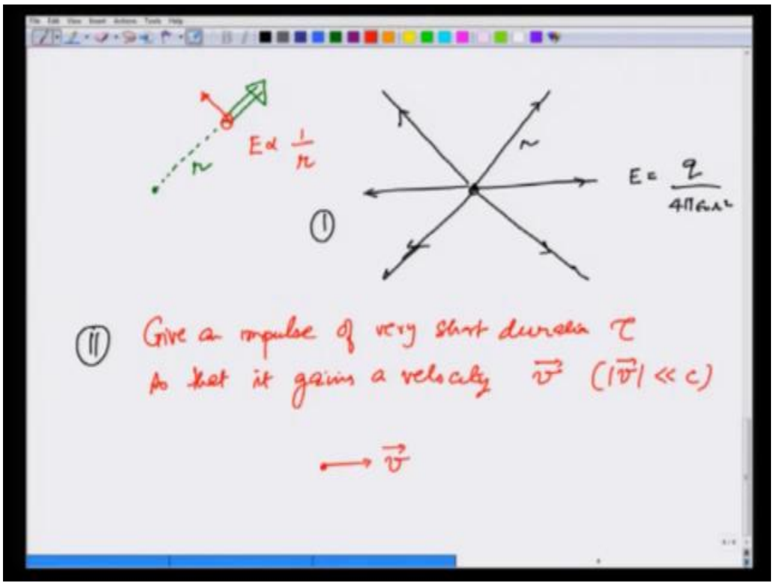

In other words, it is perpendicular to the direction of propagation, and e will be proportional to 1 over r. If I can show that an accelerating charge gives me a propagating disturbance, which goes as for which the e field is 1 over r, and is perpendicular direction of propagation, I have shown them the radiation. So let us see that, suppose this charge at rest. I take a charge at rest. This has an electric field. I will make three or four line, lines like this. And this e field is nothing, but q over 4 pi epsilon 0 r square, where r is a distance, and this field is radially out. Now suppose, this is step one. Step two give and impulse of very short duration tau to this charge, so that, it gain a velocity v, and again we are going to focus on the cases where the magnitude of the velocity is much less then this field of light. So, this charge now, is moving with speed b, with velocity v. It has been given this tau impulse for very duration for time tau.

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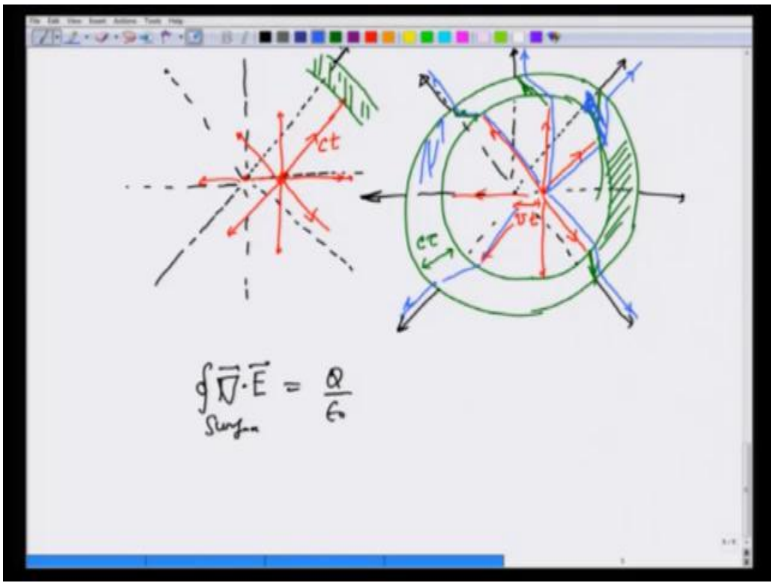

Let us see what happens now. So, here was this charge initially at rest, and this field was going out like. I am making it radially out, and this has given a k. So, that in time t it reaches here. Things are little exaggerated; it reaches this distance v t. Now in this same time t; since the charges in same position the field also has changed, and v is very small though the field is going to be radial about this position of charge. Let me again make the same lines that I made for the charge when it was at rest. However, this cannot be redial all over the space, or it cannot be this red field all over the speed, because this propagation is the finite speed of light. So, this will become redial, the red field exchange only up to the distance c t. So, this distance is c t, after that for some period tau. Now I do not know what the field is, but certainly need not be radial. The reason is very simple. During tau that small time period, the charge was accelerating, and therefore, I cannot actually attach an inertial frame to it. If I could attach in inertial frame to it, I will see the field in that has field exist in the round frame, but I do not know.

I certainly know, because when it moving a velocity we have certainly know, that I can attach a frame to the charge in which the field is radial, and since velocity small it remains redial in a ground frame also. I certainly know that outside the seat of the field is redial again. This in between the two regions, which I am showing through the green I do not know; the nature of field. So, let us now make this picture again. So, I have this black address charge, and up to a distance c t and little beyond that, after that the field is radial all over the place. Let us do it on this side also. So, I will make this circle, is one circle like this around it. There is another circle like this; outside the out of the circle of the field radial, on this side also. This distance between the two circles is c time tau. The tau that small duration time during which I give the impulse. After time t the charge particle has come here, this distance being v t.

And now the field will be radially out from this. But only up to this inner circle, because that information that has moved reaches only this part, in between something else happens. Now, notice that in (( )) equation, we assume that divergence of e integrated over surface, is equal to q over epsilon 0, which is Gauss's law this remains in where, no matter which frame I am in. So, the number of lines, if I take number of lines representing the charge remains the same outside and inside. So, the only way they can be there therefore, added is that I connect then through this green field out here, green field out here, green field out here, green field on the site. So, the field lines are looking like this. Let me make them in one colour clearly like this here, goes out goes out, comes here like this goes out and goes out. Similarly here it goes up, goes out like this and goes out. And you see this is the field line structure, wheel on the side is like this. Again when I looked at the field inside it was redial. Field when out sitting at the charge moving with the constant velocity, again whatever I saw in that frame.

For small velocity I can say, the field is essentially the same in the ground frame also. In between I do not know, the only thing I know is that, the number of lines should remain the same outside or inside, and therefore this is the blue line show the way, they only way I can connect them. Only simplest way we can connect them. But if I connect them like this something interesting happens. In this region between two circles here, you see the blue line has a component which is perpendicular to the directions redial direction. So, what is happening, now as we gave the acceleration the impulse, this small region which is of width c tau is started propagating out this with the speed c. So, there exist this region, corresponding to size is to those times, when the charge accelerated, that has the field perpendicular to the redial direction, or perpendicular direction of propagation. So, we have established that there exists a field in those times when the charge is accelerating, which is perpendicular to the direction of propagation. Next we want to show that it is 1 over r, and therefore calculate the power radiant.