Electromagnetism

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Lecture – 57
Electric current

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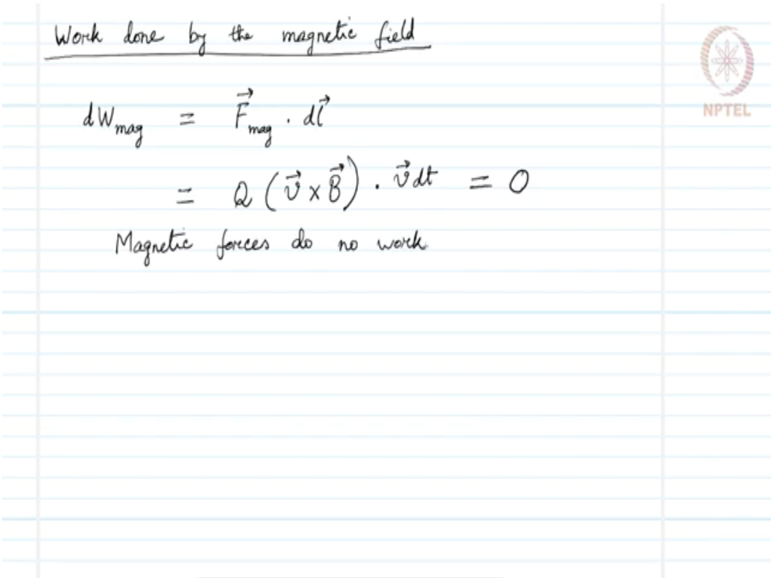

Now, let us consider currents in a bit more details.

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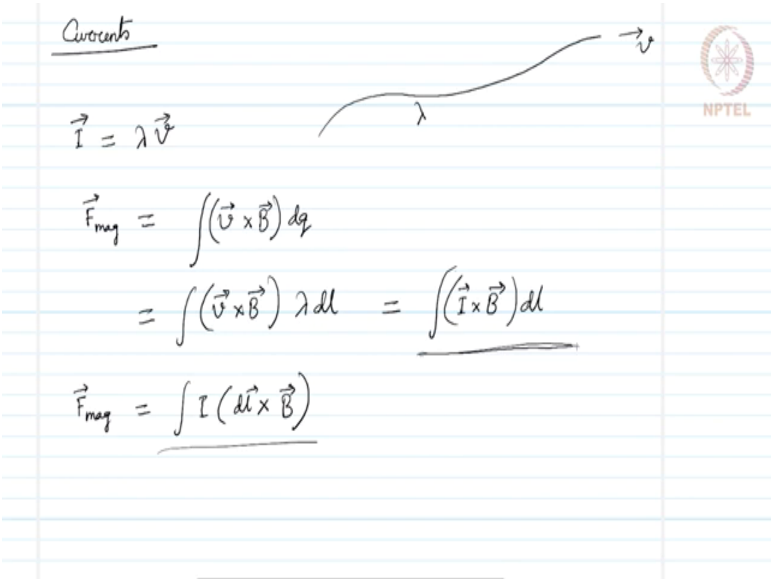

If we consider a line like this with charge density lambda, uniform charge density lambda on it. And if we consider that this line is moving along this direction with speed v or velocity v. Then the current due to this kind of an arrangement is lambda times v.

So, its the charge times the charge that passes through one point at unit time that is the current. And its important to note whether current is a scalar or a vector the charges are moving along a particular direction that is we are considering now. Although in reality the charge carriers move along many different directions and the resultant motion is considered as the direction of the current.

But current always has a direction. So, current must be a vector quantity and its proportional to the velocity therefore, it velocity is a vector quantity therefore, current must be a vector quantity. Let us write this in vector notation. And if we do that then, the magnetic force can be expressed as for in for an infinitesimal charge dq moving with velocity v. So, this would be the magnetic force.

And if we now consider as many such dq infinitesimal charges and sum over all the forces for the entire system entire charge distribution, then we will have to integrate over that and we will get the total magnetic force. That equals for the example of the line charge distribution that we have considered. v cross B times lambda dl and this means this is I cross B what is I? I is lambda times v. So, these two make it I dl integration over that. Now I l and dl are in the same direction in this case they cannot be along different direction.

So, we can also alternatively write that magnetic force is I times dl cross B; if we consider that the charges are moving on this wire. So, the dl and the velocity of that charge that could be along the same direction there is no question of that being in the different direction. So, this expression is also valid and it means exactly the same as this expression. Let us consider an example of this force [FL].

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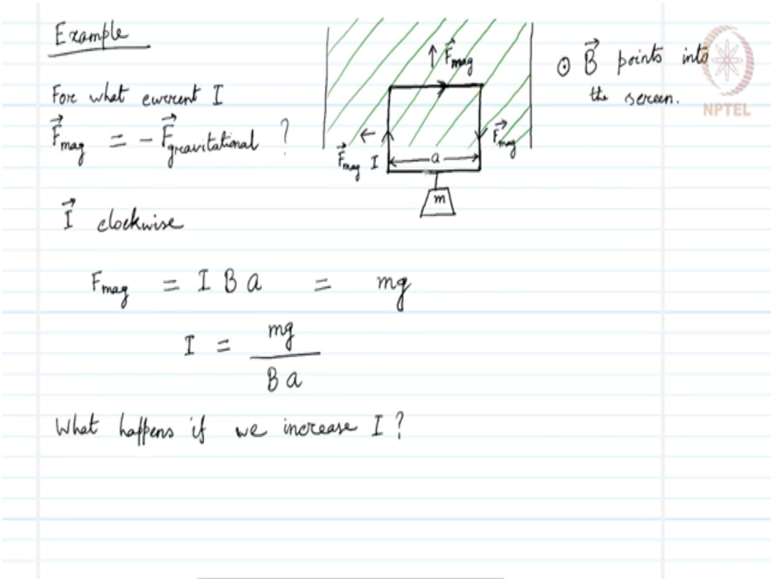

We consider a rectangular loop of wire, supporting a mass m hanging vertically with one end into the into our screen in the shaded region. So, we have a rectangular loop like this and this rectangular loop carries a current. In this direction and there is a mass m hanging from it like this. Now, we have a magnetic field in this region say, I am shading it with green; in this region there is a magnetic field and not outside.

So, the width of this loop is a; now the question is that for what current I flowing on this loop? Would the magnetic force exactly balance the gravitational force that is acting downward? We are supposed to find for what current I magnetic force would be equal. Opposite to gravitational force this is the question that we are supposed to answer.

Now first of all well, we must tell the direction of the magnetic field. The magnetic field is into the screen, in order to solve this first of all we have to find the direction of the current.

We have already shown some direction let us verify whether this is correct or not given the direction of the magnetic field.

We need the loop being pulled upward by the magnetic field otherwise its not going to help us. So, I cross B is important B is into the screen along this arm the left hand side arm there would be a force along which direction. Let us see its I cross B applying the right hand rule we will get something like this.

So, the force will be along the left on this part. Similarly on the right side part here this part the force will be along this direction, it will not help in balancing this loop against the gravitational force. Let us consider if this be the direction of the current in this arm remember, the other arm is not subject to the magnetic field. If this be the direction of the current in this arm then applying the right hand rule will get.

So, I cross B; that means, the force points upward, upward would be the direction of the magnetic field magnetic force. So, the direction of current that we have drawn here that gives the force in the correct direction. So, the current would be clockwise after finding the direction of the current we have to find.

The magnitude that is sufficient to balance it the magnitude of the magnetic field on this upper arm. Because that is the only arm that matters the side arms, they will have force that will be equal and opposite to each other they will cancel out. And on the lower arm there is no magnetic force acting.

Therefore, only the force on the upper arm that is important to us and that is current times the magnetic field times the distance, how? Because if we consider what we have done earlier here magnetic force is equal to integration over I B dl. So, if we consider this here; because the magnetic field is uniform. In this region, integration over IB dl will give us IB a where a is the width of this loop marked here. And the magnetic force we have already discussed that on the vertical arms it cancel.

So, we need to the magnetic force to balance the gravitational force. So, that will be mass times acceleration mg, that gives us current to be equal to mg over B times a. So, this is the amount of magnetic field. Now let us ask a curious question, what happens if we increase the magnitude of the current? We will have stronger magnetic field along stronger magnetic force than the gravitational force.

So, we will have the weight being lifted into the magnetic field. But once this arm the lower arm enters the magnetic field region, we will see that also experience as a force magnetic force and that magnetic force will certainly be downward. So, then the magnetic forces will balance each other and the gravitational force will bring this entire loop down a bit. So, that the lower arm is out of the influence of the magnetic field and it will remain stable there.

So, the this system will be lifted to some extent, where the lower arm just remains outside the influence of the magnetic field, it cannot enter the influence of the magnetic field this kind of a magnetic field. Because that way there would be no resultant magnetic force and gravitational force will clearly win over the magnetic force. So, if we consider the weight being lifted, can we say that magnetic force is performing some work on this? Its something for you to think, we can discuss about it sometime later.