Electromagnetism

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Lecture – 78
Electrodynamics

So, we have understood how magnetic fields behave in a linear material. After doing this let us move on to the idea of Electrodynamics.

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Electrodynamics

Ohm's law $\qquad \sigma \rightarrow$ conductivity

$\vec{J} = \sigma \vec{f} \qquad \vec{f} \rightarrow$ force per unit charge

$$\vec{J} = \sigma\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

$$\vec{J} = \sigma \vec{E}$$

Joule heating $\quad P = VI = I^2 R$

To begin with let us introduce ourselves to Ohm's law. If we consider sigma to be the conductivity not the free charge density anymore sigma is conductivity that tells how good a conductor material is. Then, the volume current density J can be expressed as the conductivity times the force per unit charge. And this is the current which means; so, the force per unit charge can be given as electric field plus v cross B. If v is the velocity of the charge and B is the magnetic field to which it is subjected.

And then the current density can be written as the conductivity times this. Ordinarily, the velocity of the charge is so small that the second term can be ignored. So, we have very slow moving charges or there is very slow motion of the charges along one particular direction. So, the average of v becomes very small. So, we can write down that the volume current density is just the conductivity times the electric field, that is all.

And in this kind of a situation, we also have heat dissipated in the conductor if there is if the resistance of the conductor is R then the Joule heating that is the amount of power dissipated can be given as the potential difference between the two points of the conductor times the current that flows which is according to this according to Ohm's law I square times the resistance.

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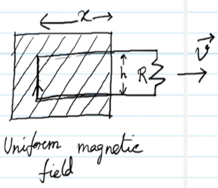
Electromotive force emf

Motional emf

$$\mathcal{E} = \oint \vec{f}_{mag} \cdot d\vec{l} = vBh$$



$$\phi = \int \vec{B} \cdot d\vec{a} = Bhx$$

$$\frac{d\phi}{dt} = Bh\frac{dx}{dt} = -Bhv$$

$$\mathcal{E} = -\frac{d\phi}{dt}$$

Let us introduce the concept of electromotive force, in short it is known as emf. Let us consider a situation where a motion generates an emf. emf is just the driving force behind a current it is like the difference in potential similar to that. Let us consider, we have this region with a uniform magnetic field.

And we have a current carrying wire like this at this end there is a resistance R, the height of this current carrying rectangular loop is h and this loop is pulled out in this direction at a velocity v. With this, the motional em so, this will generate some force on the charges because, we have electrons in this wire and when they are being pulled out in a magnetic field.

So, let us consider this of the rectangular loop there are electrons and the electrons will have a velocity along this direction, along right direction and if we have a magnetic field that is pointing into the screen. We can see that the velocity of the electrons are along the right and the magnetic field is pointing into the screen.

So, the elect so, the charge is there, if it is positive charge if positive charges are carriers; they will try to move upward. That means, if the magnetic field points into the screen then this will be the direction of the motion of these charges if this loop is pulled out in the right and that will generate an electromotive force which can be given as epsilon equals closed integral over this loop the magnetic force dot dl prime sorry, dot dl. Which is velocity times the magnetic field times the height that this loop has.

So, only this arm that we have marked here, that we have discussed so far we will contribute to this force not any other part. Because, the force on this part and this part they will be exactly equal and opposite to each other and they will cancel. So, only this part will only this vertical arm the force on it will survive, nothing else will survive. And, what is the flux through this loop? Magnetic flux, that can be given as integration over the magnetic field dot da which is B h time x, where x is this much distance.

As the loop moves out, the flux decreases. So, d phi dx can be written as B times h times dx dt sorry, d phi dt can be written as this. Which is nothing but, minus B h v dx dt gives us v minus sign comes because dx dt is negative. And therefore, this electromotive force is given as minus d phi dt. So, it is negative to the rate of change of flux through the loop.

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emf

$$\vec{f} = \vec{f}_s + \vec{E}$$

For ideal battery $\quad \vec{E} = -\vec{f}_s$

$$V = -\int_a^b \vec{E}\cdot d\vec{l} = \int_a^b \vec{f}_s \cdot d\vec{l} = \oint \vec{f}_s \cdot d\vec{l} = \mathcal{E}$$

And so, this was the motional emf. In general the emf can be given as the force is force due to some external source, that is chemical force due to battery for example, plus the electric field. That brings in the force on the charge and for ideal battery there is no resistance in the battery, then if we do not have any resultant force; that means, in the steady state for ideal battery we can write in the steady state it becomes the electric field is exactly equal and opposite to the source force that is the force due to battery.

And then v that is the potential difference from say point a to point b, negative integral of the electric field dot dl over this two points, that gives the source force from point a to point b dot dl, f s dot dl. Which is, if we have a closed circuit f s dot dl over a closed loop line integral and that is the electromotive force.

So, this is how we can define an electromotive force. When the forces external force due to a battery for example, is exactly balanced by an electric force, we have we can this way find the potential difference the potential that is the electromotive force in this situation.