Engineering Physics-II

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Module No. # 4

Lecture No. # 6

We shall start discussing the effect of the magnetic field on currents whereas, all these time, we were actually looking at the effect of the currents, in producing the magnetic fields. And as a prelude to this discussion at the fag end of my previous lecture, I started with the Lorentz Force, and said that magnetic forces have the unique property; the magnetic field has the unique property, that it does not do any work on a particle charge particle.

So, let me repeat that argument quickly and go on to discuss the forces of interaction between various current elements, and we will find certain very interesting things that happened and let us proceed slowly.

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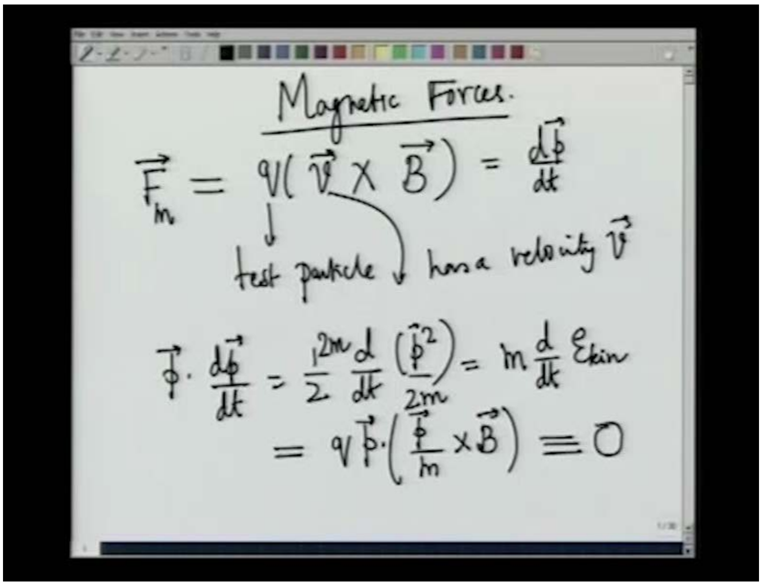

To start with, I write my Lorentz Force expression, the magnetic part of it, as q into v cross B; so here, there is a test particle with a velocity v, this is a test particle carrying a charge q, having a velocity v and it is moving in an external field B. At this point, we are not interested in the magnetic field produced by the test particle, which is the reason why I am emphasizing that it is moving in an external field B. Of course, if I have a large number of particles moving in an external field B, then there is going to be a magnetic force F M, the Lorentz Force; and they themselves constitute a current and they will produce their own magnetic field and that would have to be taken into account, if you have to solve the problem completely.

But at this point, we are not interested in that, we are only interested in the motion of the test particle in the external magnetic field. In fact, that is how you solve the problem of particle in a uniform magnetic field, particle in cross electric and magnetic field, particle in a uniform magnetic field, electric field perpendicular to that, but having time dependence so on and so forth. But our purpose is not to solve any of those problems, let us leave them as exercise for all of you to work out; these problems are listed in almost all the books.

The point that we want to emphasize is that, this is nothing but dp by dt therefore, we have p dot dp by dt is nothing but half of d by dt of (p squared), and if you people permit me, I can put a factor 2 m here, and I can put a factor 2 m here, where m is the mass of the particle. And this is nothing but m d by dt of my kinetic energy, this is nothing but the kinetic energy that I have here, the rate of change of kinetic energy and that is simply given by q p dot p by m cross B, because velocity is nothing but the momentum divided by the mass.

So, what do I conclude, I have a product a dot a cross B, this is identically equal to 0; in other words, if I take a take a charge particle and put it in an external magnetic field, the motion will be a very complicated motion on the surface of its sphere. And what is that surface of this sphere, p x will change, p y will change, p z will change, but in such a manner, that p x square plus p y square plus p z square is equal to constant, mod p are equivalently root to m e, is the surface of a sphere of radius root to m e. The particle has to execute a motion; it cannot come out of that surface of that sphere.

So, there is no magnetic work done by the magnetic fields, and yet magnets are used to do a lot of work. If you go to a huge ship yard, you see these cranes having very, very powerful magnets, and they will keep lifting a lot of steel, iron or whatever whatever we have to understand that. But before we do that, let me start discussing the concept of a force between various current elements; and in order to do that, let me rewrite the Lorentz Force expression in a slightly different manner. In any case, you people will kindly notice that if the particle is at rest, there is no force acting on it, because B is identically equal to 0, B cross B is identically equal to 0.

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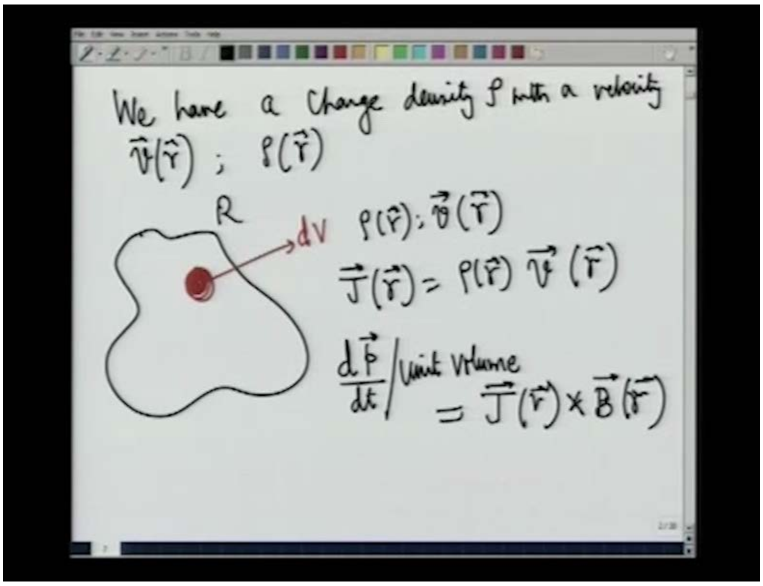

So, now suppose we have a charge density rho, so I am considering a small region in space with a velocity v of (r) of course, my rho is also a function of r. So, what I mean is I have a certain region R in space where the charges are moving, I consider this small region volume element d v, and then this small volume element d v I have my rho of (r); and since the volume element is small enough, all of them can be taken to have the same velocity that is, the velocity density at that particular point.

So, I am characterizing the charge density and the velocity density at that particular point, characterize by this small point therefore, what is my J? My current density is simply given by rho of (r) v of (r). Now, it is a very simple matter to generalize the Lorentz Force expression, for a single charge particle to the Lorentz Force expression, to this current density and what is that dp by dt, but this is not dp by dt for a single particle, but it is per unit volume, so per unit volume or if I were to consider the momentum density, the momentum density at that particular point R, that is what we mean by unit volume.

This is nothing but J at that particular point, cross the magnetic field at that particular point, what we now want to do is to make use of this expression, and do not look at a volume destination of this particular kind, but a current loop. That is what we are interested in and write down force per unit length of the current loop.

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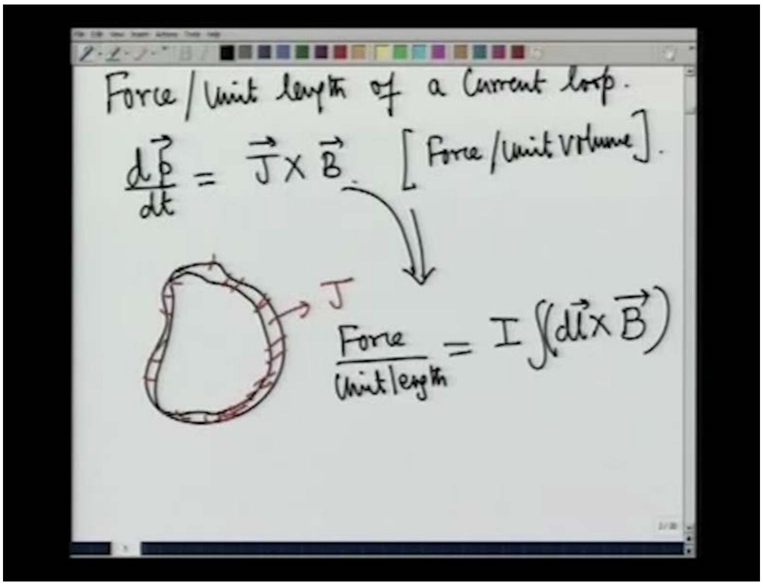

So, what we want to do is to adopt the expression to find the force per unit length of a current loop, so I had dp by dt is equal to J cross B force per unit volume let us not forget, force density if you feel like. So, what I mean is, J is restricted to a small region in space, and what is this small region, that is the region indicated by this part, so have a close loop, this is the wire. So, J is restricted to this therefore, what I will do is I will integrate this J with respect to that small region that surface area; and that will give me the current.

So, the adaptation is straight forward, this tells you that force per unit length of the loop force per unit length of the loop is nothing but I integral (d l cross p), I integral (d l cross B), the left hand side is a vector which I have not indicated, so I d l is of course, the total charge flowing per unit time, q into d cross B because I by t q into t dl by dt is your v; so this is the expression. So, once you are given this expression, what does it tell me? It tells me that find the direction of the loop, so let me indicate that again.

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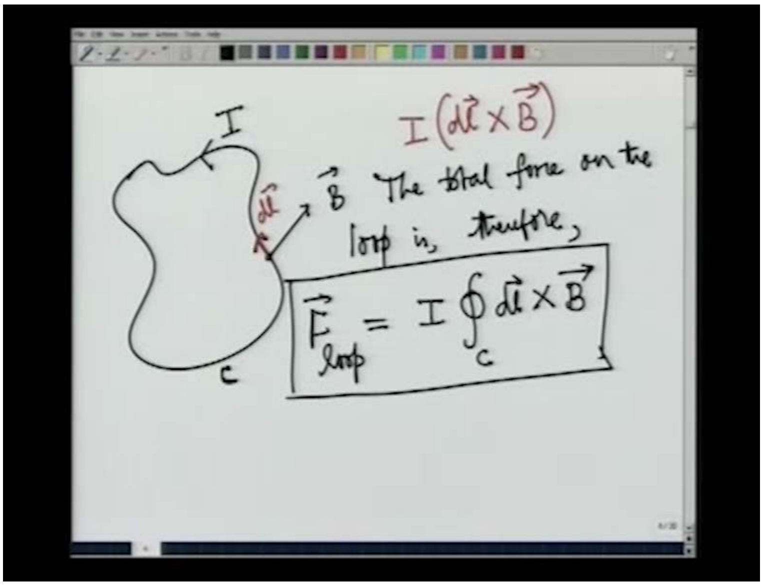

So, I have my loop here, there is a current I which is flowing and there is a magnetic field; so let me take this point. Suppose the magnetic field is in this direction, dl is along this direction, let me indicate it through the red line, my dl is along this direction, my magnetic field is around this direction. So, how do I find out the force at this particular point, the force where at the small length dl is simply given by I dl cross B, now what will I do, if I am interested in the total force, the total force on the loop is therefore therefore, F I will write loop.

Simply given by, I still have the current, I know I integrate with respect to this loop, this is my loop, let me introduce that I will call it c the curve dl cross B, so we have found an expression for the net force acting on a current loop carrying a current I. Now, one thing that you noticed here is that, we are all the time looking at close loops, and not open wires; open wires are a figment of imagination.

Because after all you need the current to be induced and the current to be drained, you need a source and the drain; it has to be connected to your battery or whatever. So, suppose I now imagine that the magnetic field is uniformed everywhere, what is the situation that I am interested in, you can for example, look at a case where you have a long solenoid carrying a current.

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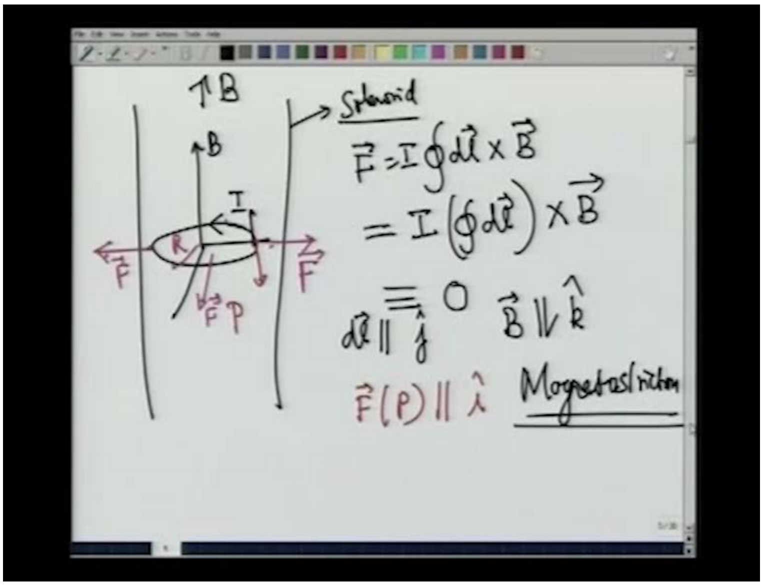

Therefore, my magnetic field B is uniform everywhere, and I put a loop inside the solenoid carrying a current I, the Magnetic field is around the Z direction and this is in the x y plane as you people can see, and this is the solenoid. The loop is in the plane perpendicular to the axis of the solenoid is that part right that is what we have. So, I can indicate that, this is my direction of the magnetic field.

Now, I can integrate the total for the total Force acting on the loop therefore, I will write F is equal to integral dl cross B of course, there is a current which is sitting here, but then since, B is a constant field all over the place, it is not going to change its direction, it is not going to change its magnitude. We conclude this is equal to I (integral dl) cross B, and integral dl is equal to 0, because it is a close loop, it is identical equal to 0.

So, what do we say, if you have a loop of any shape what so ever, put it in the x y plane uniform magnetic field along this z axis, the net force is on that is equal to 0, that means I have to actually have what gradient in the magnetic field, if my current loop is to experience the force. Again here, I should be exercising a little bit of k in making this statement, this is not entirely correct, just because the integrated force is equal to 0 on the loop, does not mean that the individual parts of the loop do not experience any force, please remember that.

So, for example, at this point the current is along the y axis, along at the x axis, the current is along the y axis, because I is along the phi direction. My magnetic field is along the z axis, so what is it that I am going to get? I am going to get x cross k or I cross k which is J therefore, there is actually a force along the radial direction. Let me make it clear, along the x axis if you look at it, dl is parallel to the unit vector J, my B is parallel to k therefore, at this particular point, let me indicate; this is the point that I am interested in, my force at the point (p) along the x axis is J cross k parallel to i.

In other words, the direction of my force is simply given by this direction, my force is acting in this particular direction; in a similar manner if I look at this particular point, my force will be acting in this direction, at this point, the force will be acting radially outward. In other words, what the magnetic field is doing is to produce a radially outward field of all points of the loop.

And what are we doing in rating this expression, I am integrating of course, the force component here cancels the force component here, the Force y here cancel the force here and we get the result of the net force is equal to 0. But the statement at the net force equal to 0 should not be confused with the statement that there is no effect of the magnetic field on the loop, it is incorrect. In fact, if you give me the coefficient of expansion of the length, because of the application of the force, the appropriate young's modulus or whatever, you will see that the magnetic field actually has a tendency to stretch the loop.

If we start with the radius R if we start with the radius R, it will get slightly stretched to R plus dr, so please do not assume that the magnetic field is not going to have any effect; we are simply saying that the magnetic field is not going to have any effect on the centre of mass of the loop, because the centre of the loop is going to sit. Of course, if you take the idealize limit that the dipole is becoming very, very small, the loop is becoming very, very small, the current is becoming very, very large such that, I into a squared is constant.

In that ideal situation where there is an intrinsic magnetic dipole, an idealized magnetic dipole, it is only then that you can say that the uniform field does not have any effect, but otherwise, there is always an effect. And that is actually to stretch the object; these forces are called magnetostriction magnetostriction. In a similar manner, there are forces of electrostriction and all these are used for various sensors actually to build, very, very sensitive sensors, and I will leave that as an assignment for you people to figure out what it is.

Now, for the time being, let us forget about the fact that the wire can get stretched, let us assume that it is made up of a some kind of an ideal rigid wire, which cannot be stretched, the elastic constants are all very, very large, is that ok? We have to apply incredible force even to cause a very, very small displacement, if I have that kind of a situation.

Then of course, the force is equal to 0, we have to ask then what kind of a magnetic field is it that can actually produce, what that can actually produce an effect on this kind of a circular loop; that is the question that we have to ask ourselves. In order to answer that question, what I will now do is to make a Tailor expansion around the magnetic field at the centre, let me indicate that to you.

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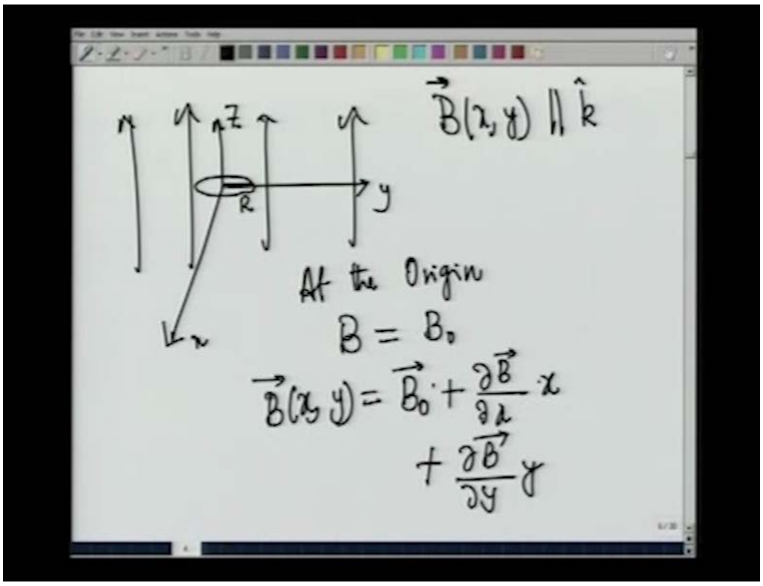

So, I have a magnetic field, let us say along the z axis, so B is parallel to z axis and it is a function of k x and y parallel to the z axis, so as I move away from a reference point in the plane, it is going to change and I put a small loop here, and the radius of the loop is very, very small; that is something that you have to take in order to make a meaningful expansion. I will take the origin of my coordinate system at the centre of the loop, so let me indicate here, so this is my x axis, this is my y axis, this is my z axis, and at the origin which is a centre of the loop, my B is simply equal to B naught some number.

What is the magnetic field in the neighborhood of that origin, because the loop is a very very small loop, I will write B of (x, y) is B naught plus delta B by delta x into x plus delta B by delta y into y hat into y, this is the expression that I have, all of them along the z axis. This is only for the purpose of as illustration that I am writing of course, what we have to do is to generalize that, all of them are in the same direction therefore, now, let me introduce the vector sign here, with the understanding that, all of them are in the same direction. I now (()) this expression in to the expressions for the total force on the loop, what is the data have.

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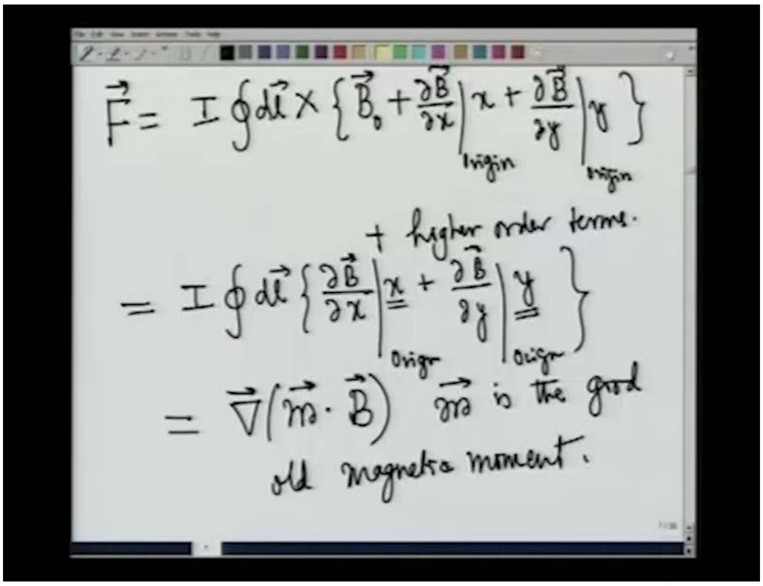

My force is therefore, given by I integral dl cross B which I am now going to write as, B naught plus delta B by delta x at origin x plus delta B, I have to put my vector sign; otherwise, it would be an observed expression, delta y at origin into y both higher order terms. What is it that we want to say, the statement that we want make is that, the first time is going to give no contribution, because B naught will come out dl is what we have.

Therefore, this is essentially I into integral surface integral dl delta B by delta x, which is a fixed vector, let us not forget that into x, because it is evaluated at the origin plus delta B by delta y evaluated at the origin into y; that is what I have. So, now, you people can actually see that, as I move along the loop as I move along the loop, the magnetic field is changing. In the 0th order approximation, the magnetic field was given by B naught, but

I say move along the loop, the magnetic field is changing, x and y indeed corresponds to the coordinates of the points on the loop, because that is where I am interested in evaluating the force; that is where the current is flowing. Therefore, we are essentially calculating the first moment of the magnetic moment; with the first moment of the dl together with the I. And what does it give me, it essentially gives me the magnetic moment, it is a very trivial integration for you people to work it out, I am not going to work it out for you, let me leave it as an exercise; this can actually will be written as a gradient of (m dot B) where m is the good old magnetic moment, magnetic moment.

So, at last we have been able to derive an expression on an infinitesimally small magnetic dipole taken to be highly rigid no extension, no expansion, no elongation. Then we write F is equal to gradient of m dot B, so it essentially tells you the magnitude and the direction of the force depends on the gradient of the inner product of the magnetic moment with the magnetic field. Of course, if the magnetic moment and the magnetic field are perpendicular to each other, there is no force acting on them.

If they are parallel to each other, there is a positive force, if they are antiparallel to each other; there is a different kind of force. So, in doing this we have actually sleeked in the notion of a magnetic potential energy, let us recall that.

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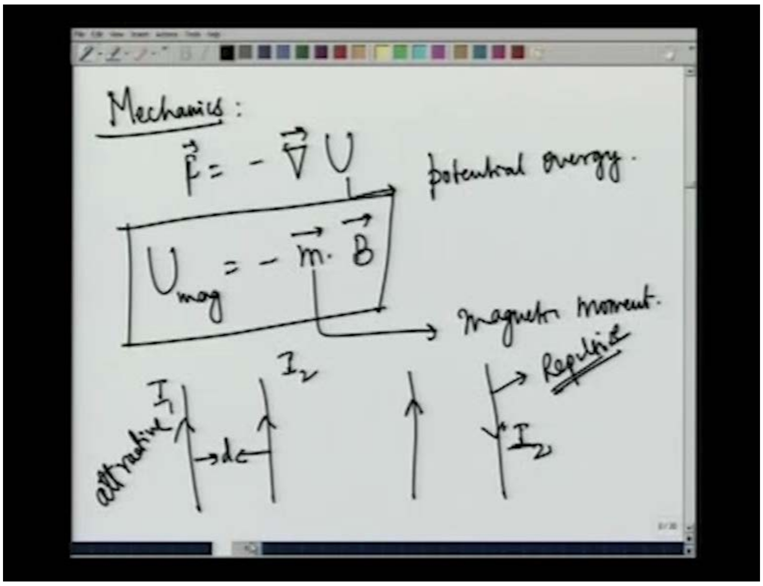

So, recall from mechanics, what is it that we write, in mechanics we wrote F is equal to minus U, where U is the potential energy, so by that token, I can now write a magnetic potential energy which is nothing but minus m dot B. Never forget, what you learnt in mechanics, every system tries to minimize its potential energy, it wants to sit in the bottom of the potential well; that is the minimum energy that it wants to do that. Therefore, this energy is a minimum when the magnetic moment and the magnetic field are parallel to each other; this energy is a maximum, when the magnetic moment and the magnetic field are anti parallel to each other, so this is my magnetic moment.

If I have understood this, there must be a simple way of illustration of this fact, and the best way of illustrating this fact is to go back to the age old example of the force between two currents. So, this is configuration number 1, where there are two currents I 1 and I 2, the distance between them is d, now please find the force between I 1 and I 2 the force that I 2 is exerting on I 1.

Let me consider the other configuration, were I have my I 1 in this direction, but I 2 in this direction my I 2 is in this direction here, the currents are antiparallel to each other, if you go back and if you wrote dl cross B, you do not even have to do that, if you just make use of the Lorentz Force expression. You will find that it is attractive in this configuration and repulsive in this configuration; in this case, of course the two magnetic moments are all parallel to each other.

The two magnetic moments are antiparallel to each other, this is what we have and this is the basic idea behind what magnetic flipping, flipping of the spins Zeeman effect, etcetera etcetera, so this is what we have from this particular expression.

(Refer Slide Time: 25:57) Now, let me go back and rewrite my expression in a slightly different way, I said that my force is given by gradient (m dot B); m is a constant vector and therefore, you might be tempted to write this expression as m dot del operating on B, but that is incorrect that is incorrect, that would be too much of a hasty calculation. If you did a careful calculation, in fact you are going to get another expression, and that is nothing but m cross curl of B, this is the vector identity; so this is the exercise for you.

So, you should not imagine that the net force on the magnetic dipole is m dot del into B, there is a m cross curl of B, but what does Maxwell's equation tell you, Maxwell's equation tells you that m cross curl of B is m cross J mu naught m cross j. And what is this J, this J is not the current density correspond into the test particle, but of the source of the magnetic field, source of the field.

Now, for the kind of configuration that I am writing, I am looking that the magnetic field far away from the sources, in fact that is where the dipole approximation works. Therefore, if you are a test dipole, he is sitting at a point where the source of the magnetic field is not there, this can be removed. This can be removed and we simply get the expression m dot gradient of B, so what you have to do is to calculate the quantity m dot del of B, and then you should be able to find out what the force is.

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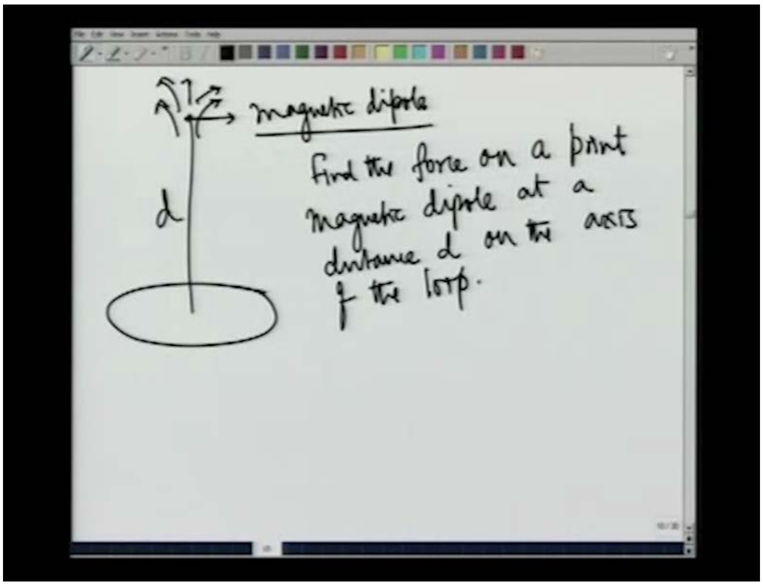

So, in order to gain some experience, let me go back to my age old problem, what is it that I had, I had a current loop, I had my z axis; now I will put a magnetic dipole at this point, magnetic dipole and you people know how to calculate the magnetic field into vicinity of the axis, we already did that, because we said that the field lines behave like this, let us not forget that. So, find the force on a magnetic dipole, on a point dipole, if you feel like case, magnetic dipole at a distance d, this is my distance d on the axis of the loop, passing the centre of loop, I do not have to write that.

You can put your magnetic moment along various directions and see what happens, and then, if you did that, you will be able to appreciate the meaning of this particular expression. So, much about the magnetic field, but before I proceed, there is one a very very curious phenomenon which I would like you people to notice, and that is that instead of electro statics where unlike charges attract and like charges repel, so actually let me write that explicitly.

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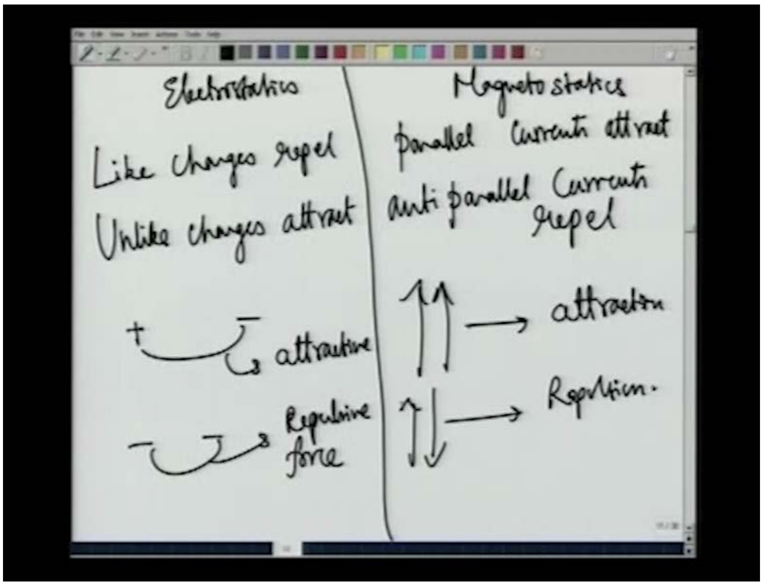

Let me make a contrast between electrostatics and magneto statics, electrostatics, magneto statics, in the case of electrostatics, like charges repel, unlike charges attract, and electron and proton attract each other, two protons that repel each other that is the mystery of the strong interaction. What is that force that can actually overcome the powerful coulomb repulsion between a proton and a proton inside a nucleus, that is the question which people have bothered about for a long time, whereas in the case of magneto statics, if you consider two straight wires for example, parallel currents attract and antiparallel currents repel (No audio from 30:28 to 30:37).

So, if I have a plus and a minus attractive force and if I have a minus and a minus, it is a repulsive force, but if you have two parallel currents attraction, and antiparallel currents mean repulsion. So, suppose you have two wires carrying parallel currents and you want to flip the sign of one of the current, then you have to do a lot of work because there is a repulsive force from attraction to repulsion is the reward; there we have to increase the energy of the system.

In other words, this suggests that the currents always try to align in the same direction or equivalently the magnetic moments always like to be parallel to each other. The way you actually decrease the energy of the system is that, if there is one magnetic moment in one direction, all the neighboring moments also align in the same direction; they do not try to go in the opposite direction. But what happens in the case of electro statics, if I bring the positive charge, the way I decrease the energy of the system, is to surround by a lot of negative charges; that is the reason why your dielectric constant epsilon is always greater than 1.

You have to worry about this sign of the analogs quantity right that will be your mu, the relative permeability, this is your dielectric permittivity, I will come to that in a short while, but before I do that I have to contrast the statement made in this particular page, in this particular slide with another very very curious thing, which seems to complete with the statement that parallel currents attract and antiparallel currents repel.

It is not going to violate that, but it is going to be some kind of a counterintuitive example, let me give that and then go on to discuss magnetic fields in matter and induction side by side; this is the plan for this lecture and the next lecture, what is it that we want to do.

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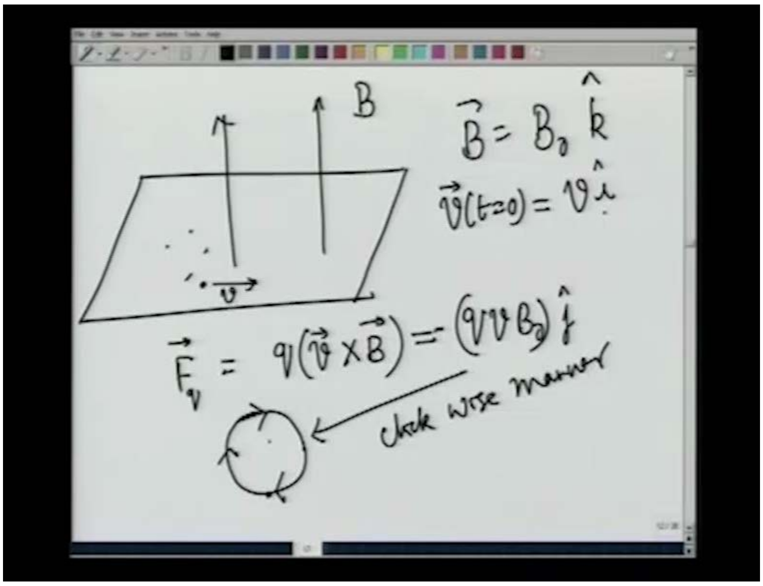

What we want to do is to imagine that, there is a large number of particles in the x y plane, we are not interested in the motion along the z direction, so this is my x y plane and there is a uniform magnetic field perpendicular to the plane. So, the particles are free to move in the x y plane, and they all carry certain kinetic energy, I will convert this into a very interesting problem in a short while, and I am interested in what is it that happens for these charged particles in the plane.

Let me take one particular test particle q and let us say that it has a velocity v at a time t equal to 0, so my B is given by B naught into k all over the space and v at time (t equal to 0) for one of them is simply given by this speed into I fine. Now, I can immediately write down the force acting on the particle. So what is my force? My F q is simply given by q v cross B very good, this was along I direction, this was along k direction, I cross k is g; so I have q v B naught into J with a minus sign.

Suppose, I want to show it pictorially, what is it that happens, so at this point the particle was having a velocity along the I direction therefore, obviously, I should look at this particular point let us say. Now, there is going to be a force acting along the minus z direction minus negative axis therefore, is my magnetic field is along the positives of direction, what will be the nature of the loop, what will be the direction in which the particle is going to move?

The particle you people can check is going to move in a clockwise manner, this implies clockwise manner; clockwise manner provided the charge is positive. In other words, the current that is induced is clockwise of course, if the charge is negative, it will move in an anti-clock wise manner, but q v will always have the same sign; therefore, the induced loop the mean current that is produced by the magnetic field is clockwise. Now, let me contrast the situation with what is happening, how do I produce a uniform magnetic field? The uniform magnetic field is actually produced by solenoid.

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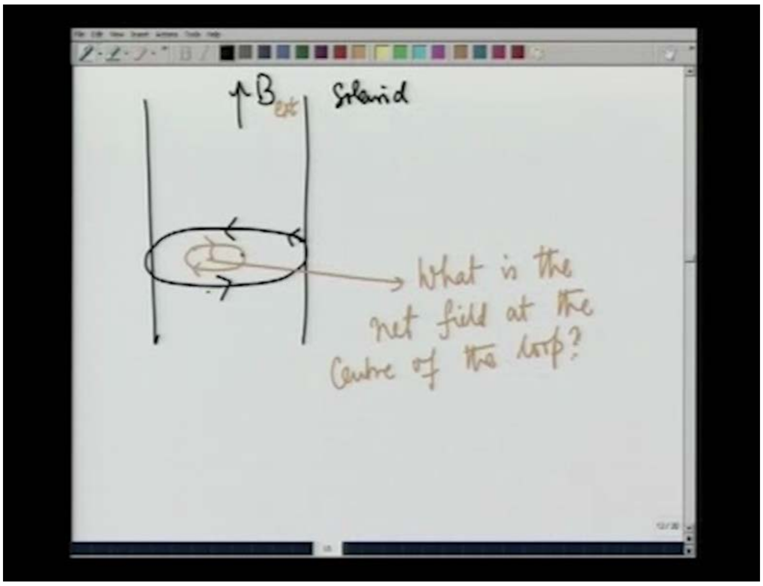

So, this is my solenoid, and what is my solenoid composed of, my solenoid is composed of large number of circular loops which are stacked like this, and if I have to produce a magnetic field along the z direction, the current is invariably anti clock wise, the magnetic moment is along the z direction. What I have now done is to take a particle inside the solenoid, I have given it an arbitrary velocity and how does this particle move, the way this particle moves will be in contrast to this in an anti clock in a clock wise manner.

So, now, what I will do is to look at the time averaged motion of this charged particle therefore, this will constitute a current loop, is that right? This will going to count a current loop, and now I can ask myself what is the field produced at the centre of the loop. So, the question is what is the field, net field at the centre of the loop? I hope all of you are appreciating the question that I am raising.

There is an external magnetic field, now let me add that tag to this, there is an external magnetic field; that external magnetic field induces a time average current indicated by this brick colored loop; that loop will be moving in an anti clock wise manner and it produces its own magnetic field. So, what do we do now, we do not solve this problem, but we write a series of problems.

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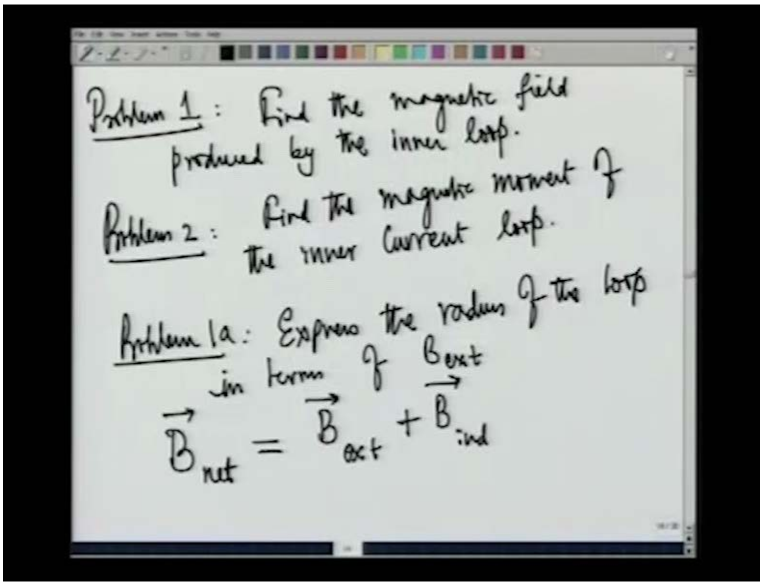

So, let me start with problem number 1, find the magnetic field produced by the inner loop is that right, it is very easy to find, you already know a field produced by a current loop, find the Magnetic field produced by the inner loop. Problem 2, find the magnetic field, magnetic moment of the inner loop current inner current loop. Now, how do I find the magnetic field produced by the inner loop, let me call it as problem one a, you have to know the radius of the loop. So, express the radius of the loop in terms of what, B external, express the radius of the loop in terms of B external and therefore, write B net is equal to B external plus B induced.

And argue whether, the magnitude of the B net is smaller or larger that the B external, you people will find that invariably the magnitude is smaller. Now, the problems one, two and 1 a are some kind of warm up problems that I gave you; now, I will give you a realistic problem in fact, it is eminently realistic, this is what you will find in plasma physics in tokomak environment, this is the first problem that one solves.

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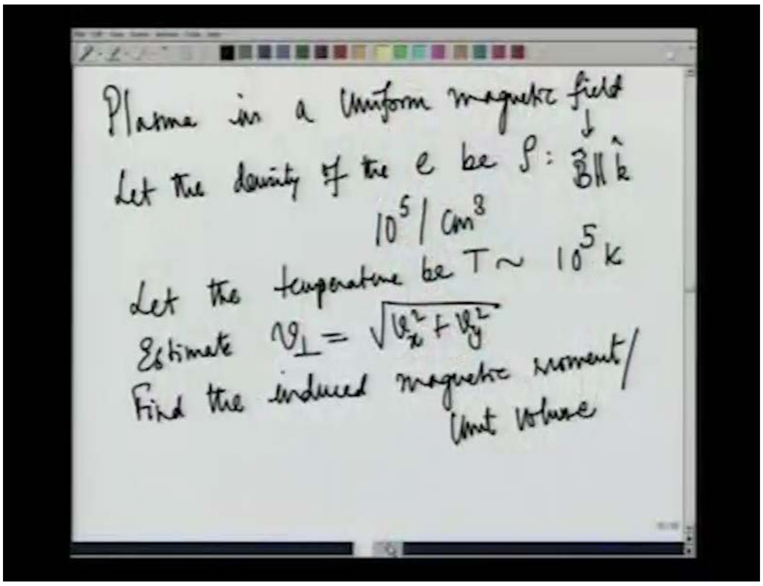

So, what we shall now do imagine is to look at plasma in a uniform magnetic field in a uniform magnetic field, and what is a plasma overall neutral, but completely ionized. The positive ions are all of course very, very heavy; the negative ions are light, because the negative ions are nothing but pure electrons, whereas the positive ions are all heavy atoms, is that ok.

So, although they are completely electrically neutral, if I produce a reasonable magnetic field, let us say of the order of 1 tesla, what response to the magnetic field is predominantly the electron and not the background positive charge, the background positive charge only ensures overall neutrality. In fact, that is what happens in your conduction in metals, and that is the same thing that happens here.

Now, let the density of the electrons be rho, so that could be of the order of let us say, 10 to the power of 5 per centimeter cube, you can convert it into the meter cube appropriately, there will be a large number 10 to the power of 12, 10 to the power of 4 whatever, let me give you the density. Now, I have to give you the velocity, but I would not give you the velocity, but instead let me give you let the temperature be t let the temperature be t, and I have to look at a completely ionized atom.

The energy required to ionize hydrogen atoms is of the order of 10 to the power of 4 Kelvin, so let me make this of the order of 10 to the power of 5 Kelvin. So, that they are all relatively free of each other; it is completely ionized, this is the temperature that I am interested in. Now, given the temperature t, there is a mean momentum and a mean energy given by the equipartition theorem; ignore the component of the momentum along the z direction, because the uniform magnetic field is along the z direction, B is parallel to k, so you should worry about the velocity in the x and the y direction.

So, estimate V perpendicular, what is v perpendicular, root of v x square plus v y square from equipartition theorem, then you have a Magnetic field perpendicular to the x y plane and there is a v perpendicular, and I have given you a density rho, what will happen, it will induce a current all over the space, all over the x y plane therefore, now find the induced magnetic moment.

You see, I am not interested in just the induced magnetic moment at a point, but I might be interested in a induced magnetic moment per unit volume, that is what you have to find. You have to simply multiply it by rho, find induced magnetic moment per unit volume and this induced magnetic moment will produce its own magnetic field.

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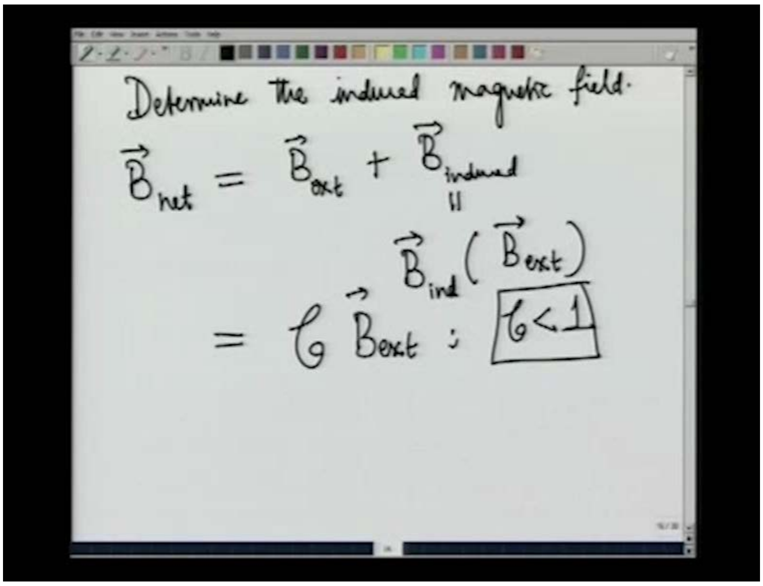

So, now as a next step, determine the induced magnetic field, so I have B net is equal to B external plus B induced, and what is B induced the function of, B induced is a function of (B external). If there were no external magnetic field, then there would have been no mean magnetic field because each particle will be moving in a random direction therefore, the magnetic field, the mean magnetic field would have been equal to 0, that is what I have.

Therefore, this will be some constant into B external instead of being 1 and obviously, this constant is less than 1 this constant is less than 1, please evaluate this and if you did that, actually discussing the concept of magnetic fields in media. I want to discuss what, paramagnetic response, diamagnetic response, ferromagnetic response, in order to illustrate diamagnetic response, I will appeal to this particular example, two parallel currents attract each other.

So, this is the physics that gives rise to paramagnetic response, and whatever we have told in this problem is what is going to give you the diamagnetic response of course, the ferromagnetic response is something very, very different. Therefore, depending on the state of the matter, depending on the nature of the magnetic field that is there and the nature of the magnetic moments in matter, you can either get paramagnetism or diamagnetism; this is something that we have to introduce.

In order to actually wind up the story, before I enter into the discussion of the magnetic fields in material and write down the boundary condition, I should go back and ask myself, what is this confusion between the statement, that the magnetic fields do not do any work, because p dot dp by dt is identically equal to 0. But on the other hand, I always find magnets doing a lot of work in fact, at my home I have induction heater, where there is a magnetic field which is going round, and current which is going round.

And then the coil is not even in contact with that current, but by induction there is a current introduced in the other coil and it gets heated up. So in order to do that, what we need is to understand the phenomenon of Faraday induction. So, what I will do is to spend the rest of this lecture, and probably the part of the next lecture, listed in the principle of induction. I am not going to spend too much time on induction, because I know that you students have solved enormous number of problems, starting from your 12th standard, I will give you the basic physics.

The basic physics is extraordinarily important, because it is the first instance where people were able to actually unify seemingly different forces; until Faraday came to the picture, until Faraday performed his famous experiments, and he gave the result, he summarized it in terms of the Faraday law. People had believed that magnetic force and electric force have nothing to do with each other.

For the first time, Faraday showed how what I call as an electric field and what I call as a magnetic field are two faces of the same coin that is the first example of unification. The second example of unification is due to Maxwell, who showed that what we call as optics is nothing but a branch of electro dynamics, and today the driving force physicists is to actually try to understand all forces, all fundamental forces from the view point of a what, in a unified fashion.

You people might have heard of the great physicist Salam, so there are a model called the Weinberg Salam Glashow model, this tells us that the weak forces. What are the weak forces, forces responsible for the decay of a neutron, a neutron becomes a proton and a electron and a neutrino that and the electromagnetic forces, are all actually the faces of the same coin, there is a unification.

And today, we have a large number of people trying to working on unification of forces, so Faraday's law of induction apart from being of immense technological importance. In fact, it is so important, the story goes that when Faraday demonstrated that a minister in the cabinet asked what is the use, and Faraday said to have retorted, I do not know of what use it will be, but I am sure you will collect taxes based on that. And today, we know that almost every electric equipment, almost everything has an inductor, is that right, that is what we have, it was highly profited, but it is also the driving force for the development of physics. Therefore, let us start with induction, and then move on to the discussion of magnetic fields in material media.