Engineering Physics - II
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Module No. # 04
Lecture No. # 07

So, we have been discussing the effect of magnetic field on currents the so, called Lorentz force expression, and I to show to something interesting in my previous lectures; namely, if the currents are already existing; then parallel current attract, and of course, anti parallel current repel therefore, it might be preferable to have parallel currents, if you want to decrease the energy of the system. And that is something, that we summarize the writing the energy as minus m dot B. The interaction energy between a magnetic moment, and the magnetic field, but on the other hand, if there are no currents to start with, but let us say, that the charge particles are all moving randomly. So, that the net current is 0.

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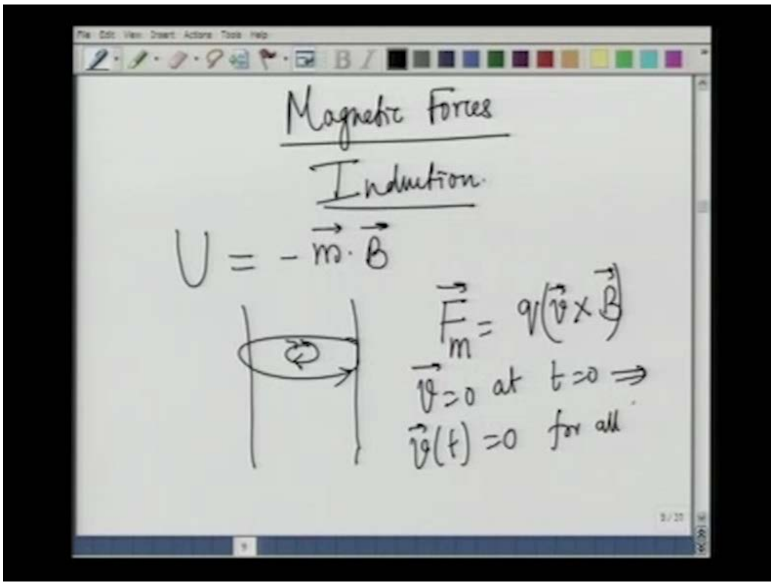

If you now switch on a magnetic field or rather if they are subjected to your magnetic field; then their path gets curved; they start moving in circle or orbits the cyclotron motion. And then, we found that the loop itself produces a field, which opposes the original magnetic field. So, these two situations had to be contracted contrasted with respect to each other. And therefore, depending on whether you actually induce a current in a medium or where there are intrinsic currents in a medium. The response of a medium changes in the first case, you have the so called diamagnetic response; in the other case you have the so called paramagnetic response; that is something, which I would like to discuss in other words, it is not easy for us to understand the distinction between the diamagnetism, and the paramagnets. Unless, we make a distinction between currents induce by the magnetic field, and also current already preexisted.

Now, this does not mean of course, that we are going to get a complete understanding either of diamagnets or paramagnets in this lecture. In fact, paramagnetism is much tougher than, what we think it is, I will come to that in a short while, but this is indeed is the basic idea. Let me repeat the example, that I gave you, what I did was to take an infinitely long solenoid, and the solenoid has of course, current loops which are like this; then, what I did was to consider a small charge particle within the solenoid; it had a velocity, it can be any velocity in the x y plane, and then we argued that the loop produced by the test charge is actually clock wise; if one of them is anti clock wise, and another will be clock wise; therefore, you find that the response always tends to oppose the external magnetic field.

In fact, I gave you an eminently physical problem namely that of plasma, I gave you the temperature, I gave you the mass; I gave you the magnetic field of the order of one or two test laws. Let us say, and I ask you to compute, what is the net magnetic field I hope, you people have done that, because it is only then that you will be able to understand, what is it that happens. However, this does not allow us to straight away move on to discuss the nature of the magnetic fields in media, because there is still one ticklish question; namely, the magnetic field does not do any work on a charged particle? Now let me, look at a medium, where all the charged particle are at rest; let us say, the atoms are at rest or the mean velocity is equal to 0. In fact, they could even be at rest.

Now, when I switch on a magnetic field many a time actually the system responds, but then, if you go by the Lorentz force expression. The magnetic force is given by q v cross B; this equation tells, you that v equal to 0 at t equal to 0 implies v of t equal to 0 for all t; this is indeed the famous statement, that the magnetic does not do any work; if you are at rest you continue to remain at rest, if you are moving with a certain speed v you continue to maintain the speed v; it is only the direction of the motion that changes, but then that is not the way things happen. We know magnetic fields appear to be doing the work all the time; therefore, the answer to that question as to, how a magnetic field can actually do the work; it can actually cause a change in this speed not merely in the direction; the answer to this question is provided a very famous law, which is a part of the Maxwell equations - the four Maxwell th equation; namely, faraday's law of induction.

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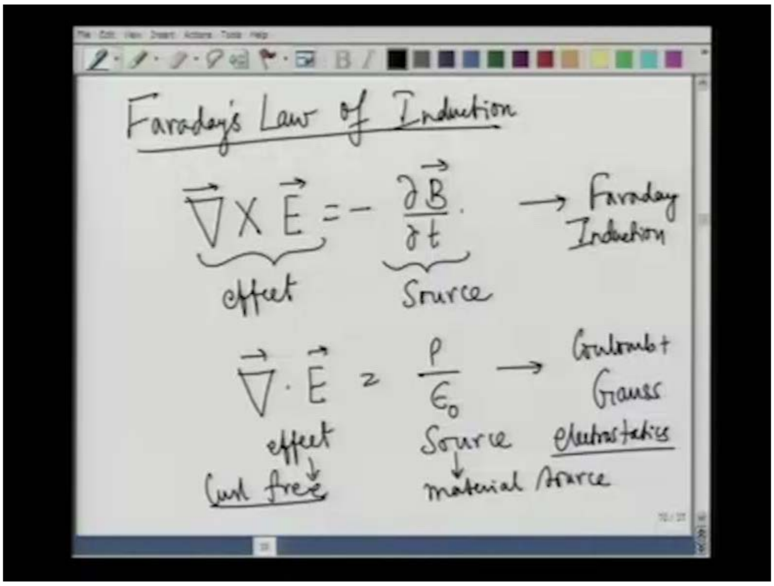

So, let us discuss that now, before I proceed to consider magnetic materials; faraday's law of induction as, I was telling you in my previous lecture has a significance, which goes much beyond mere appearances. Faraday's law of induction is the law, which unified for the first time electricity, and magnetism, until then people pretended people believe that electricity, and magnetism have nothing much to do with each other. We are independent phenomena, but faraday was able to show that actually, they are related to each other.

So, the first unification ever of the forces seemingly different forces; namely, electric forces, and the magnetic forces, were shown to be two different facet of the same interaction; namely, electromagnetic interaction by faraday; number two, faraday's law of induction also puts the concept of a field on a very high pedestal, the way you learn electrodynamics in most of the books; elementary books; they introduce the electric field, magnetic field, only as some tools for evaluating the effect of the one charge on the other charge or the effect of one current or the other current. But if you carefully, analyze faraday's law of induction; you will see that the fields have an existence of their own faraday very seriously believed in the concept of a field. In fact, he is the person who wrote lots of you know, lines of force diagram, and things like that. In fact imagine that, the fields recite in a universal medium called ether; and it is going to cause displacement vortices etcetera; and it is, this idea that was further taken up by Maxwell in order to give rise to the notion of an electromagnetic field, and it was the genius of Maxwell, who actually recognize that, what we called light is nothing but an electromagnetic field an disturbance in the electromagnetic field; that is propagating in free space.

So, faraday's law of induction is very - very important for us; apart from, it is in numerous - in numerable applications actually. So, let us start discussing faraday's law of induction. The law is stated in a very simple way, and it tells you curl E equal to minus delta B by delta t. So, what does it mean for us, from the view point of the equation; let us, not forget that we always look upon the right hand side as the source.

So, this is the source of the electric field, and the effort is shown in the left hand side, which the differential equation, because curl is a linear derivative operator, and this is the effect. Now all this time, we were use to the idea that electric fields are produced by charges. So, let me contrast it with the coulomb law or gauss's law that we have written. So, what is the contrast divergence E equal to rho by epsilon naught.

So, here is another source; and here is the effect; it is good to contrast these two. So, this comes from faraday, and this comes from coulomb plus gauss, because gauss wrote it in this particular form, what is the difference, if you look at the right hand side of the bottom line corresponding to electrostatics so, this is induction; and this is electrostatics; if you look at electrostatics, the source is a material source, that is a very important notion. The source is a material source made up of atoms ions, electrons protons, etcetera. The source is a material source, and what is the kind of source of electric field that the material source produces, this is curl free that is, if you only had a material source, and no changing field, divergence will be equal to rho by epsilon naught, but curl E would be equal to 0, and remember, when we discuss electrostatics in media, and we looked at the interface, we kept on using the fact that curl of E is equals to 0 again, and again, in order to do what in order to write down the boundary conditions. In fact, it is the relation that curl E is equals to 0; that allow to - allows to express electric field as a gradient of a potential; you can easily see, that the minute I have a time dependent magnetic field. Now curl E will not be equal to 0, my electric field cannot be written as the gradient of a potential. So, if you want to state, the principal of conservation of energy, then you have charge particles, which are all moving, they are producing currents; they are producing time dependent electric fields; they are producing time dependent magnetic fields; that problem is not at all straight forward. In fact, it is quite complicated, and perhaps, when you do a full flesh course on electromagnetic theory including the production of electromagnetic, you will be able to understand.

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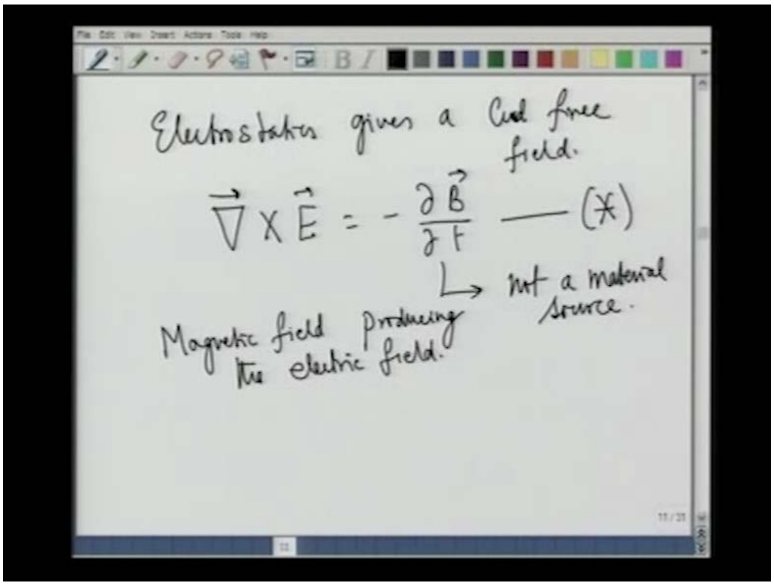

So, the electrostatic gives you a curl free field let me, write that down electrostatics gives a curl free field, but what does induction gives you? Induction mind you is characterized by curl E is equals to minus B by delta t, and this is not a material source. The source for the electric field is, another field called the magnetic field. So, we have magnetic field producing the electric field, and (( )) this equation; let me, called it as a star; it is impossible to have a time dependent magnetic field without an accompanying an electric field. That is something, that should be etched in your memory; just as it is impossible to have a charge density without an accompanying electric field; it is also impossible to have a time dependent magnetic field without a electric field, because if the right hand side is not equals to 0 nor is the left hand side is equals to 0.

Now, you people can easily convince yourself that if you have curl E equals to minus delta B by delta t what does it mean; now my electric field is not going to diverge anywhere because it is curl E actually it is going to go round - and round - and round; let me illustrate that.

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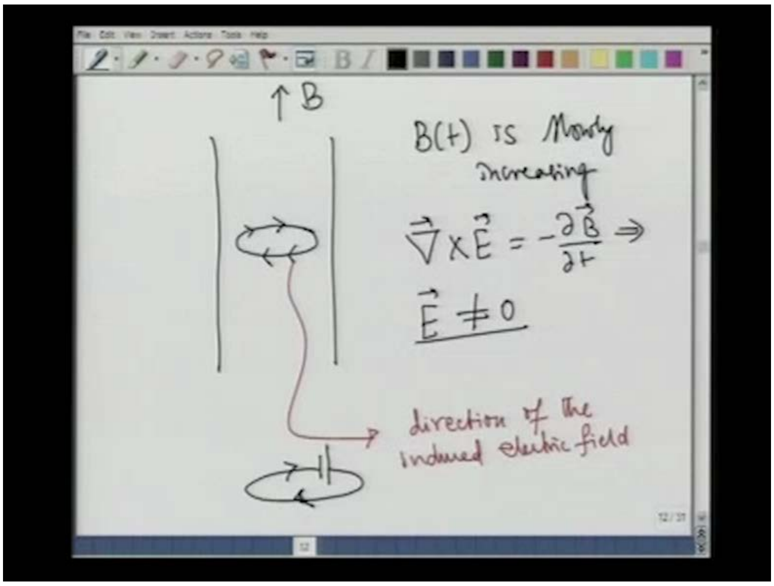

So, let me look at a situation, where there is a solenoid producing a magnetic field a very, very long solenoid infinite for all practical purposes; that is, what I have here, and now let me say, that my B of t is slowly increasing in fact, we are going to take this example to state several problems for you to work out all of them; you are familiar from your twelve th standard, and your own course in your engineering. So, I am not going to spend any time discussing the solution, but I will merely state the problem. So, let me look at that. So, B of t is slowly increasing, that is what I have here.

Now, if B of t is slowly increasing, what does it tell me curl E equal to minus delta B by delta t implies E not equal to 0. So, let me look let this region inside, and let me ask, what will be the nature of the electric field. So, the electric field will be curl E in the sense that my electric field will go, please pay attention to the minus sign, the electric field will go along the tangential direction. So, this is not the direction of the current, but this is the - this arrow prefers to the direction of the induced electric field. Now, suppose I want to ask you, how would you produce such a tangential electric field? Well imagine that, I request this loop by a conducting circuit, then what would happen. So, let me show it here, if I had replaced that loop here conducting circuit; if I want to produce a current of this particular kind, what would I do? I would actually break this circuit at a particular point. So, let me rewrite it again. So, I would break this circuit at a particular point, and I put a voltage source.

So, if and I put a voltage source of this particular kind; then what would happen, I would actually produce an electric field. Because I am going to produce a current, and therefore, you see the time dependent electric field, the time dependent magnetic field is actually acting like a source of the EMF except that, there are no batteries, there are no connections, but nevertheless, if you put a circular loop, and even if you take all the charges to be at rest initially this electric field, which is going to be induce will start acting, and you know that a charge particle at rest will start accelerating in the presence of an electric field. It is tangential of course, there is going to be a dissipation, there is going to be J is equal to sigma E whatever we learnt in the case of the ohm's law will be applicable, therefore it change in magnetic flux is a source of EMF; that is the first lesson, that we learnt a change in magnetic field is a source of EMF. So, here is the first problem for you take the previous example, let the loop have a resistance R, let the radius of the loop be I have already used up the notation R for the resistance. So, let me call the radius to be d.

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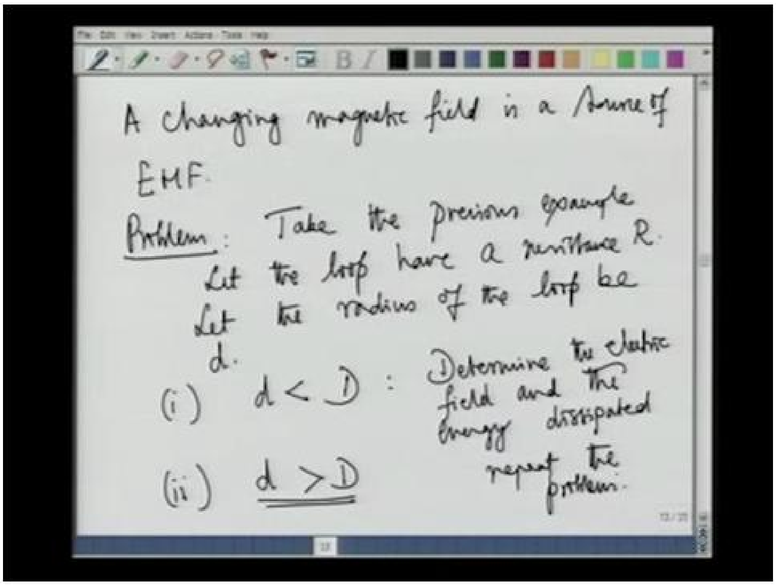

Now, you can see, there are two situations, which are possible. So, case one is d less than D; what my D let me, come back here this radius of the solenoid is D, and we are saying there is a loop here, which has a radius d. The first case is d is greater than D. So, what is it, that you have to determine the electric field, and the energy dissipated very well, and repeat this problem; in the other case, d greater than D repeat the problem.

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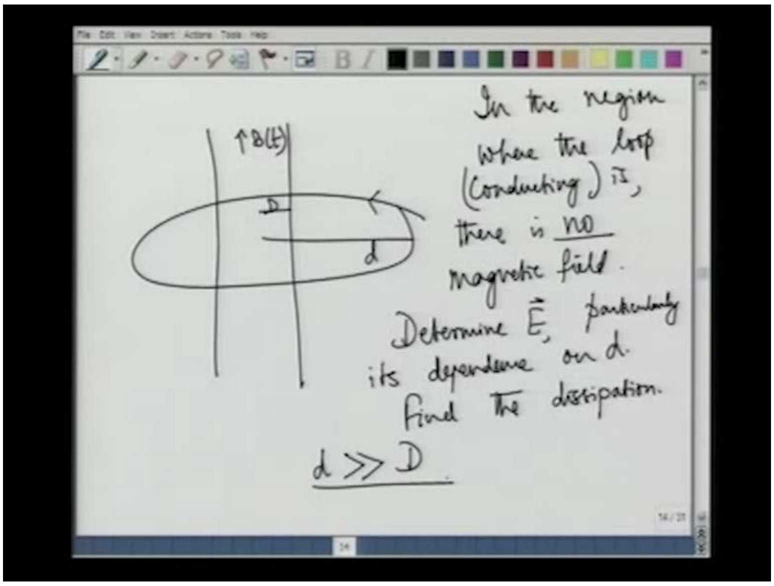

So, what happens in that particular case I have an infinitely long solenoid and I surrounded by a loop of various d and this is d; it is very important that you solve this problem, because in the region, where the loop is conducting loop. The conducting loop is there is no magnetic field; the magnetic field is somewhere inside, and yet the magnetic field is somewhere inside acts like a source it produces an electric field which is curl E. So, determine E particularly, it is dependence on t particularly its dependence on t, and find the dissipation standard problems, but worth doing that. This problem of course, rises a host of questions there are all fundamental in nature; that is, when I am cranking at the magnetic field. So, I have my B, because a function of time.

Let us say, my current is slowly building up in the solenoid; I am doing the work as, I keep on building up the current in the solenoid; I am supplying in the energy. Let us say now, part of that energy is coming into this loop, and what happens to that the energy, that enters the loop is taken up by the charged particles. Because the energy comes in the form of the electric field; the charged particles pick that up, and they start moving the energy is converted into the kinetic energy of the charge particles, but then because of the inelastic collations, they start moving at a uniform velocity instead of, moving with the uniform accelerations, and they continuously start dissipating energy. So, the big question is, what is the mechanism of the transfer of the energy, that I am supplying into this solenoid, how is that energy getting transfer to the loop, which is far outside please notice, this d can be as large as you want; so, long as there is no other disturbance eventually, that information has to reach that, and faraday with his great genius argued that the energy has to go from the solenoid to the outer loop is that right for example, I can take to be d to be much - much greater than d through a field. So, what is it, that I do imagine that, we are all in a swimming pool, and then I want to send; and I want to disturb another person; all that, I have to do is to push the water, and the water waves propagate and of course, the energy is stored in the medium.

The medium keeps on transferring it; either as a longitudinal wave or as transverse wave whatever we want, and then it can go and reach the other person. So, faraday used this idea in order to raise, as I told you the concept of a field to a very high pedestal; it is not a some kind of a doing a calculation; it is not a intermediate step. In fact, it has fundamental significance, because of this. there are other very - very important questions associated with it; and that is whether this information that, I am supplying the energy can be transferred instantaneously or it takes a finite time, that is a very, very important question.

So, what happens suppose I am speaking, and that information is to reach you; that information cannot reach you with a speed greater than the speed of sound, because by definition the speed of sound is the maximum speed. That a medium can support in a similar manner in the faraday picture, if you believe that there is a medium, then I should be able to compute the speed analog, a speed of the sound, and I should ask, what is the top most speed, and it is these considerations, which gave birth to the idea of relativity the famous Michael, and moral experiment; I will come back to that in a short while, but right now, let me go back, and look at a few more applications, but you should settle it at time of in order to solve this problems.

So, there are these twp problem for you, the loop inside the solenoid, and the conducting loop outside the solenoid in one case of course, the electric field goes slight one over R; in another case, the electric field probably will be increase linear in R; please do work them out, because it is only then that you will gain experience with whatever you are doing there is another very remarkable fact about faraday’s laws; if induction, which was lost c over by almost everyone; except one person, and that was Einstein.

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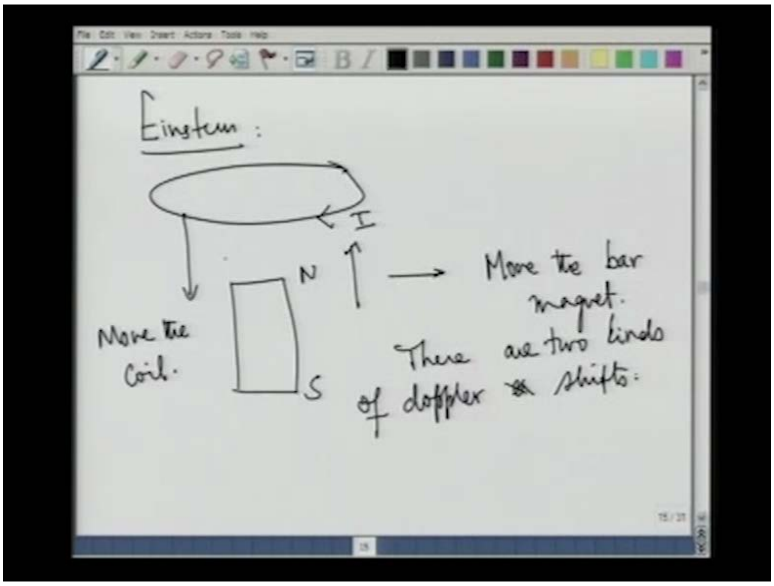

And that is the following thing, and faraday has described that very beautifully in his notes. There is a very well written book by Purcell on electricity, and magnetism. And Purcell is a great physicist; he got a noble prize for NMR. So, there in fact, that particular page from faraday's note has been printed. So, you should certainly read that, and that are the experiment of faraday, look at this.

So, let me imagine that, there is a source of magnetic field. So, there is a magnet; let me, take a bar magnet, and let me put a coil here. So, there is a north pole, and there is a south pole, and probably I should remove this arrow here. Therefore, let me just put a coil here; how do I produced a time dependent magnetic field, here is a very interesting question; one thing, I can do is to move the magnet. So, move the magnet that is one particular way, yet another way is, I hold the magnet stationary, and move the coil go back, revise all that you have studied about sound, and the propagation wave in your mechanics course.

If you believe in the existence of a medium, what should happen; then the magnet moves with respect to the medium, it creates a disturbance is that part clear to everyone; when I am speaking, I am the source of the sound I am the source of the sound I move towards the medium; I move towards you in the medium; I move away from you in the media; and I am going to create an appropriate doppler effect.

Now, if I am a trust, and if there is a tuning fork, which is there to detect; let us say, some sound emanated at by some frequency, and if that starts moving at the same velocity. It is not going to produce the sound, because the source of the sound is, what matters the vibration of the source of the sound with respect to medium is, what matters in all these things.

So, by that token, if you want to induce a current in this so, let me schematically, show it by that, and if you believe in the medium; you would argue that, that should be an asymmetry between the motion of the magnet, and the motion of the loop. Let me, give an example; again the same old example, but let me make it precise, there are two doppler shifts - two kinds of doppler shifts, and all your entrance exams are based on that; suppose the source is moving with respect to the medium, and they receive it at rest, you have one kind of doppler shifts.

Suppose, the force is at rest with respect to the medium, but the receiver is moving then there is another doppler effect, and this asymmetry occurs, because the speed of the sound is independent of the speed of the source, but it is depend on the speed of the observer.

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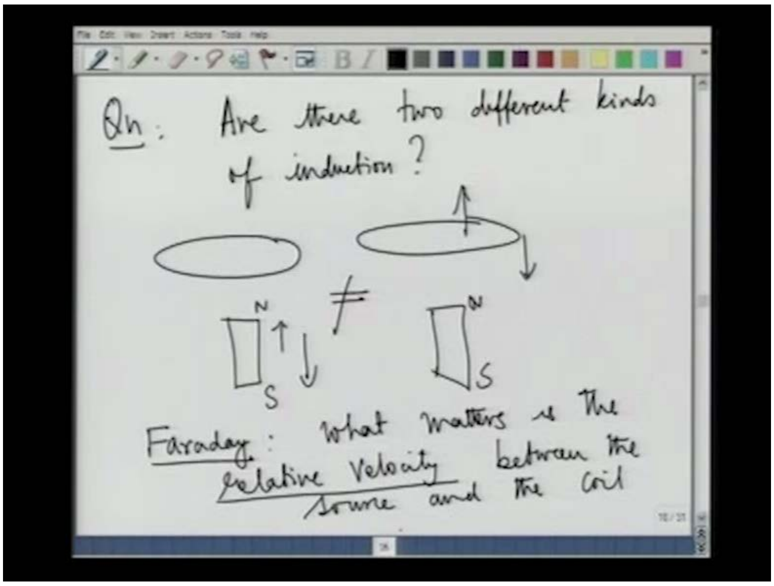

So, there are two kinds of doppler shifts by the same token; we ask ourselves the questions are, there two different kinds of induction. I hope all of you are able to come along with me, I hope you realize; why I am asking this question are there two kinds of induction. So, the first induction corresponds to my bar magnet moving this way; this way; and the second corresponds to the bar magnet is at rest my coil moves up or down are there two kinds of sources; if you really seriously believe in the existence of a medium, then there should be an asymmetry; this should not be, this the motion of the source with respect to the medium should not be the same as the motion of the receiver with respect to the medium, after all the coil is receiving the effect of the motion of the source.

However, as I told you, if you go and look up Purcell's book, it is the second volume in, and if you look up the relevant notes faraday writes in great detail; and he says that it really does not matter, whether the coil moves with respect to the source or the source moves with respect to the coil. So, which is the, what is the fundamental observation of faraday; faraday observe that what matters is the, this is the most significant work relative velocity between the source, and the coil.

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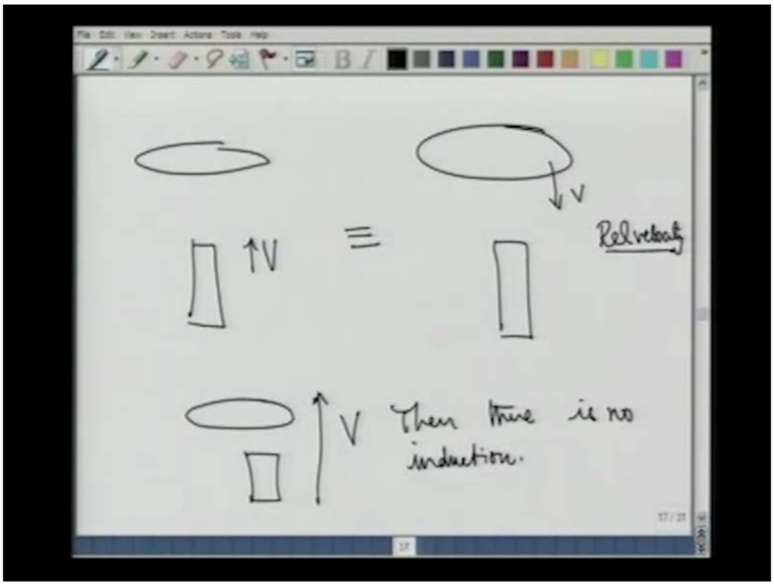

Let me show, it pictorially again for you; I have a coil; I have a magnet; this moves with a velocity v, the induced current is exactly the same as physics wise, I have a coil; I have a magnet; this moves downwards with a velocity v is that right. Let me, contrast with the third picture, where I have a coil; I have a magnet; and both of them move with a velocity v, then there is no induction. You know, it is said that beauty lies in the eyes of the beholder; actually the truth - the hidden truth is also in the eyes of the beholder. This is something, which faraday documented very meticulously, very carefully, and very explicitly. And yet almost all the physicist probably including faraday believed that there should be a medium, which is mediating which is supporting the electromagnetic field. It was taken over this concept of medium was taken over by Maxwell; Maxwell wrote the equations, and people believed that, those equations are valid in a very - very special frame of reference namely that reference in which the medium is at rest is that.

And people developed an elaborate theory to understand that Lorentz force one of them, and Michael has performed his famous experiment to actually determine the speed of the earth with respect to ether; and all of them overlooked the simple fact that, what matters is the relative velocity on the other hand; what Einstein did was to pay attention to this basic fact. And if you look up his famous nineteen naught phi paper on special theory of relativity, which is called on the electrodynamics of moving bodies; he does not refer to Michael's in model experiment; he does not refer to in fact, any arrear work either of Florence or Poincare or anybody he simply refers to faraday's work and he says that, because what matters is the relative velocity perhaps, we should not think of a medium.

This is a very - very fundamental observation, and those of you who are interested in knowing, how electrodynamics gave rise to special theory of relativity. The famous mass energy equivalence should certainly go, and read up a nice book. In fact, the introduction by Einstein himself in that paper is extraordinary. So, you see faraday's law of induction it is importance transcends mere appearances; it contains actually, some kind of a hidden seed, which gave rise to what special theory of relativity; having said that now let me, come back to the applications; you know that, there is a host of applications, because of induction of course, sometimes there are also problems. Because of a d currents, and things like that, I am not going to discuss each of them individually, because every book on electrodynamics gives you a large number of problems; you should certainly take time to work them out. So, let me start with a few examples and quickly go over to discuss one after the other.

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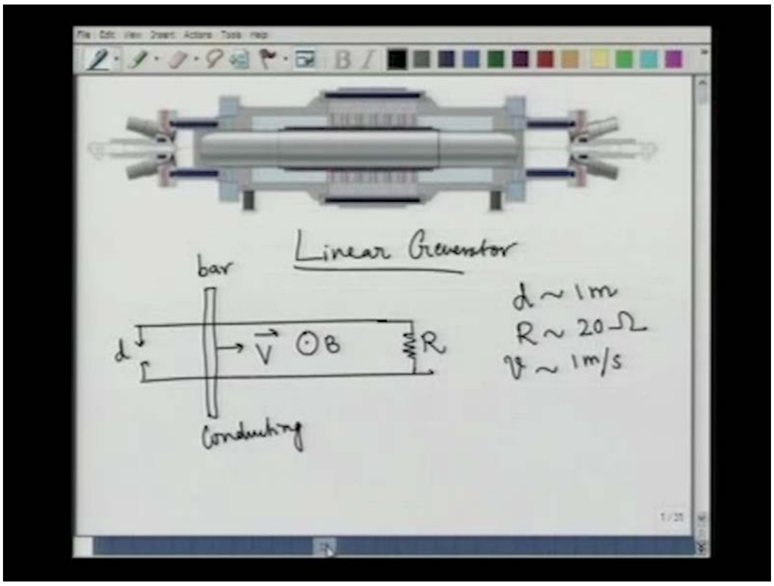

Now, the simplest example of the principle of induction is what is called as a linear generator; which I have indicated here. So, as you can see the magnetic field is coming out of the surface, and here is a bar; and what happens, I start moving the bar, this is a conducting bar; this is a conducting bar it starts moving with a velocity v; in this particular direction now, what do you do that part, I will leave it as an exercise for you people; please, write the faraday's law of induction into as a, what as a integral equation everyone knows how to do that is that so, maybe I should do that. So, let me do that for you.

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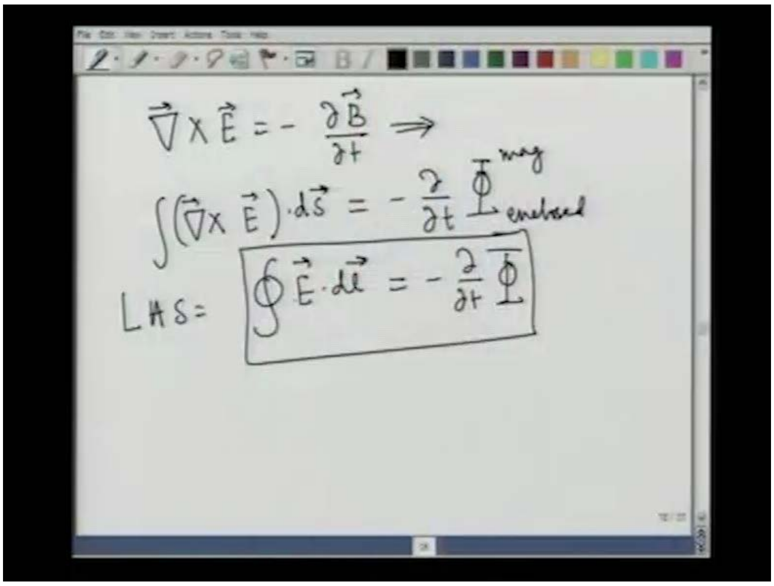

So, curl E is equal to minus delta B by delta t equal implies; obviously, I am going to evaluate a surface integral, which is an open integral is equal to minus delta by delta t enclosed the magnetic flux, and what is this my LHS is nothing but integral E dot d l over a closed loop, this is equal to minus delta by delta t phi. So, you can see that this electric field is not conservative, because if it were conservative, I would have written E equal to grad phi, then grad phi dot d l over a close loop would have been equal to 0. So, the charge particle keeps on going round, and round, and work is continuously done; that is, because this E is characterized by the fact that curl of E is not equal to 0.

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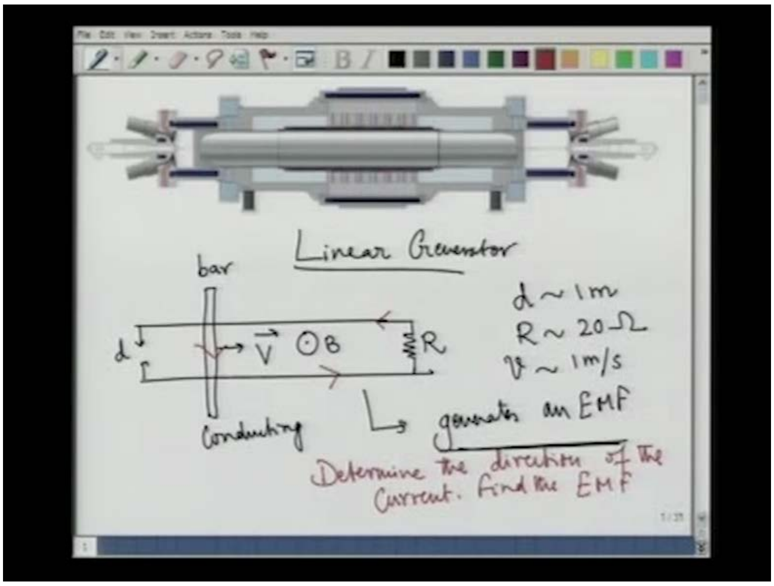

So, what do we do? We come back to this problem, and you will find that as the bar is moving the flux enclosed is going to change. Because there is a certain velocity here; therefore, this generates an EMF of the, because of the relative velocity, and because there is a generation of an EMF there is going to be a current. This current, I am going to denote symbolically actually, if you fix the direction; I am only going to show it symbolically. So, the problem for you is, determine the direction of the current. In fact, you can do something better imagine a huge generator, that is why it is called a generator of EMF; let it is d B of the order of one meter let, the resistance be of the order of twenty ohm's. In fact, all the resistance put together.

And suppose my bar is moving with a reasonable speed, one meter per second. It is quite a large speed; we should also find out, what the EMF is so, find the EMF. So, here you have a very interesting example of, how to generate an EMF? Again you should ask yourself, and try to answer at least qualitatively, who is doing the work, in order to generate this EMF, because there is joule heating; because there is R the resistance; how much is that of the order of 20 ohm's I square R is the energy, that is dissipated per unit time; therefore, you have to ask, who is doing the work; and that part I will leave as an exercise.

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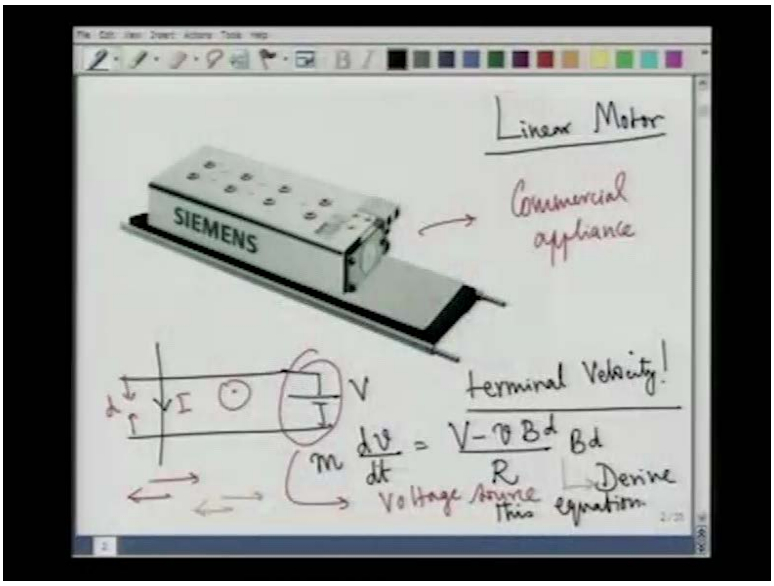

Now, the next thing is actually to look at a linear motor, what do I want to do here? I want to use the concept of a change in the flux, in order to make something move linearly; and on the top for illustration, I have shown you a commercial application commercial appliance and what do I do here in the original case, what I did was to put a resistance.

Now, I replace this resistance by a voltage source my magnetic field is still in the same direction as the previous case. So, my dimensions are the same d, now what is going to happen, this is an extraordinarily nice problem. So, please take time to solve the problem, and I have written down the equation here, I want you to derive that. Because of the voltage source, the current starts, flowing the current is going downwards the magnetic field is coming out of the plane; therefore, there is a Lorentz force, that Lorentz force starts acting, and the bar moves either this way or that way. So, what is the problem for you make use of the Lorentz force expression, and find out the direction of the bar.

So, the bar should move either in this direction or this direction; please, determine that. Once, it starts moving, because I have put a uniform magnetic field perpendicular to the plane; there is a change in the flux, when there is a change in the flux, it induces its own current; which opposes the motion, and that I will indicate either this way or this way. So, now, you see there is a competition; that is taking place between the Lorentz force, which was there initially, and the induced E M F, which is coming from faraday's law is that part by with everyone; what happens, if the two forces balanced, there is going to be a terminal velocity, and all that I have written in this equation m d v by d t is v minus v B d by R into B d. So, what is the problem for you? Please, derive this equation derive this equation and of course, the terminal velocity corresponds to putting d v by d t equal to 0.

We have a beautiful linear motor, and let me repeat my question, please answer, who is supplying the energy for your particle to do this? In this case of course, there is a frictional force, there is an applied force, and there is a terminal velocity, this is a very - very nice problem, and a very simple illustration of the idea.

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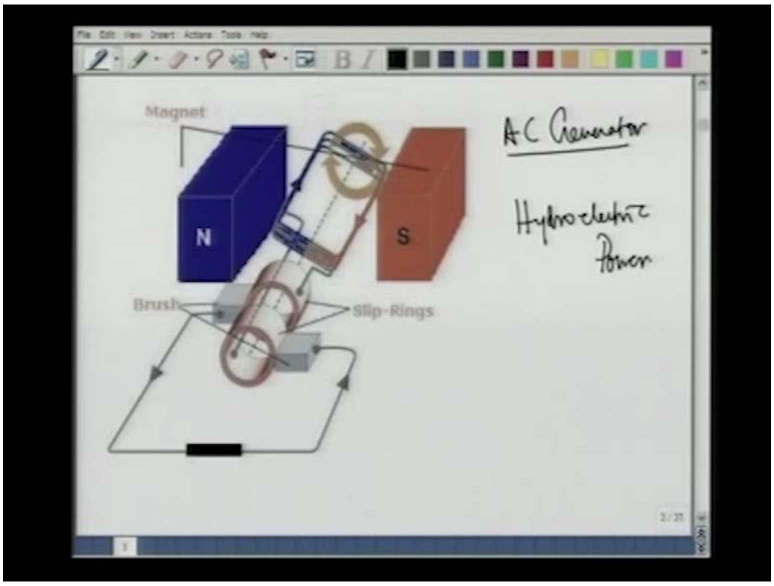

The third problem is of course, is very famous all of you are familiar with this; I do not have to make a problem out of this; this is you famous A C generator; you have the north, and the south poles. And we have a turbine, whatever motor which is rotating inside, it keeps on changing flux, you put a brush. So, that the current is always, and the slip rings. So, that you always control the direction of the current, and this is what is used in hydroelectric power generators, go to a hydroelectric power station close by now a days you have so, many So, many hydro electric power plants; all over the country you will be able to see huge setups corresponding to this. So, let me not spend any time corresponding to this.

The fourth example is, again something that you would solve to a very large extent, I do not want to get into this, because this is actually a problem in inductance also these are the transformers, and transformers as you know come in real huge size. In fact, because of this induction the currents are generated the loss is. So, much they are all dipped in very cold oil, and all that you will see at the street corners.

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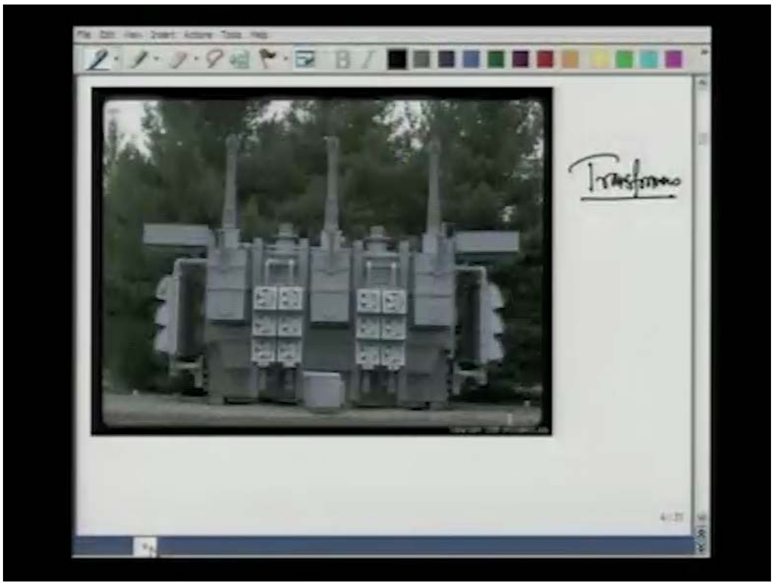

This is a matter of very - very large transformers; let me not worry about that, yet other application is a magnetic; break you change the magnetic flux; there is an induced field, and then the two come, and the clasp each other; that is what is going to happen.

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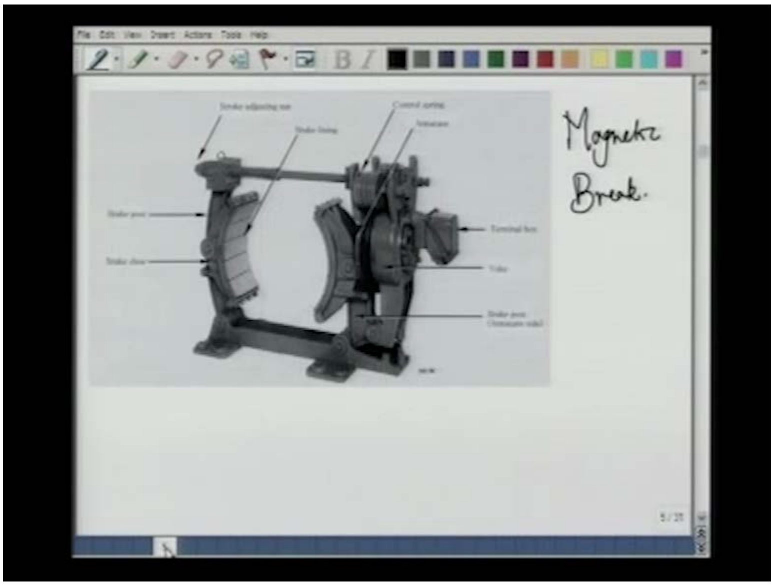

So, please ask your instructor to actually, explain the idea behind this. And apart from that, we have host of other applications; there as I told you electric heater, which works on the principle of induction. So, that you do not have to worry about insulation about shock, and things like that then a d currents; actually, it is the a d current, that plays the role. So, in all the situations, you see that faraday's law of induction is put into great use. It is there all in pervasive in hundreds, and thousands of applications, and for us not only is, it is importance. Because of it is applications in electric electromagnetic equipment, but it is also there, because it throws great light very - very it gives us very, very important insight on the very nature of electrodynamics; unless, I told you, it is faraday's law of induction, which is the first forerunner for the idea of the principle of relativity, which revolutionized our understandings of space time you will probably, get a little bit - more hint on that from the next inspector; who is going to look at modern physics. So, let me stop this discussion at this particular point.

I have discussed induction at the great length. And I have told you, how the induced field actually opposes the original field, and I have contrasted that with the situation; where if the currents are already there, they like to build up, if the currents are not already there; they like to oppose each other. Now, the time is right for us to actually discuss magnetic fields in materials. It is still (( )) statics; let us do that, and after that we can go on to study the electromagnetic waves, but for that we have to supply one more missing link namely, displacement current; we will do that later.

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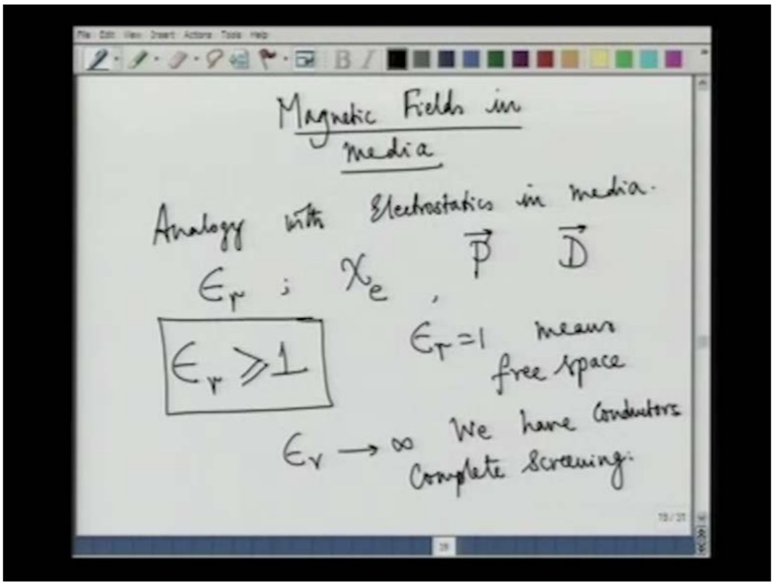

So, let me return to the proper subject matter, which I wanted to discuss today, namely magnetic fields in magnetic materials in media; I am not going to spend too much time setting up the notation, and all that, because we did really work hard; when we did electrostatics. So, analogy with electrostatics in media, and let us remember, what are the crucial quantities that we introduced - we introduce relative permittivity; we introduce the susceptibility electric susceptibility; we introduce the concept of a polarization; and then we introduce D the so, called displacement fields. So, we have to introduce quantities analogous to this electrostatics. In this particular situation, before I proceed the most important statement that, one I have to make is that my requirement of stability thermodynamics tells us that epsilon r is always greater than one; why is that.

So, if I take a positive charge, and put it in a medium; the only way to decrease the energy is to surrounded by negative charges; that means, my p the polarization field is always opposite. The direction of the applied field epsilon R is always greater than one, and the way we have defined epsilon r is always greater than equal to one, and epsilon r equal to one means free space in the limit epsilon r going to infinity; we have conductors, we have conductors because now the electrons are the charges or completely free to move, and it will cost complete screening - electrostatic screening is there, you can screen yourself completely from the electric field. So, this is what we have, when it comes to electrostatics. So, this is what we have when it comes to electrostatics. So, in a similar manner, I should develop a mechanism in order to discuss the properties of the magnetic field in the media.

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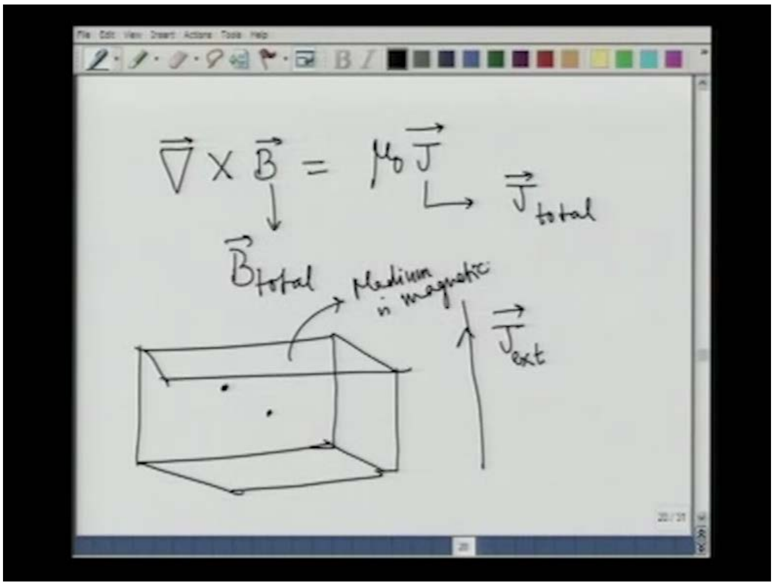

So, what is it that, I have to do, I have to start with the fundamental equation curl of B equal to mu naught J, and let introduce a whole set of notations. This equation is unchanged, what do I mean by that this is J total, and this is B total medium or no medium; they broke no violation of this law is that part clear; what is going to happen is something slightly different, and let me make a picture. This is a convenient picture; the results are more general, than what I have written in the picture. So, this is a chunk of a magnetic material. Let us say, and then there is a source of a current, which I will denote by this J, I will call as J external.

Now, of course, there are two possibilities; either the material is magnetic or non magnetic; obviously, we are interested in a magnetic material. And let me say, that I am interested in the fields, at this particular point. So, probably I should make it into a block, I have a block of this particular kind, and I am interested in the magnetic field at any given point. If this medium, this is a section of a medium is non magnetic, then the magnetic field at this point will be simply given by curl of B equal to mu naught J external, but the question is, if the medium is magnetic, what is B.

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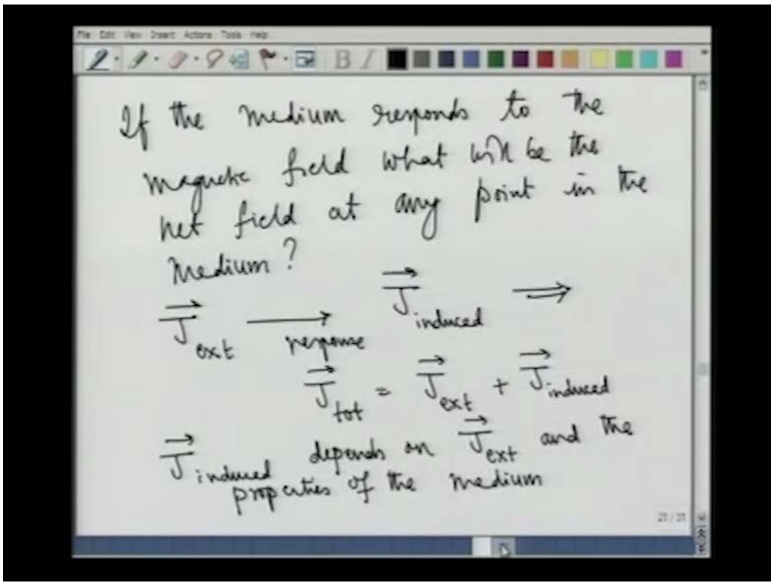

Let me, write that question explicitly, if the medium responds to the magnetic field; what will be the net field at any point in the medium, that is the question; obviously, I cannot answer this question starting from the first principles; I have to make a model, and we will do it step by step. So, let us write these following things, my input is J external; and how does the medium respond? The medium responds is, through a J induced there is an induced current. So, what is the net current, this implies that the net current is given by J total is equal to J external plus J induced.

Now, we ask ourselves how do, I determine J induced; that is the question that I am going to ask myself. So, what do I say J induced depends on, what J external, and the properties of the medium J induced depends on J external, and the properties of the medium, and what is it that people found.

People have got found a large number of experiments on water, bismuth, cobalt, nickel, whatever whatever glass; people have performed a large number of experiments; and people have found that the response is always linear.

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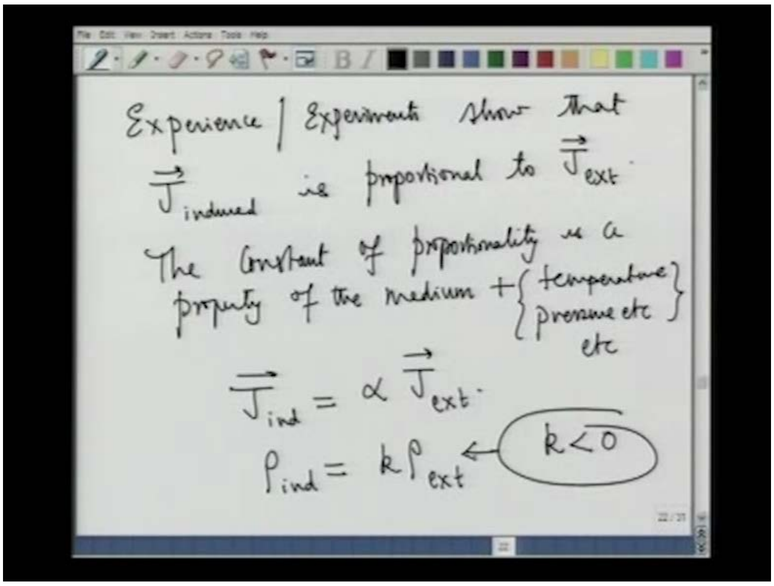

So, this comes from experience. So, experience - experiments what do, they show that J induced is proportional to J external the constant of proportionality is determined by the properties of the medium. So, let me write it the constant of proportionality is a property of the medium plus quantities like temperature, pressure, etcetera, external conditions etcetera.

Now, I am in a position to write explicitly, what is it? That I wanted to do J induced is equal to some constant. Let me, call it as alpha J external; let me go back to the electrostatic analogy; and ask myself, what is it that happens, I had rho induced was proportional to rho external. So, let me introduced a slightly better notation rho induced (( )) equal to k rho external, and k was always less than 0, because every charge gets surrounded by unlike a charge; that is how we induced a dipole. So, the question that we are asking is, what the sign of alpha is so, let me ask myself that question; what is the sign of alpha. Let me, repeat in electrostatics the consent of proportionality is always less than 0, but here there are two possibilities alpha greater than 0, alpha less than 0, when alpha is greater than 0, you have a current in a given direction, then the currents induced currents are also in the same direction therefore, they tend to increase the magnetic field, and these are called paramagnetic materials.

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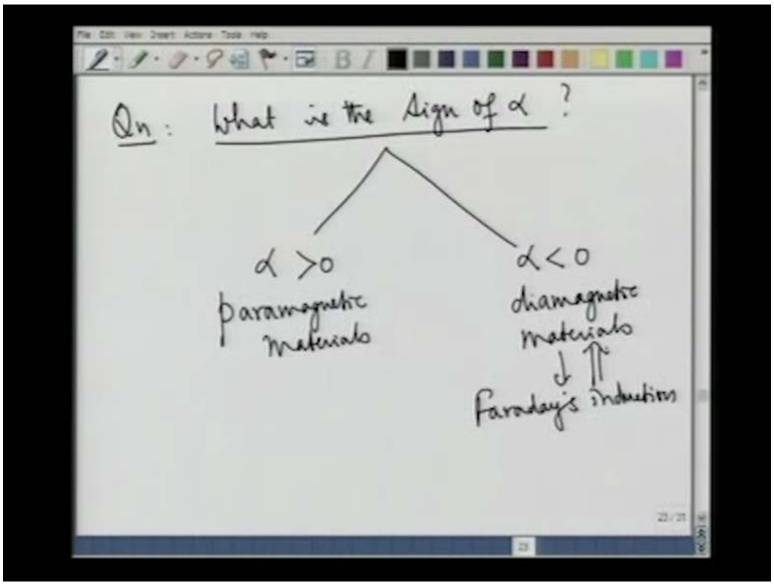

When alpha is less than 0, you produce a current, but that current will be opposite to that of the original current; therefore, it produces a magnetic field, which competes with the original field it tries to cancel; it is that right therefore, these materials are called diamagnetic materials. And where did we get diamagnetic materials from faraday's inductions; let us not forget about that faraday's inductions, always implies diamagnetism whereas, as I told you, if there are already some magnetic moments or random currents; which are already sitting in the medium, then there can be a paramagnetic material.

Therefore, we should now be able to actually characterized both the paramagnetic, and the diamagnetic materials in a careful fashion. Let us, do that there is a certain baggage that we have to carry, which has come historically I have to introduce a few more quantities, just as you introduced in electrostatics the displacements field d the polarization p etcetera, etcetera. Here, I have to introduce a notion of a magnetization induced magnetization; I have to introduce a field called h, and then that I that, I think is called the magnetic field; and these called magnetic induction; anyway let us, not bother about that. And I have to introduce the appropriate susceptibility. So, let me do that slowly.

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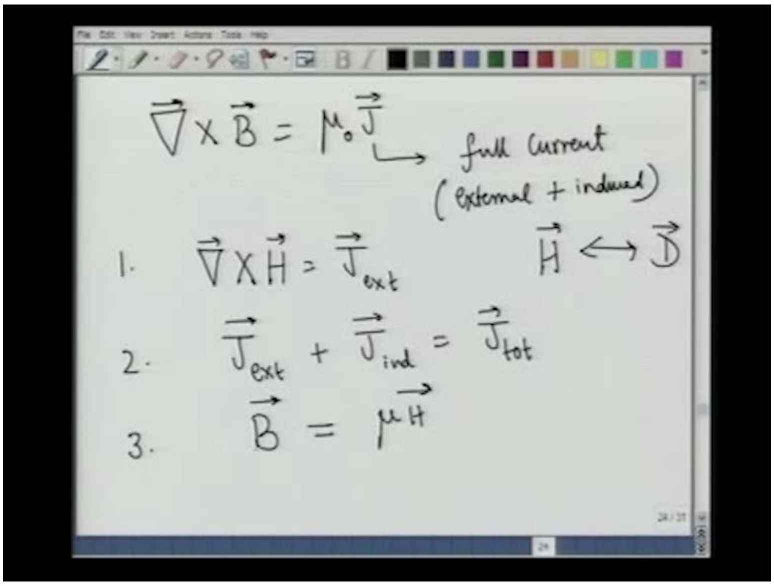

So, the first equation, that I am going to write is curl of B equal to mu J, and this is the full current, what do I mean by that external plus induced; suppose, there were no medium, then I would have had only external, and I have to put a mu naught, because Maxwell's equations are universally valid.

So, now let me introduce the first quantity namely curl of H is equal to J external. So, what is the analogy H is analogous to D see what matters is actually, the difference between the free space permeability, and the permeability in the medium. So, people became smart; they have observed mu naught in the definition of h one over mu naught in the definition of h; this is the first thing, that we have to do.

The second thing, that I have to do is to write J whatever, I wrote earlier external plus J induced is equal to J total, and the third thing that I have to do is the induced magnetic field should be proportional to the external current, but the external current is the same as H therefore, I will now write one more equation B equal to mu h; there we have the mu naught the permeability of the free space. Here, you have mu of course, if you are sitting in the free space; mu is equal to mu naught; and B equal to mu H; which becomes the same as, whatever we wrote earlier; what we have to now do is to collect all these relations, and study the physics correspond to the diamagnetic, and the paramagnetic response, that will take a time some time about ten fifteen minutes; let us say so probably, what we should now do is to stop at this particular point, and resume the discussion, and see which are the materials, which are paramagnetic, which are the materials, which are diamagnetic, and we will also see their applications in a few cases, and then you go on to study the generalization of (( )) law through the displacements current; which will naturally, lead us to electromagnetic phase. So, let us stop here.

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