Experimental Physics I
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Lecture - 55
Study the induced e.m.f of inductance coil

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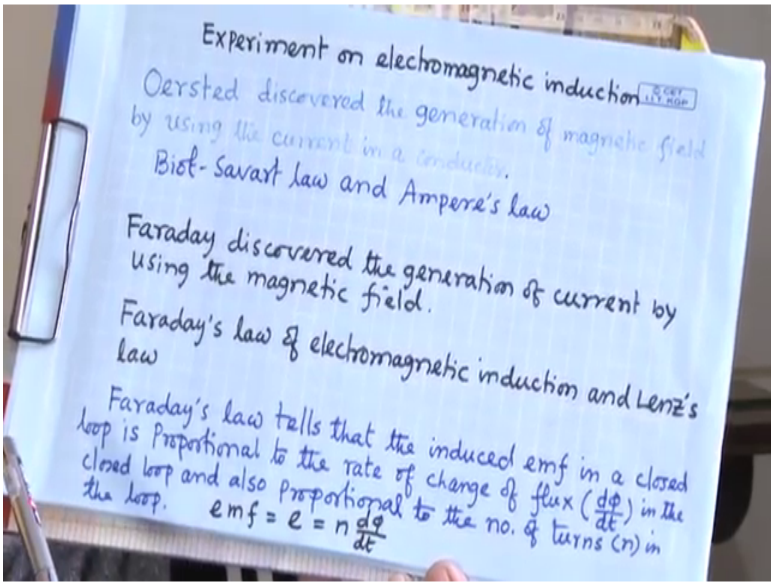

So, today we will discuss about the experiment on electromagnetic induction. See you know this electromagnetic induction basically Oersted discovered the generation of magnetic field by using the current in a conductor right. So that was the first discovery of basically Oesterd that from magnetic field can be generated, when current will flow in a conductor. So, just by using so as a consequence this law of came up that is Biot-Savart law and Ampere's law, both laws are basically same ok. So, it gives relation with the current and magnetic field, and some other constant terms are there.

So, then the just reverse effect that that was discovered by Faraday. Faraday discovered the generation of current by using the magnetic field; so, here using the current magnetic field was generated. Now, this reverse effect is using the magnetic field, whether current can be generated or not yes. So, current can be generated or voltage can be generated, so that was the discovery of Faraday, so very famous law Faraday's law of electromagnetic induction also Lenz's law ok.

So, basically this two log gives the relation of the magnetic field, and the current or voltage. So, what was that Faraday's law and Lenz law. Faraday's law tells that the induced emf in a closed loop is proportional to the rate of change of flux, so that is d phi by d t rate of change of flux, if phi is flux. So, d phi by d t in the closed loop and so this so it will then, it will produce, it will produce induced emf that induced emf is proportional to this change of flux rate of change of flux, and also proportional to the number of terms in the loop ok.

So, so if you take a loop if you take a loop in a magnetic field, and if magnetic field changes, so with time then there will be induced emf in the loop. So, these induced emf is proportional to the change of magnetic field. So, basically change of flux; so there is relation between the magic field, and flux that I will tell you and also proportional to the number of terms in the loop ok. So, induced emf induced emf that is e equal to basically n number of turns in the loop d phi by d t, they are proportional, so there is a proportionality constant.

If you use proper unit, so this constant is will be 1, so e equal to n d phi by d t, so that is that is the Faraday's law of electromagnetic induction. But, then basically Lenz found that, so found that this there will be there will be negative sign here, there will be negative sign here, what is the significance of this negative sign? So that is basically the Lenz law.

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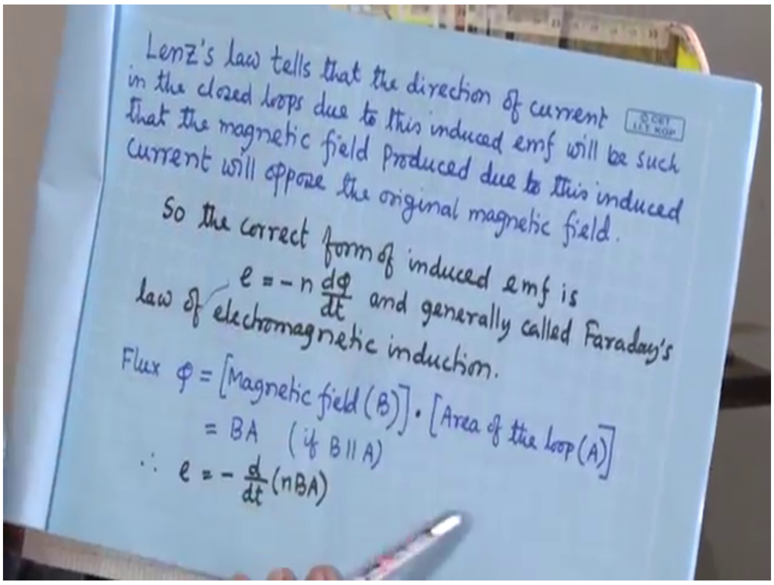

So, Lenz law this tells that the direction of current in the closed loop due to this induced emf, whatever induced emf e in the loop is generated due to Faraday effect Faraday's law, so that for that induced emf, there will be current in this closed loop there will be current in this closed loop. And if there is a current in a in a closed loop, it will produce magnetic field.

So, Lenz law tells that that induced magnetic field should be should oppose the should oppose the original magnetic field ok. So, induced emf direction or current direction induced current direction should be such that. So, this induced magnetic field will oppose the original magnetic field, it will not favour ok, so that is the Lenz law. So, for that basically this combining this two law of so this correct form of this induced emf is basically minus n d phi by d t. And generally, we call it as a Faraday law ok; Faraday law of electromagnetic induction ok.

So, now so here n is number of terms that is fine phi as I told this is a flux. Now, flux is basically it is a related with the magnetic field; so magnetic field dot product of area of the loop ok. So, B dot A B dot A, generally if B is parallel to A if B is parallel to A, then it is BA. So, normally it happens that is we place this loop in such a way that it is axis of the loop passing through the centres that will be parallel to the magnetic field direction.

So, generally this direction of the area is basically normal to the normal to the surface of this of the area. So, then induced emf e equal to minus d by d t nBa nBa nBa ok. So, from this formula, it is clear that that induced emf will vary. If you vary n number of turns in the loop closed loop, it will vary induced emf will vary, if you vary the B. Also induced emf will vary, if you vary the A area right.

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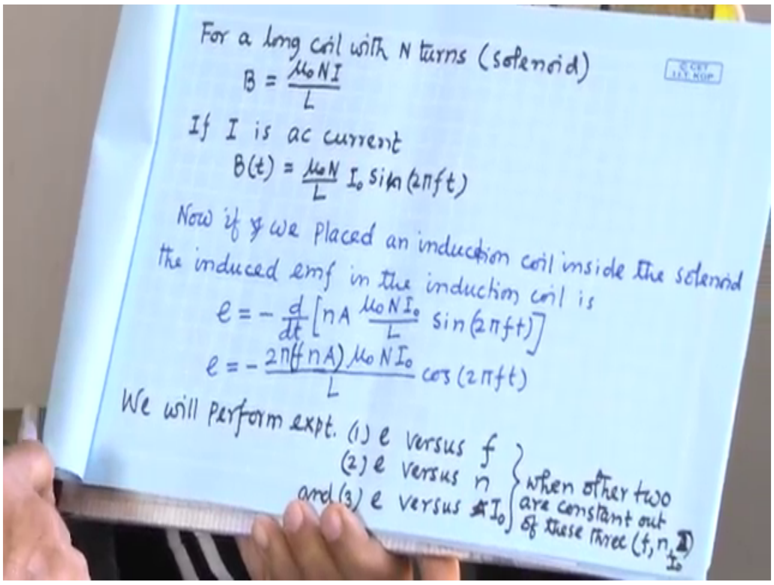

So, now B, this is the original B ok, where we have put the loop closed loop. So, this B if we generate this magnetic field in a electromagnet in a electromagnet means, if current flows in a coil, so it will produce magnetic field. And that for a long coil with N terms is (Refer Time: 08:48) we tell solenoid.

So, if we use solenoid to generate the magnetic field, so this relation is B is equal to that already we have derived in other experiment, so B equal to mu 0 N I by L. So, mu 0 is the basically permeability of this of the medium in this in the solenoid ok, N is the total number of terms in the solenoid, I is the current flowing in the solenoid, and L capital L is the length of the solenoid ok.

So, now if you take I is an ac current, then magnetic field will be a function of time. So, B is a function of time is will be equal to the mu 0 N L I 0 sin. So, if you take this variation of I is a sin function, so I 0 sin 2 pi omega t, so omega is 2 pi f t ok, f is frequency ok. So, now you have a solenoid, and there you are varying the magnetic field, this magnetic field is varying with time, so its variation is like this.

Now, if you place that induction coil, another this whatever I was telling closed loop, so that is now I am calling this induction coil, inside the solenoid inside the solenoid, so then the induced emf in the induction coil will be so whatever the relation we found e that will be equal to minus d by dt n A B that was n A B. So, now B is replaced with this one B is replaced with this one ok.

So, induced e m f you are getting, so basically minus 2 pi f frequency, so these are we have differentiated this part, other part is constant. So, f n A mu 0 capital N I 0 by L cos 2 pi f t ok; so this is the relation of induced emf with other parameters. So, here this induced emf, so this basically we will study we will study the variation of induced emf or dependent of induced emf depends on some parameters here. So, how induced emf will vary with this parameters, so that is what we want to study.

So, basically we will perform experiment. So, this e versus f e versus f, if you vary f, how this induced emf will vary, remaining constants the others other parameters. Then we will study the variation of variation of induced emf e versus n, n is number of turns of the induction coil number of turns in the induction coils. So, varying the induction coils, we will study the variation of this induced emf.

Also we will study the induced emf variation of induced emf as a function of I 0, as a function of current as a function of current, so this basically here I should replace this I 0 cos this part as a rms rms current ok, so because we will measure rms current. So, this just you can take as a I this you can take as a I I rms. So, some other factors will be there 2 or 2 root 2 etcetera; so, this you can take as a current. So, we will vary current and study the variation of the electron emf induced electromotive force.

So, also we will study the variation of variation of induced emf as a function of A as a function of A area ok. So, area as a as a function of diameter basically, so area is a pi d by 2 whole square pi r square, so r is d by 2 diameter. So, basically, we will study study the variation of induced e m f as a function of different parameters mainly the frequency, the number of turns in the induction coil, the current in the basically current in the field coil field coil. So, whatever solenoid we are telling that is a field coil, this a coli which is giving field, so we will vary this one. Also we will vary the diameter of the of the induction coil ok.

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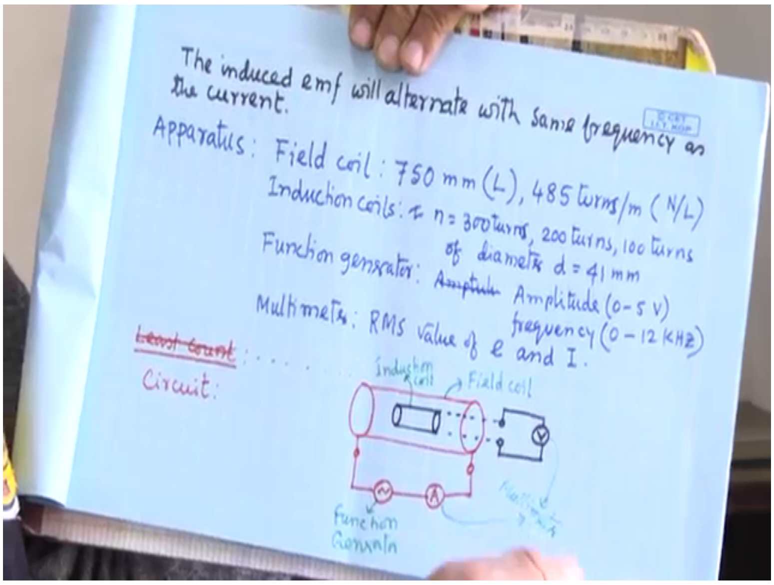

So, let us see the apparatus for this experiment.

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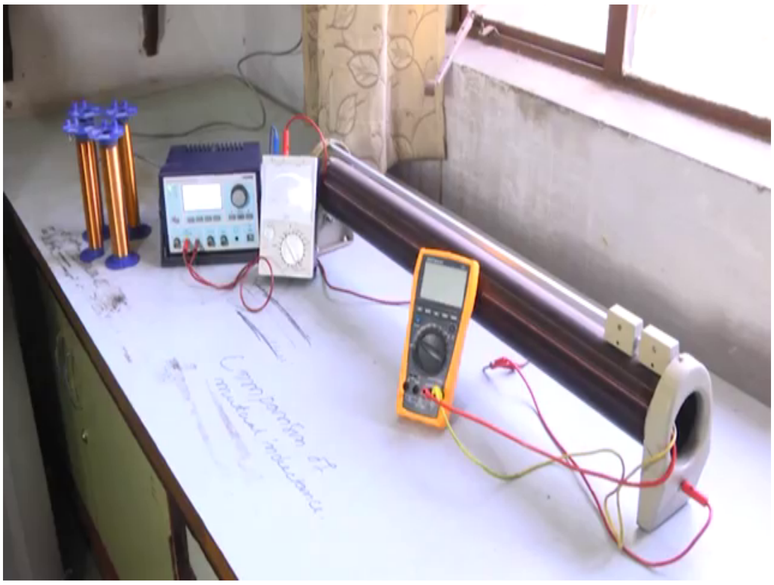

So, here this is this very simple experimental setup for this experiment. So, as I told that in this setup what are the apparatus we require? We need one solenoid. So, this is a solenoid this is a solenoid, you see the number of turns, it has many number of turns ok; so, this is the solenoid.

So, now I have to I have to pass current through this through this solenoid. So, for that an ac current I want to pass through it. So, I need basically function generator, so this is a function generator. It will give ac ac voltage to this to this to this solenoid, and then basically we will get ac current of same frequency, which will pass through this solenoid ok; so this the function generator.

Now, basically what is the current flowing through this solenoid that for measuring that one I need, so I have ; we have collected one multimeter. So, basically multi-meters we can measure current, voltage, and then resistance. So, we are interested to measure the current, so that is why here this knob we kept it at in current amperes ok. So, we need one ammeter, so here this multimeter we are using as a ammeter ok.

So, let me show you connection. So, let me show you connection, you see this is the power supply ac power supply ok. So, now this ac power supply; so these coil have this I have to connect this power supply to this coil. So, it has two end, it has two end; one end is here, and another end is here.

So, you see if you look at the circuit if you look at the circuit, so this one is connected at this place, this is this connected here; so this end is connected here. So, current we will go through the solenoid, and come back through this other end and it is connected to the ammeter or multimeter, and this is going back to the other end of the source.

So, this a complete circuit, this is a complete circuit for this solenoid ok. Now, through this solenoid, I can pass current I can pass current, I can vary the amplitude of the current as well as I can vary the frequency of the current. So, from using this source power supply ac power supply ok, so this part is complete.

Now, next part is that. So, when current is varying, so basically magnetic field generated, inside this solenoid will vary right. So, it will vary because of the frequency because frequency is basically the time variation right. Frequency is nothing but the time variation of some signal ok.

Now, current is varying; current is varying with some frequency, so that means rate of change of current in the solenoid that is happening means, magnetic there will be change of magnetic field with time. So, inside the solenoid, I will get the change of magnetic field with time. So, now if I put induction coil inside the solenoid, so then this induction coil it will see the magnetic field, it will see the variation of magnetic field. So, then there should be induced emf, there should be induced emf in the induction coil and that induced emf will major, so that is the experiment we are going to do here.

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So, here I will I have put this induction coil that I will show you that I will show you, so we see this is the induction coil, this is the induction coil. I think I have to what is this it is in it is another multimeter, but I have kept it in I will use it as a voltmeter.

Now, we see so this is a completely independent circuit ok. Here this induction coil, and this coil have this coil have total the small n that is I that is what I told you say that is 300 number of turns, it has 300 number of turns. And it has diameter here written you see phi 41, so it has diameter 41 millimetre. So, corresponding area of this of this induction coil one can calculate.

So, these coil other specification also written here, but I am not interested about this other specification. So, here in our expression this number of turns, and this area is important. So, for this so this coil now, I want to place in the magnetic field, where this magnetic field is changing with time.

Now, there should be induced emf induced voltage, and that voltage I will get in this voltmeter right. So, there is a current I have put 15 milli ampere current is set. So, reading you can see this a it is a you see it is a is in the range of 300 milli ampere. So, this scale 0 to 30 that we have to use I think is so 0 to 30, we have to that we have use.

So, it is a it is in the I kept it will in 30; 300 milli ampere range that means, this is not 15 milli ampere. So, it will be a 150 milli ampere right. So, current I have set at 150 milli ampere.

Now, this current is changing with some frequency here this frequency. So, here some it is a amplitude of this sinusoidal wave. So, I will just let me keep a 10 10 volt. Here basically we have put 10 volt amplitude of the sinusoidal wave is 10 volt, now its frequency I can check its frequency; so here there are options to check it.

So, now frequency is there is the 4 kilohertz this frequency is 4 kilohertz. So, frequency is 4 kilo means that voltage I am not interested about the voltage. So, if I vary voltage, then I will be able to vary this current flowing through this through this solenoid. So, I am interest about the current in the solenoid as well as the frequency of that current in the solenoid.

So, I have to note down this frequency, I have to note down this frequency 4 kilohertz, I have to note down this current that is 150 milli ampere. Now, in this situation, so I have to note down also this one number of turns small n is 300, and diameter is 41 milli meter that I have to note down. Also total this length I have to note down capital L, I have to note down the total number of turns in this in the solenoid, so that is already if that is given, I will tell you what are the data for these.

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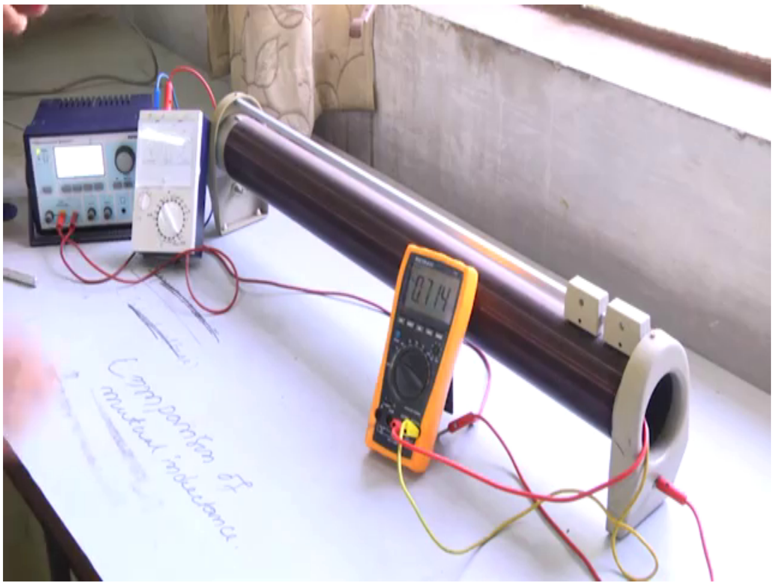

Now, you see this is 0, now this induced emf is 0. Now, let me put inside the magnetic field inside the magnetic field of the solenoid, then if I put inside, but I cannot see, because I have put in dc mode, it is the auto mode is the ohm, but why this the voltage well this is the voltage, but it is showing dc, ha now it is ac mode ok. So, earlier it was dc mode that is why it as showing 0. Now, it is in ac mode. So, you see this induced voltage is 0.714 volt 0.71 volt. So, I have to note down this reading ok.

Now, what you want to do? Now what do you want to study. So, this is the induced emf. Now, I want to study the variation of induced emf as a function of frequency keeping all other parameter constant right keeping all other parameter constant. So, all other parameter will remain constant. Now, I will change frequency, now I will change frequency. And note down the change of the induced emf, so that is you have to make table and you have to do it.

So, here frequency now is 4. So, I should start basically from say 1 kilohertz, then 2 kilohertz, 3 kilohertz, 4 kilohertz, 5 kilohertz that way you have to up to up to 10 kilohertz, we will do this experiment. But, since it is at 4, so I will not go down; so, I will show you at frequency 5 kilohertz what happens. So, I will change the frequency, I will change the frequency at I will go to 5, I will go to 5 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5 5.0; so now this 5.0.

Now, here you see earlier it was 0.741 probably; yeah So, now it is 0.667. So, it should increase frequency is increasing this voltage should induce voltage should increase, but unfortunately is decrease. So, why it happens? Now look at this current look at this current, current was as 150 milli ampere. But, now current is I think 120; 20 milli ampere; so current is change.

Now, because I told that I have to keep other parameter constant right. So, basically I have to keep this current at 15 not 15; 150 milli ampere right. Now, question is when I change the frequency, why this current decrease? That means, resistance of these circuit is increased yes resistance of the circuit is increased, because this is the solenoid is a inductor right. So, inductor this resistance is omega L 2 pi f L. So, omega equal to 2 pi f, f is frequency, now frequency is increased. So, these inductive reactance is increased that is basically resistance ok.

So, f has increased, so resistance of these solenoid is increased, so that is why current decrease. So, I have to apply higher voltage to bring it back to the 150 milli ampere, so that is what I have to do now, I have to do now, so let me amplitude go to amplitude, and then it was 10 volt earlier. So, now I will change this volt increase this volt to bring it back to the 150 milli ampere, you see it is increasing it is the increasing. So, I have to change voltage as long as it is going back to the 150 milli ampere yes; now, it is 150 milli ampere more or less ok.

So, further whatever voltage I need, I have to apply, but important thing is that our current. So, it is now it is 150 milli ampere ok. So, my let me see this whether frequency is at 5 yes, frequency is at 5 kilohertz. Now, current is 150 milli ampere; so all now all other parameters are constant, only I have changed this frequency from 4 to 5 right kilohertz. Now, you see here this induced emf, it is 0.853; earlier it was for 4 kilohertz, it was zero point 0.741, now it is 0.853 mole. So, you have to note down.

Now, go to 6 kilohertz, go to 7 kilohertz keep the current constant at 150 milli ampere, and take the reading. So, then you plot it then you plot it. So, let me go to this, I will show you. So, in our apparatus basically field coil that solenoid. So, it has it is a length is 150 milli meter. And it has total number of non not total number of turns, number of turns per meter. So, 485 turns per meter, but I need, so that is basically capital N by L ok.

So, I know L. So, I can find out basically this total number of turns in the solenoid there is capital N. So, induction coil whatever I put inside, so its number of turns is 300. And other also I have you see I have many basically I have many many induction coils; so of different number of turns of different diameter.

So, when we will do other experiment if I want to vary the n small n, if I want to vary the area, so I can use different different induction coil. So, we have function generator we have function generator ok, it is amplitude brings its a 0 to 5 not it is not correct 0 to it will be 0 to 25 volt; its range is 0 to 25 volt not 5 volt. And frequency 0 to 12 kilo hertz ok. So, this is the range is given. So, within this range you have to do the experiment. And we have used multimeter two multimeter we have used. One is used as a ammeter, another is used as a voltmeter ok.

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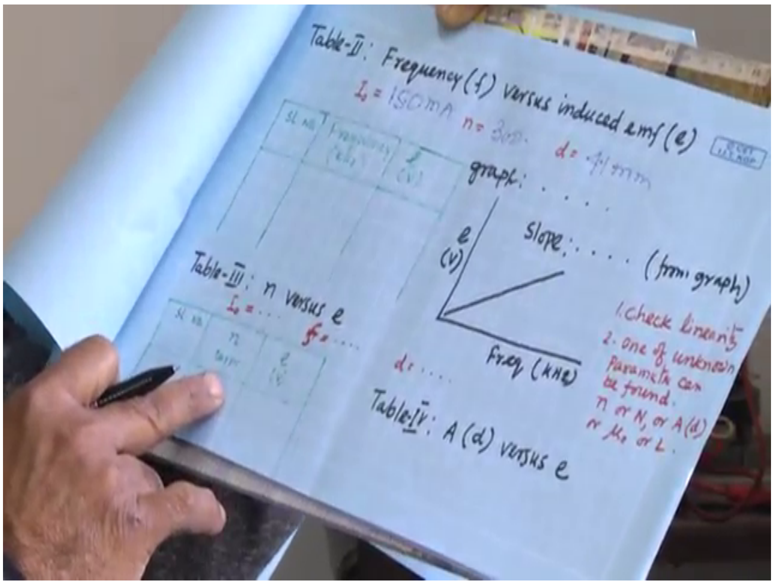

So, so you have to continue taking data. So, this data I whatever I was taking, so current versus induced emf not that one. Frequency versus induced emf right frequency versus induced emf. So, for that I 0, I have taken 150, so you have to note down 150 milli ampere. Number of turns n is that the 300, and diameter is 41 milli meter ok, so that you have to note down.

So, for this now I am varying the frequency, and then I will note down the induced emf right. Then I can plot this one. If I plot induced emf versus this frequency, so I will get basically straight line. And from there you can find out the slope, and that slope is you can from this slope basically you can calculate, you can calculate some unknown parameter. One of them if it is unknown, you can calculate. So, say mu O is unknown, if it is unknown or you want to find out.

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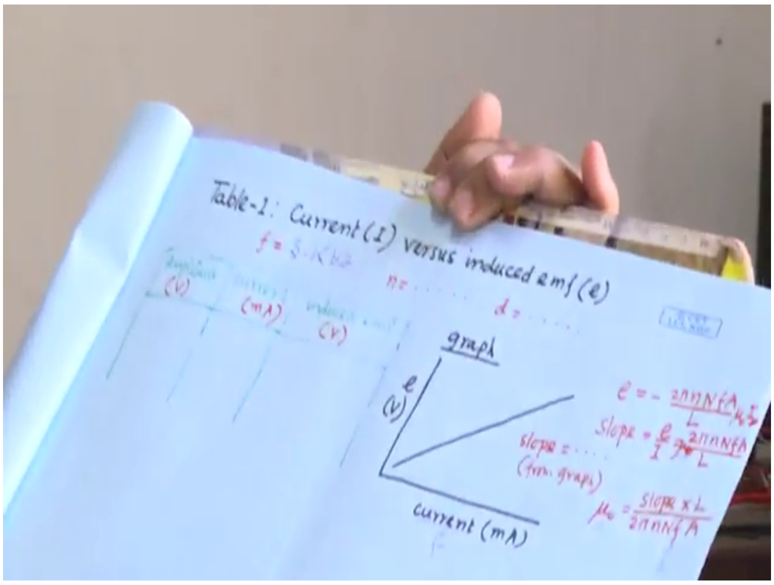

So, from the slope you can find out, I think I have not yes. Here I have shown you is a in terms of current anyway. So, slope is from this graph you have to find out, and this slope is here I have written e by I, but in other cases it will be e by f e by f, I will go there. So, this part will be the slope. So, all other parameters will be known to you, and then you can calculate this mu 0, you can calculate this mu 0 ok.

So, so here it is f is there, but since I was showing you data for the as a function of f, keeping I 0 constant. So, this f f basically, we will put as a as a I 0 ok. And here this current instead of current we will plot f ok. So, same similar experiment, we can do just here whatever yeah here whatever I showed you, keeping this frequency constant at a particular value n, and d also this for same induction coil.

Now, so here now it is it is frequency is 5; 5 kilo hertz right ok. Now, I will change the current it is at it is now at 150 milli ampere, now I will change current. So, let me go to the; let me go to the amplitude voltage. So, now it is 150 so then let me go 160 milli ampere 160 milli ampere yes, because it is division it is 10 is division is 10. So, it is the 16; 160 milli ampere, for that reading is 912; 912 millivolt or 0.912.

Now, I will change the this one is 170 170 you see, this now reading is 971 millivolt, then I will go to the 18. Now, it is one point or 1038 millivolt. So, I am varying the current, and then noting down the induced emf ok, so that way another curve we can draw. So, again you will so this induced emf versus current and from there if you will get straight line and from straight line, you will find out the slope. And from that slope again you can find out the mu 0 or already you got mu 0.

Now, if some parameter is unknown say, length of this one is unknown ok. So, you can find out the calculate the length of this. So, similar experiment you can just repeat varying the just this this coil varying this coil ok. Now if I want to want to do the experiment that variation of induced emf with number of terms. So, keeping all other parameter same. So, it is the number of turns here is 300, diameter is 41.

So, I have another coil you see, diameter is 33 bar t it is a 300 know, I cannot use I cannot use this one. So, I need diameter of 41 ok. So, I do not have this 41 diameters, but number of turns are different it is ok. So, I have two two here number of turns are 300, but diameter so what we can do, we can do another experiment where area are different diameter are different.

So, if you look at this three this number of turns are 300 number of turns are 300, but diameter is that this one is 41, this one is is 33 milli metre, this one is 26 milli meters ok. So, using this three induction coil, I can show the variation of induced emf with the diameter means with the area A ok. So, I will not show this experiment, but just you connects just you replace this one with the; we have to replace this one with this other one, and repeat the experiment, repeat the experiment ok.

So, then if you want to vary the number of turns, so I have here is the 26 number of turn is 75, this is also diameter 26, number of turns is 150. And this one is having number of turns is 300 diameter is 26. So, for a is same diameter mean for the same area, now you can vary the you can vary the number of turns, and see what is happening in induced emf ok.

So, so this is a very nice experiments, where you can see the variation of induced emf with current with frequency, with number of turns in the induction coil as well as with the variation with the variation of area or diameter of the coil ok. So, I think it is a good very good demonstration to understand the electromagnetic induction ok, so that is the contribution of basically Faraday. So, I will stop here.

Thank you.