Experimental Physics I
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Lecture – 53
Theory regarding the magnetic field along the axis of a circular coil

So, today I will discuss about the magnetic field in a current carrying conductor. So, if current is passes is passed through a conductor, then it produce magnetic field. So, what is the relation between the; between the magnetic field and current as well as what are the other parameters are involved in the magnitude of magnetic field and direction of the magnetic field that basically we get from the Biot-Savart law ok.

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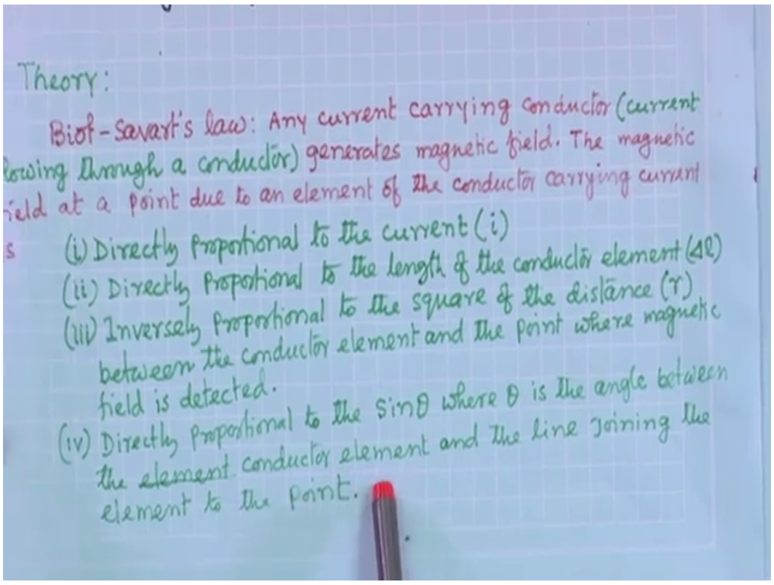

So, magnetic field in a current carrying conductor so basically Biot-Savart law. See you know that any current carrying conductors, basically current flowing through a conductor generates magnetic field. The magnitude magnetic field at a point due to an element of the conductor carrying current is directly proportional to the current, directly proportional to the length of the conductor element. Inversely proportional to the square of the distance r between the conductor element and the point where magnetic field is will be detected ok.

Also this magnetic field is directly proportional to the sin theta where theta is the angle between the conductor element and the line joining the element in to the point ok. So, this is the Biot-Savart law, so as far Biot-Savart law.

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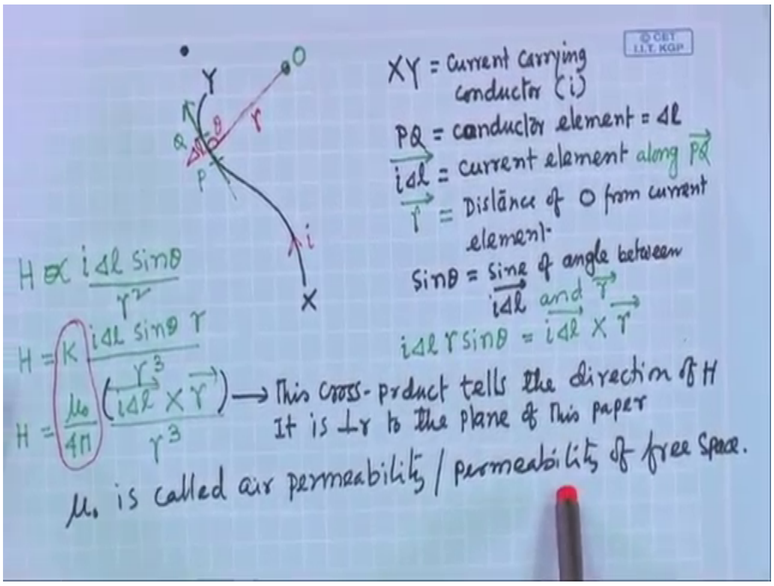

So, let me show you if you take a conductor of any form, [noise if you take a conductor of any form, say this is a X Y is a conductor; X Y is a conductor, current i is flowing through this conductor. Now, when current flows through a conductor, it generates magnetic field in its surrounding. So, what will be the magnetic field at point O that we want to find out.

So, according to Biot-Savart law this magnetic field H is proportional to the current; proportional to the current carrying conductor element, this is here P Q that this is a conductor. So, we have taken a small part of it. So, say this length is del l, so that is why we are taking element ok, small portion of this conductor. So, due to the small portion of this conductor del l, what will be the magnetic field at this at this point O.

So, this magnetic field is proportional to this length of this element, as well as is a proportional to the sin theta, where the theta is the angle between these between this element and this r; r is the basically the connecting line between this; between this O, where we want to find out the magnetic field, as well as the middle point of this of this element. So, this sin theta, theta is as I told this is the direction of the say this element and this is the direction of the point, where you want to find out the magnetic field from this from the middle point of this element. So, this is the angle theta.

And magnetic field will be proportional of the sin theta and inversely proportional to the square of the distance this r, so that is what Biot-Savart law. So, proportionality constant say K and this so H equal to we can write, here basically this proportionality constant K is mu 0 by 4 pi. So, mu 0 is called the permeability or permeanbility air permeability or permeability of the free space ok.

So, this one we can write that so we have multiplied with r and divide by r, so it is r cube and this is r basically from here I can write this. So, now i d l sin theta r. So, we can take cross product of this d l cross r. So, this so then, because this angle between d l and r, so cross product will give you sin theta. So, we can write d l i d l cross r by r cube. So, this is the factorial form of Biot-Savart law. So, this is the very important formula for finding out the magnetic field at any point surrounding the current carrying conductor ok. So, i d l cross r by r cube and this constant is mu 0 by 4 pi ok.

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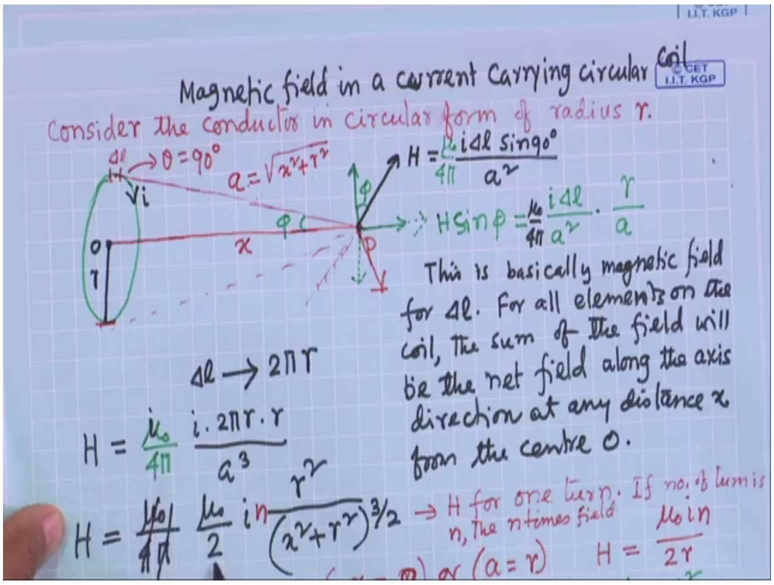

So, this now if we find out the current magnetic field in a current carrying; in a current carrying circular coil; in a current carrying circular coil ok. So, consider the conductor in circular form of radius r ok. So, this is the form of the coil, it is a circular form. Now, on the axis of this circular coil; on the axis of this circular coil, this is the center of the circular coil. And on the axis if from this point O, if distance is x at point at this point say is the point P, at this point say point P, what will be the magnetic field due to the circular this circular current carrying conductor, so that is what we want to find out.

This is the on the axis of axis also one can find out, but we are interested to find out the current magnetic field on the axis at distance x from the center of the coil ok. So, now we will use Biot-Savart law, so, Biot-Savart according to Biot-Savart law. So, let us take element of these conductors, this is the small part del l so due to this element ok.

So, what is the magnetic field here? So, middle point of the element and the point where we want to find out the magnetic field, so let us connect it. So, this will be actually earlier we in this formula we took r, but here this radius of the circular coil we have taken r; so this that is why we have taken this that a right.

Now, this is r and this is x. So, a will be so this is a perpendicular you know this x and this r is perpendicular. So, a will be this distance between the; between the; between the conductor element and the point where we want to find out the magnetic field. So, this is basically a and a will be equal to square root of x square plus r square right.

So, your magnetic field at this point will be mu 0 by 4 pi that is a proportionality constant i current is flowing this i ok, so i d l; i d l. And this angle between this; between this a and the current carrying element. So, this basically 90 degree right. So, circular coil; circular coil and then we are taking this basically it will be just perpendicular to this to this O l ok, current carrying and this conductor element. So, this angle is basically 90 degree. So, sin 90 degree divided by the distance square; distance square a square. So, from the Biot-Savart law you can find out that these are things ok.

And at and its direction is basically the perpendicular to the plane; to the plane, plane of this paper basically. In this case ok, I will not take the plane of the paper, because so it is the this direction of the magnetic field will be perpendicular to the plane, which contain the; which contain the that del l and this a ok. So, this so that means, it is perpendicular to this a, this direction of the magnetic field.

So, now it has symmetric now. So, you can take element you can take element, small element on this on this on this coil. So, there is a another element just opposite to that and in this case if you just find out the magnetic field, so magnitude will be same, direction will be just opposite to it. So, it will be this way; it will be this way ok.

So, now, you see its it will have basically two component. If this angle is phi, so this will be the phi; this will be the phi. So, H cos phi, it is perpendicular to the axis and another H sin phi, it is parallel to the axis. So, perpendicular to this axis this H cos phi and this from just opposite element, you will get these H cos phi perpendicular to this axis; they are in opposite direction, so they will cancel each other.

But yes, no it will not be in this direction, it will not be I did mistake. It will be basically, it will be this perpendicular to this it will be perpendicular to this ok. So, it will be in this direction; it will be in this direction ok, just for this element; for this element and yes its a so, H cos phi and H cos phi on for this element, so there is in opposite direction. So, they will cancel each other and both will have these horizontal component along the axis H sin phi, so that will be added.

So, ultimately you will get here this magnetic field along the axis; along the axis, so that magnetic field is H sin phi equal to H sin phi equal to i d l, whatever from here you can find out i d l by a square, so that is H and sin phi. Sin phi is basically this r by; r by; r by a, r by a, so, r by a I have written.

So, you are getting then now you have to sum up for all these small small elements. So, one can integrate also what this so? It is basically del l if you sum over this all, so that will be 2 pi r; that will be 2 pi r, circumference basically 2 pi r. So, if you add it, so that is basically del l I can replace with this 2 pi r ok. So, in integration form it is a easy to find out, but here is it has symmetry and that is why, directly you can replace del l by 2 pi r.

So, if you put this one 2 pi r and a value is square root of x square plus r square, then you are getting you are getting this right. So, x square plus r square by to the power half 3 is there, so 3 by 2 and this r r r square. So, 2 pi and 4 pi, this 2 will be there, mu 0 is there and now here i have multiplied with n. So, it is the for a one; for a one turn ok. If it has n turn, so it length will be length of this wire will be basically 2 pi r n.

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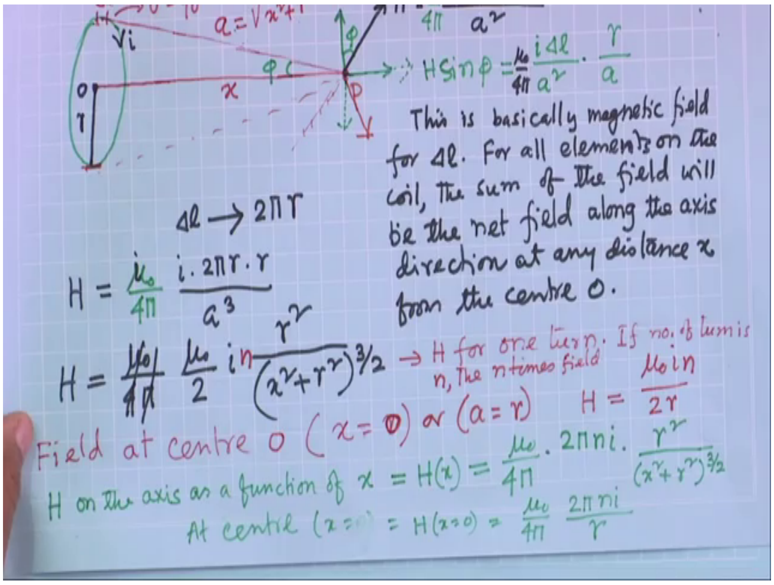

So, if number of turns is n so, we have to multiply with this number of turns n, so that is the H magnetic field at point P on the axis of the circular coil, on the axis of the circular coil at distance x. So, magnetic field is this and its direction is in the parallel to the parallel to the axis. So, this is the expression for magnetic field of a current carrying circular coil along the axis; along the axis on a particular distance x.

Now, so if x is 0 that means, the magnetic field at the centre of the coil. So, if you put x equal to 0, then or then it will be basically this a will be equal to r, a will be equal to r. So, x equal to 0 or a equal to r. So, at this condition H will be mu 0 i n by 2 r. So, this is the magnetic field at the centre of the coil, so coil have number of turns n.

So, here H on the axis as a function of x, H as a function of x on the axis. So, this expression is mu 0 by 4 pi 2 pi n i r square by x square plus r square to the power 3 by 2. And at the centre x equal to basically x equal to 0 is x equal to 0 so x equal to 0, so magnetic field is mu 0 by 4 pi 2 pi n i by r ok. So, what, so what we want to do; we want to do experiment we want to do experiment we want to do experiment using this formula as a working formula.

So, what we can study? We can study the magnetic field measuring a different distance from the centre and its how it varies according to this formula, its a varying it is a almost Gaussian form is not Gaussian, but it is similar to Gaussian ok, so that we want to; we want to we want to study as well as we can measure the magnetic field at the centre if we know the current, then one can find out the radius of the circular coil.

So, now so circular coil of n turns can be used to produce magnetic field right, to produce magnetic field. Now, to produce if you take two circular coil and placed coaxially, then one can produce uniform magnetic field between the two coils under certain condition.

If these two coils are identical and they are placed coaxially at a distance or distance between these two coil identical coil is the is equal to the radius of the of the coil, we tell then it is a Helmholtz coils and just them Helmholtz coil ok. And then between these two coil if distance r equal to the radius of the coil, then between these two coil we will we will get uniform magnetic field ok. So, theoretically you can find out that you will get the uniform magnetic field.

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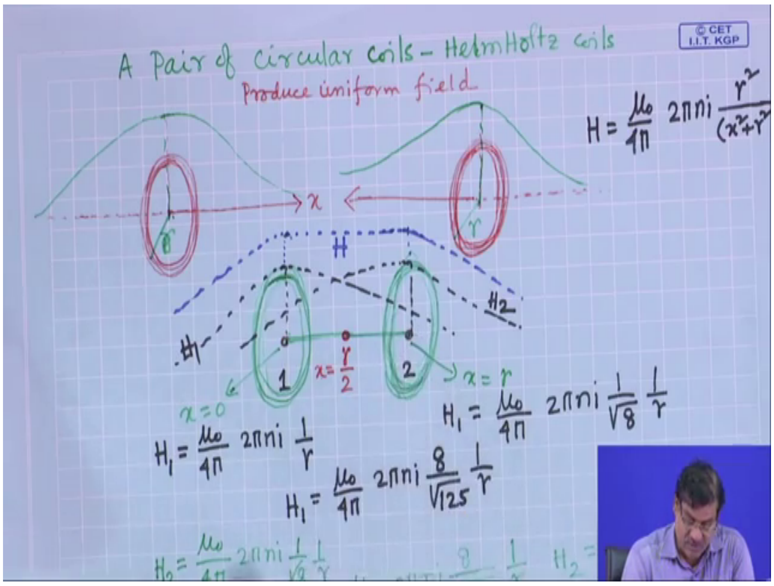

So, a pair of coils that is basically when they are identical and placed coaxially, then we tell Helmholtz coils right. So, this is the coil now magnetic field will vary like this ok. So, from the center if you go this side and say if you go other side, so it will vary symmetrically. So, here at the center this is maximum field maximum field. So, coil 1 so that what is the field you have seen that at the centre mu 0 by 4 pi 2 pi n i by r. Another coil also, it will give this field variation like this and this for this a coil 2 and this H 2, this is H 1 I have fine. So, basically this magnetic field due to this coil will vary like this ok.

Now, at the centre; at the centre x equal to 0, this is the field at distance say x equal at the x equal to r by 2 at distance, x equal to r by 2 ok; r is the radius of the coil. So, what will be the magnetic field? So, mu 0 by 4 pi 2 pi n i and from this formula if you put in this formula if you put x equal to if you put x equal to r by 2, so r by 2 means r square by 4 that means, 5 by 4, 5 by 4 r square. So, to the power 3 by 2; so you will get r cube.

And then 5 by 2 to the power 3 by 2 ok, 3 by 2. So, square root of 125 square root of 125 and 2 cube, so that is 8 basically 8 by square root of 125 1 by r ok. And at x equal to r, so this at x equal to r at distance from coil 1 for coil 1. So, what is the magnetic field at the centre this at the x equal to r by 2 this, at the distance x equal to r this.

Similarly, for coil 2 what will be the magnetic field at the centre that is exactly same, sorry at this point. So, it will be say H 2; H 2 so at this point x equal to in this case for this coil, it is the x equal to 0, I have to put so basically at this point it will be mu 0 whatever field here so the same here. For this coil 2, for this coil 2 at the middle at x equal to r by 2. So, whatever this value the same value will be for this coil 2. And at x equal to r for this coil 2, so what will be the magnetic field? So, whatever here so same field due to this coil 2, because similar same coil similar coil.

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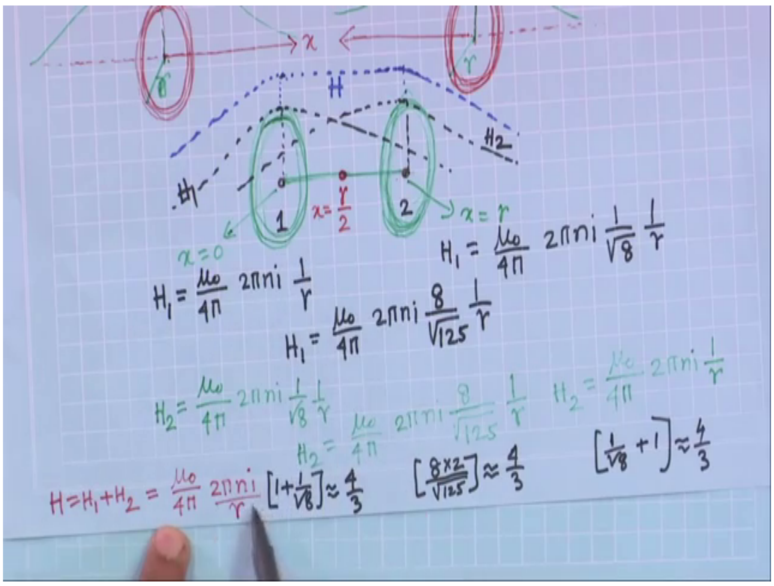

So, now for these two coils. So, here you are getting the total field for coil 1 and coil 2. So, this will be the summation of H 1 plus H 2. So, these two will give you 1 by r I have taken ok, so 1 plus 1 by root 8. So, this approximately 4 by this factor is 4 by 3 approximately. So, if we take this root 8, so root 9 if you take it is a 1 by 3, so 1 plus 1 by 3, so it is a 4 by 3 ok.

Now, at this point if you see so this will be H 1 is this and H 2 is this. So, just 2 into this one, 2 into this one this factor will be 2 into 8 by square root of 125 right. So, this is also approximately 4 by 3 and at this point so field H 1 plus H 2. So, this it will be same up of this one so this is the approximately is a 4 by 3 ok.

So, so you can see the field when these two coils are placed at distance r ok, then field between these two to centre of this coils are same are same ok. So, it is basically we will get so summation of these two. So, it is a you will get uniform field between these two. So, this is the so this from Biot-Savart law whatever we got, the expression for field using that same. So, we have find out we found that the field for circular coil.

Now, for two circular coil placed at a distance r, then this whatever field we are getting that is giving uniform field ok. So, two coils are used to produce uniform magnetic field in our laboratory. So, this experiment based on this coil circular coils is very technical, it technologically very important. So, we will do experiment in our laboratory using the circular coils. So, we want to do experiment in our laboratory the magnetic field along the axis of a circular coil coils is which is carrying current ok.

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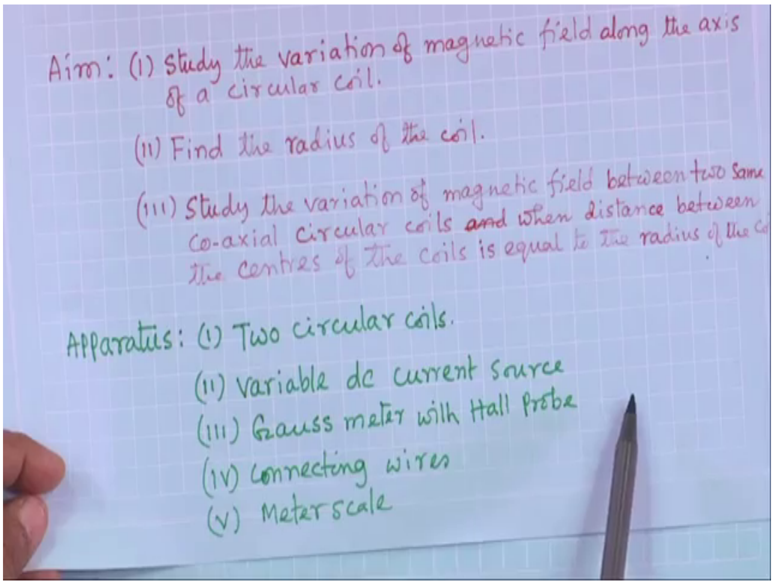

So, aim of this experiment is to study the variation of magnetic field along the axis, along the axis of a circular coil. Then find out the radius of the circular coil, then study the variation of magnetic field between two same coaxial circular coils a basically Helmholtz coils, when distance between the centers of the circular coils is equal to the radius of the coils ok, so that is what we want to study in a in an experiment.

So, for that what apparatus you need, you need two circular coils, variable DC current source, gauss meter with hall probe, then connecting wires, then we need meter scale to measure the distance. So, this is very simple apparatus we need for this experiment. And so in next class we will demonstrate this experiment in our laboratory.

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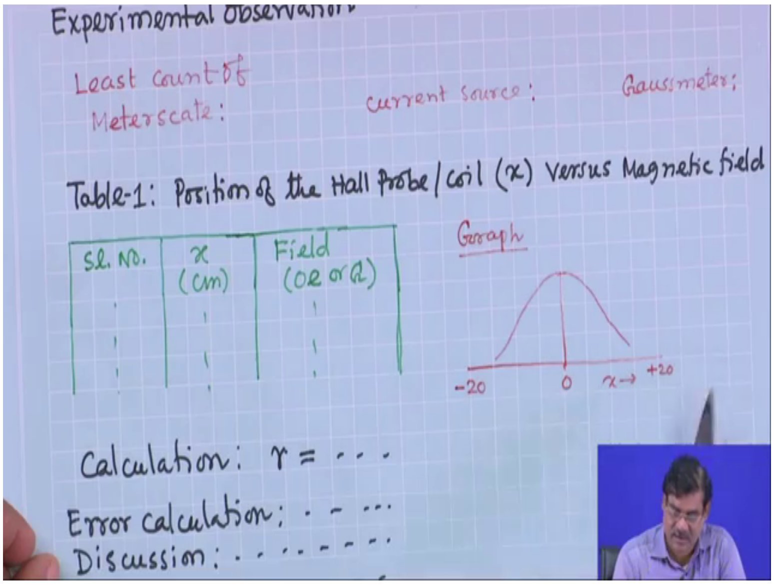

And there what we have to do we have to, so you have to note down the experimental observation. First as I always tells, you have to you have to find out the least count of your apparatus, so that is the least count of meter scale you have to write, current source for current source what is the least count, for gauss meter what is the least count that you have to noted down.

Then for this experiment just you need one table. So, basically position of the hall probe or coils versus magnetic field. So, basically you have to measure magnetic field at different distance from the coil centre, this for one coil ok. And then you have to note down, the distance x and for that what is the magnetic field at the distance you have to put the hall probe ok. Hall probe is connected to the gauss meter, so gauss meter will give the reading of magnetic field. So, you have to just note down at different distance what is the reading of the gauss meter?

And then you have to plot the graph, if you plot the graph so you have to take basically symmetrically, so from the centre left side as well as right side you have to take for different distance. And at different distance what is the magnetic field that you have to plot and if you plot, then you will see the magnetic field variation is like this ok; so that is what you have to find out.

And then you can, so now at the centre what is the value you can find out and from there you can calculate radius of the coil r ok. And now if you place two coils ok and then just you keep the distance between these two at a particular at equal to the radius of the curvature, sorry radius of the coils. And then you just put place the your hall probe of different positions between these two coils and you will see the magnetic field are same, gauss meter will give you the same reading that just you note down with for different distance and then you tell that you are getting uniform field ok.

So, and of course you have to; you have to; you have to find out the error, so error calculation you have to perform. Then you have to discuss about the experiment and what are the precaution that is you have to look down ok. So, in next class we will demonstrate this experiment in our laboratory ok. So, apart from that we will demonstrate other two experiment, one is the current this force between two long current carrying conductor ok. What is the so this basically, Lorentz force between two current carrying conductor.

And using this we will find out the permeability of air, air permeability one can find out. Performing the experiment between two straight current carrying conductor ok, so that experiment also we will demonstrate as well as we will demonstrate the inductance, when instead of AC current DC current, if you just pass AC current in a coil. So, then and if you put another coil near to it, then this in second coil the magnetic flux will change with time because of this AC current means AC magnetic field in the coil one.

So, then when variation of magnetic field or variation of flux in a coil or in the second coil, then inductance self inductance if just for a particular one coils ok and mutual inductance that is on the second coil due to the; due to the variation of magnetic field in the first coil. So, this mutual inductance basically that experiment also we will demonstrate in the laboratory in the successive classes ok. So, this is a very important experiment in the sense that in laboratory for electromagnet, we use this principle to produce magnetic field ok.

So, this is the; this is the experiment which will demonstrate how to produce magnetic field in the laboratory, so that is what we are going to perform in next class in our laboratory.

So, thank you for your kind attention.