Electromagnetism
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Lecture – 68
Tutorial on magnetic fields

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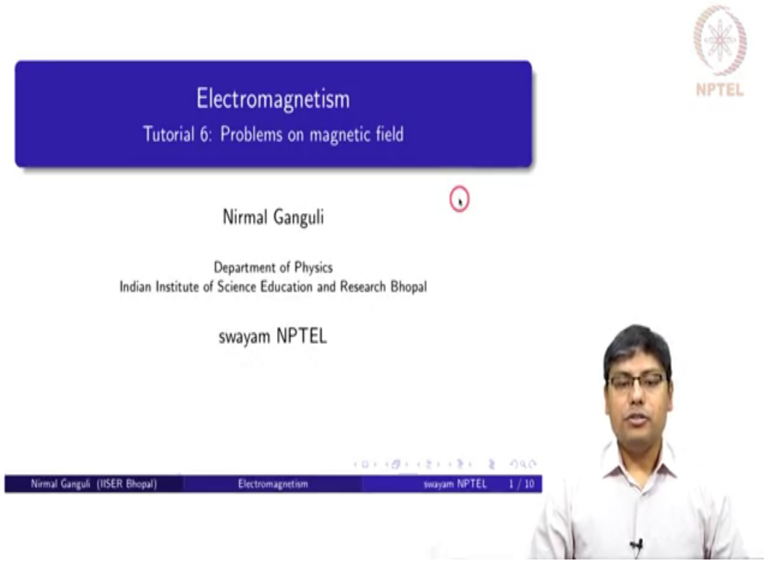

Hello, now we are going to discuss tutorial 6 and in this tutorial we are going to solve some problems related to magnetic fields.

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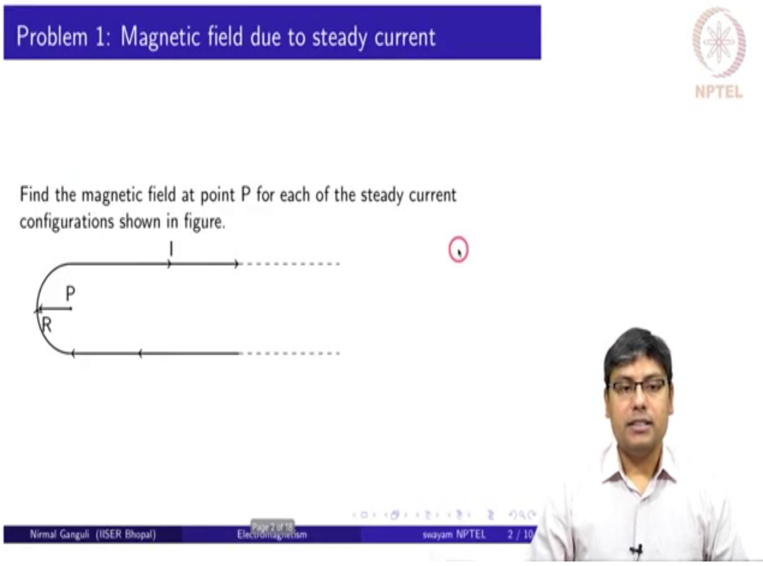

So, let us look at the first problem. Here, you are asked to find the magnetic field at point P. Here this point for each of the steady current configurations shown in the figure. So, we have one straight line here, extended to infinity from which a current is flowing in this direction and the magnitude of the current is I, the same current is flowing through this semicircular loop and its coming to another straight where of infinite extent here.

And the amount of magnitude of the current is always I. And you are supposed to find the magnetic field at the center of the semicircle of radius capital R. So, what are the steps that you are going to follow in order to solve this problem?

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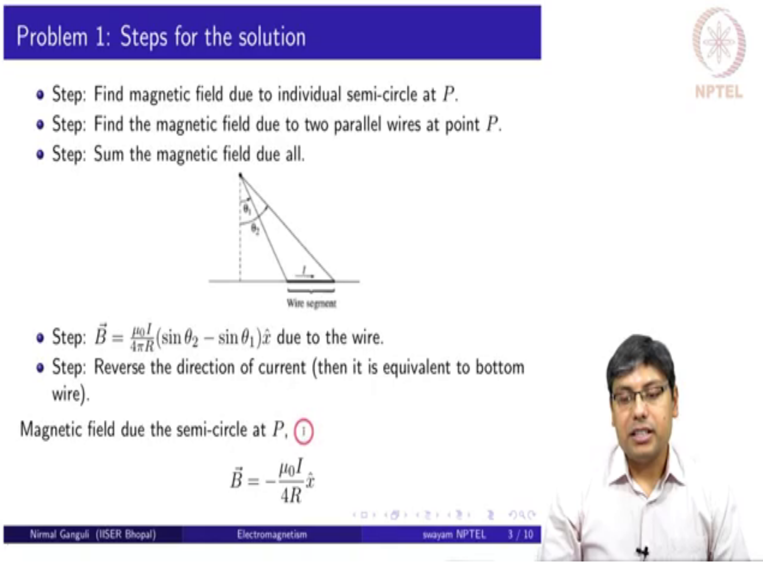

Let us look at the steps, in the first step, you are supposed to find the magnetic field due to the due to the semicircle at P, that is the center of the semicircle. Then, find the magnetic field due to the parallel wires at point P. And then sum all the magnetic fields, then you will find the total magnetic field.

So, how do we find the magnetic field due to the straight wire segments? We have worked out in one of the lectures how we can find the magnetic field due to straight wire segments. Using this kind of a consideration, here we have a wire segment and current I is flowing through this, we have expressed our result in terms of theta 1, this angle and theta 2, this angle here.

And the result was magnetic field was mu naught I over 4 pi capital R sin theta 2 minus sin theta 1 and it would be along the x cap direction. What is x cap direction? Its I cross R caps.

So, you will have I along the direction of the wire, current direction and R cap is the distance from the wire to the point of observation. So, in this case this direction would be outside the screen.

But, if we look at this case we will see that for the circular part, semicircular part, I cross R cap that will point into the screen also from the parallel straight current segments, I cross R cap will always point into the screen. So, if in this case its x direction, the direction of magnetic field for our problem would be minus x.

So, you can stop the you can pause the video at this stage and try to solve the problem yourself. And later on, you can restart the video to find any hint that you need ok. Here is the solution to the problem, the magnetic field due to semicircle at the point of observation P, that can be given as the magnetic field equals minus mu naught I over 4 R x cap. So, its along minus x cap direction and its the usual expression for the magnetic field for a semicircular loop.

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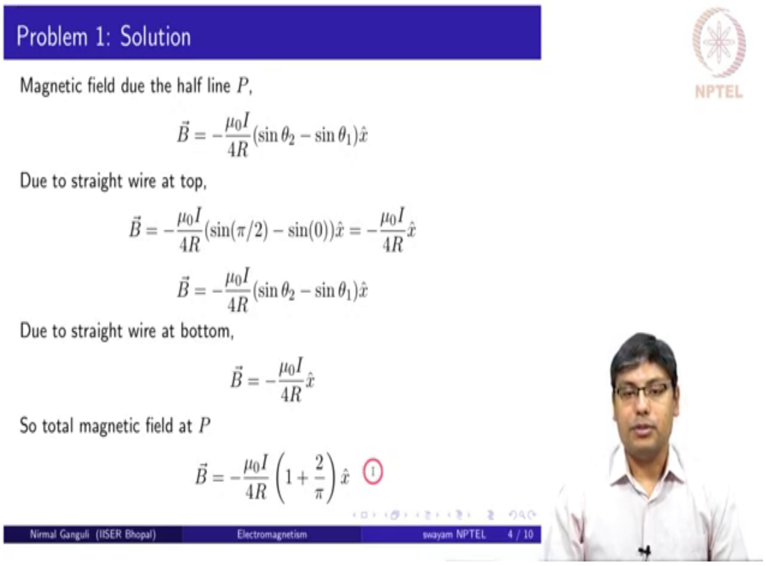

The magnetic field due to the half line P, the expression can be given as minus x cap mu naught I over 4 T sin theta 2 minus sin theta 1. And you are supposed to find where put the appropriate values of theta 2 and theta 1. For the top wire, it would be theta 2 would be pi by 2 and theta 1 would be 0 for the wire extending to infinity, for the bottom wire it would be the other way around and you will have the magnetic field B equals minus mu naught I over 4 R x cap. So, if you add everything, adding all contributions, the magnetic field would be minus mu naught I over 4 R 1 plus 2 over pi x cap. So, this is the solution to the first problem.

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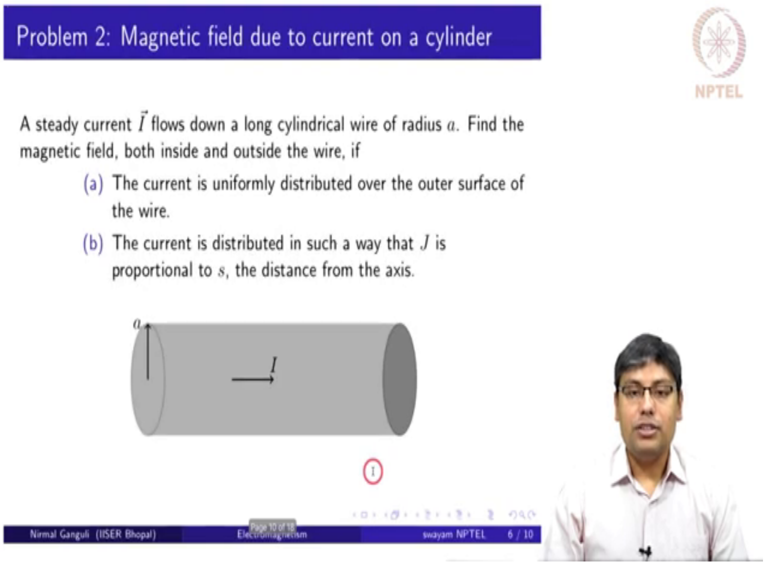

Now, let us move on to the second problem. In the second problem, we discussed the magnetic field due to a current on a cylinder. So here, there are two parts of the problem. In this problem, we are going to find the magnetic field due to a steady current I that flows down a long cylindrical wire. So, this cylindrical wire is very long and the radius of the cylinder is small a.

You are supposed to find the magnetic field both inside and outside the wire for the following conditions: condition a the current is uniformly distributed over the outer surface of the wire. There is no current inside the cylinder only outer surface, that is a surface current is flowing through the outer surface of the cylinder.

And for condition b, for case b the current is distributed in such a way that there is a volume current density J that is proportional to the distance of your point of observation from the axis. that is the distance is given as s the usual s coordinate in cylindrical coordinate systems the distance from the axis of the cylinder and J is proportional to this distance.

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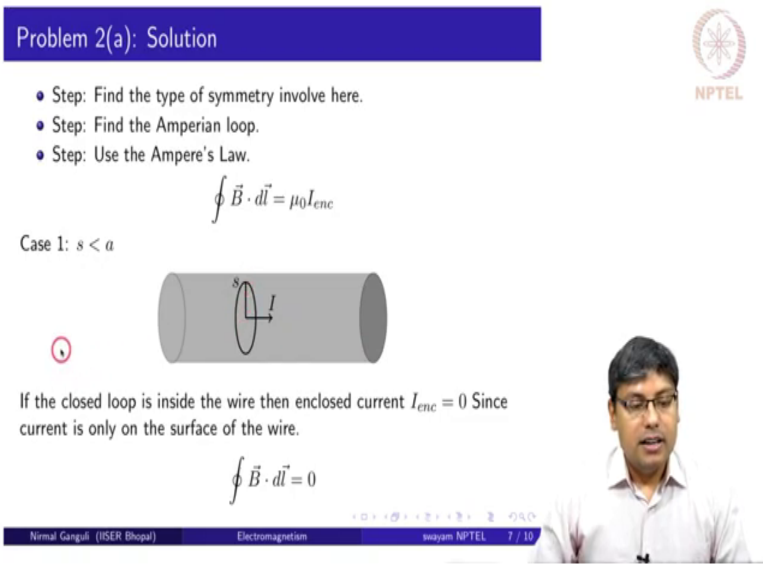

So, these are the steps that you should follow in order to solve this problem, in the first step, you should consider the symmetry involved in the problem. It is a cylindrical symmetry we can clearly see, and find an appropriate Amperian loop to be able to apply Ampere's law and then use Ampere's law in its integral form, that is close to integral over B dot dl that is mu naught times the current enclosed. At this stage you can pause the video, try solving the problem yourself and then come back to play the video and see the solution, ok.

Now, we solve the problem. For the first case, we have s less than a. That is our Amperian loop is within the cylinder, its not outside. Our point of observation is anywhere on the Amperian loop and the loop is within the cylinder. The current I is flowing in this direction and s is this much distance and in the first case, we only have a surface current. So, the loop inside the wire that does not enclose any current. The current enclosed is 0. Therefore, the cyclic integral the closed integral over B dot dl that also is 0.

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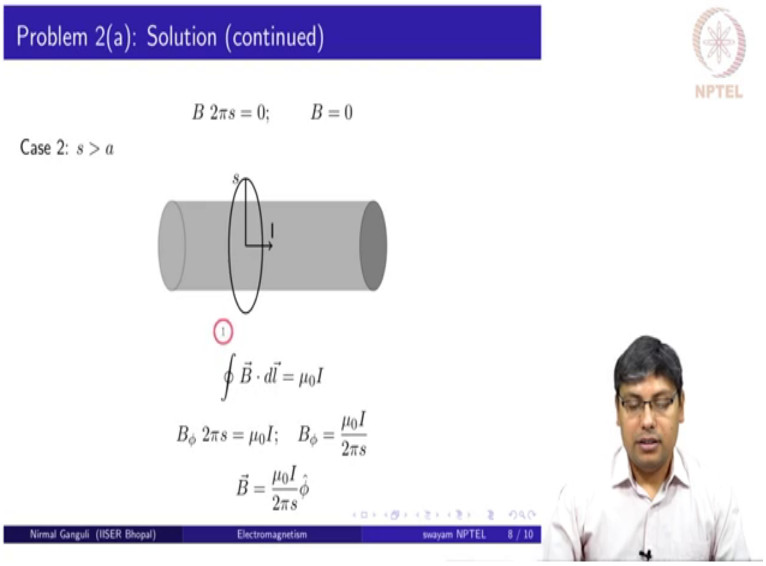

Which means B times 2 pi s, that is the length of the Amperian loop. This quantity becomes 0, which means the magnetic field inside the cylinder is also 0. And for case 2, we have s greater than a. When s is greater than a, we have Amperian loop outside the cylinder of course, coaxial to the cylinder, but outside. In this kind of a situation, we can write a closed integral over B dot dl is mu naught times I because the entire current is now enclosed by this Amperian loop.

Now once we have that, the phi component of the magnetic field we can evaluate from this because the Amperian loop moves along the phi direction. So, b phi component of the magnetic field times 2 pi s that is the circumference of this Amperain loop, that is mu naught times the current. So, B phi is mu naught I over 2 pi s and we can argue from symmetry that the magnetic field will only have phi component, no other component will survive.

In that kind of a situation, the magnetic fields expression in its vector form can be written as mu naught times I over 2 pi s along the 5 cap direction.

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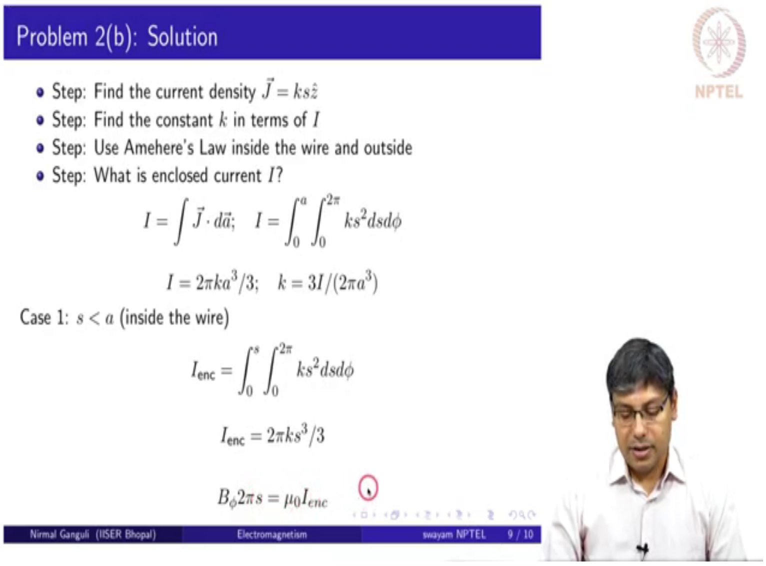

Now if we see the other case, that is in part B, where the current density was proportional to s that is the distance from the axis. So, we can write the current density as k times, k is the constant times s and that is along the z cap direction. And, if we have this kind of current density then the step the steps that you are supposed to follow is to find the constant k in terms of I, because I is given and k is something you have assumed. And then use the

Ampere's law inside the wire and outside and then, evaluate exactly how much current is enclosed and accordingly find the magnetic field.

You can pause the video at this stage. Later on, you can revisit the video after attempting to solve the problem. So here is the solution, the current is given as J dot integration over J dot d a because J is the volume current density. So, the current I is in this case, integration over the radius and the phi k s squared d s d phi. So, I can be given as 2 pi k a cubed over 3. That means, k the constant unknown constant in terms of the current can be expressed as 3 times I over 2 pi a cubed.

Now let us consider case 1, where our point of observation is inside the wire, s is less than a, there the current enclosed can be given as integration over k s squared d s d phi s ranges from 0 to s and phi ranges from 0 to 2 pi. Therefore, the current enclosed would be 2 pi times k s cubed over 3. The phi component of the magnetic field times 2 pi s is mu naught times I enclosed the current enclosed.

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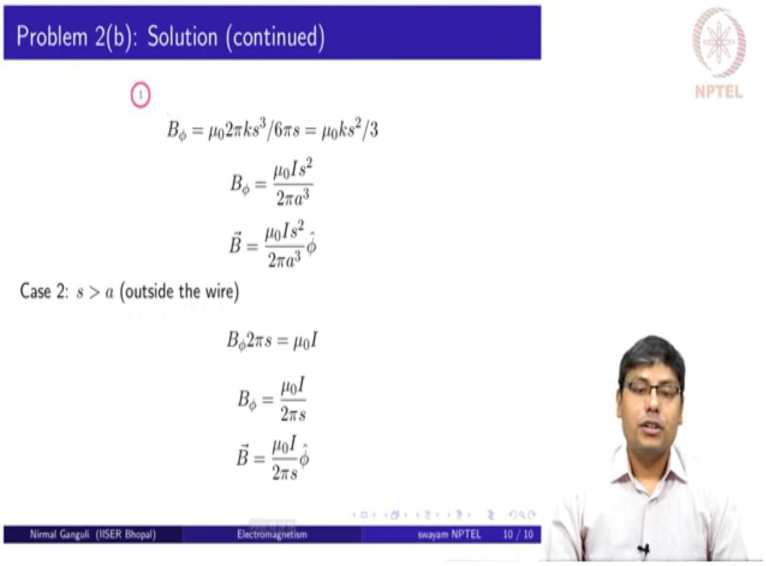

So, the phi component of the magnetic field can be evaluated accordingly as mu naught k s squared over 3 and that is the only component of the magnetic field. Now, if we put the value of k and write everything in its full vector of vector form, we can write B vector as mu naught I s squared over 2 pi a cubed along phi cap direction. How about outside the wire? Outside the wire s is greater than a.

So, the phi component of the magnetic field times 2 pi s for a similar kind of Amperian loop will give us mu naught times the entire current I because, everything every current is enclosed within that loop. So, B phi can be given as mu naught times I over 2 pi s and in its vector form, B can be expressed as mu naught times I over 2 pi s along the phi cap direction. So, that is all in this tutorial.