Basic Electrical Circuits
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Lecture - 1
Introduction to the course; Current and Voltage; Kirchhoff's Current and Voltage laws

So, we believe, that finally, that you are able to see me and hear me. This course is entitled basic electrical circuits. Welcome to the course. I am Nagendra Krishnapura from the department of electrical engineering at IIT Madras. What we will do in this course is to learn about ways of analyzing circuits, ok.

So, it is not about any particular circuit or any particular gadget, but a general technique or general techniques for analyzing any circuits if you can expand to any new circuit that you may come across. As I mentioned earlier, please feel free to interrupt the lecture by raising your hand and I will also try to be systematic and give you time, let us say every few minutes, every 10 minutes or so so that we ((Refer Time: 00:59)) the doubts clear.

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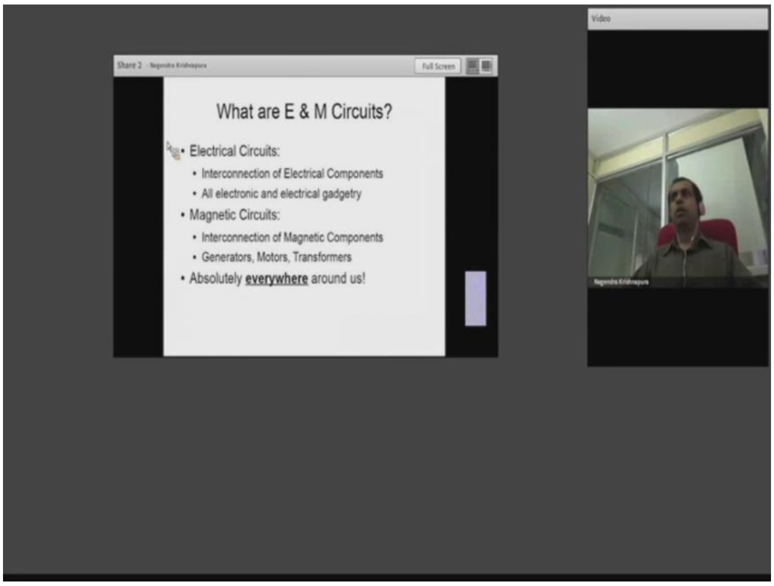

Here is a presentation that sort of outlines what we will be seeing in this course. In fact, it turns out, that in this semester I am also teaching a course at IIT Madras, entitled Electrical and Magnetic Circuits. What I will be talking about on this online course will be only the electrical circuits, part of it.

Now, what are electrical circuits? Electrical circuits are interconnections of electrical components and basically, the every electronic or electrical gadget, that you see, forms an electrical circuit and magnetic circuits, that is the point of information are interconnections of magnetic components. And I think all of you would be coming here with transformers and motors, they form magnetic circuits.

In this online course, our focus will be on electrical circuits and they are absolutely everywhere around us. You will be able to see electrical circuits, you are probably using so many electrical circuits in your day to day life.

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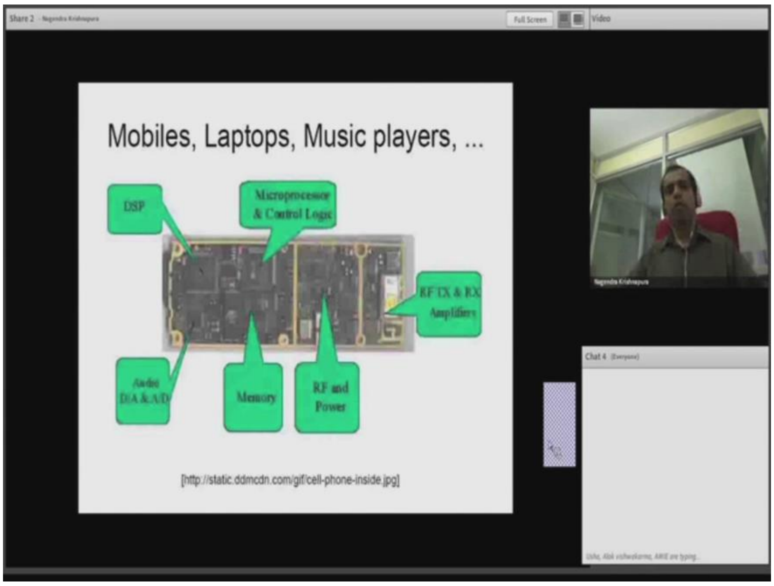

So, just as an example, the laptop onwards I am making this presentation, your mobile phone, music player, the headphones, that I am wearing, all of these things form electrical circuits. In this picture, you can see an example of mobile phone, which is opened up and it has a number of complicated circuits inside. You build up the circuits hierarchically from simple elements to more complex circuits and they are put together to make the bigger circuit and so on. So, finally, you end up with a very large circuit.

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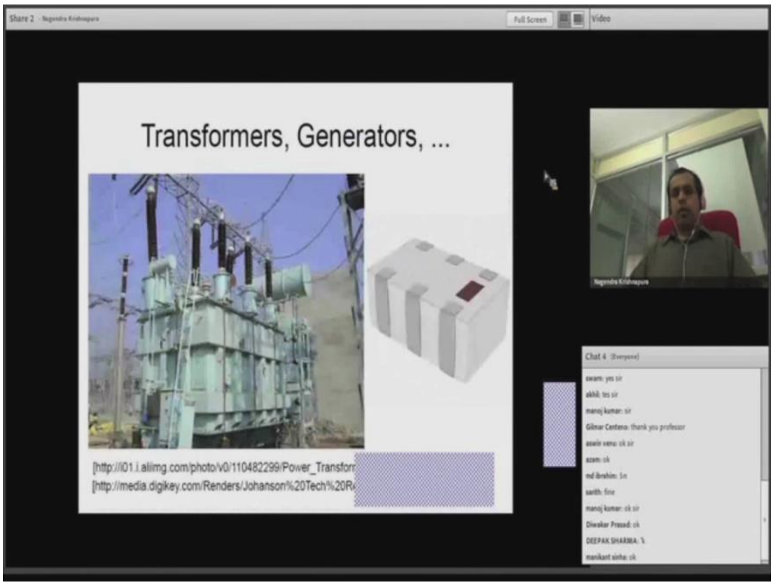

As I was saying, a mobile phone is a circuit as is your music player and so on. And here, I have shown a very large, physically very large circuit on the left side. It is a transformer, that is used to bring power to your homes and that is also a circuit. And on the right side is another transformer. The one on the left side is probably as big or even bigger than this room in which I am sitting and one on the right side is a couple of millimeters, they are both transformers, ok.

The main point I want to drive home is, that circuit themselves come in all shapes and sizes, but there are some methods of analysis, that are applicable to all circuits and that is what we will be discussing in this course.

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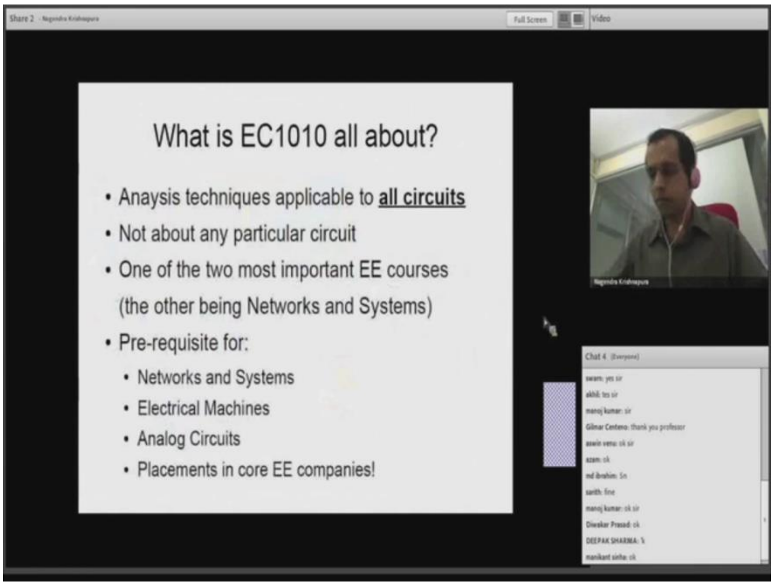

So, as I said, this course is about analysis techniques applicable to all circuit and it is not about any particular circuit. And in terms of that if you look at electrical engineering curriculum in any university, this turns out to be one of the most important courses, ok, mainly because it lays foundation for number of courses, that you will encounter during your electrical engineering curriculum such as, networks and systems, where you will analyze circuit using more advanced technique, such as Laplace transforms.

And some of you may have gone to do courses in analog circuits. The things that you learn in this course, the methods of circuit analysis are absolutely essential for that course. And also, some of you may be studying in detail electrical machines. Again, the detail, the analysis method learnt in this course will be useful for that and in terms of that also if you want to get a job in electrical engineering and a lot of electrical engineering companies, the interviews will start with some basic electrical circuit questions, ok. So, it is by and large a very useful course for your further studies as well as your career and so on.

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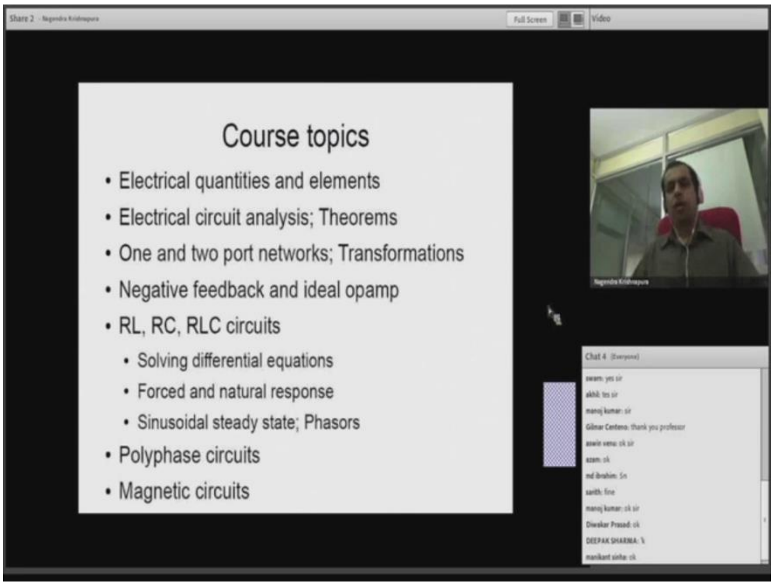

Now, what are the topics that we will go through? First, we will have a discussion on electrical quantities and elements. Some of you would be already familiar with this. I think all of you will have some notion of what voltage is, what the current is, what a resistor is and so on. And also, you would have studied both in High School and later, some basics of electrostatics and electromagnetics, ok.

And the things, that we deal with voltages and currents are related to what we study in electromagnetics, such as fields and charges, but we will not deal with, we will not go down to the level of fields and charges, but we will stay with voltages and currents. So, in the initial start of this course, I will also tell you how these things are related to each other.

Then, after we discussed electrical quantities and elements, we will see, how to analyze circuits. Again, at some level, for very simple circuits you would be familiar with this, but we will see how to scale it up for large circuits, which will be arbitrary large, ok. Now, in terms of that there are also certain theorems, certain general theorems about circuits, which are very useful in analyzing circuits, in representing circuits and so on. We will discuss those things.

Then, we will talk about what are known as one and two port networks. It will be very clear what I mean later, ok. One port means, you have one set of terminals where you can apply a voltage of applied current. Two ports means, there are two such pairs of terminals where you can do the same and so on, ok. And there are ways of transforming between multiple ways of representing these circuits. We will also study those things.

And overall, the other interesting things, that we will study is the opamp, not in great detail, but as an ideal opamp. It forms a basic electrical network and from that you can make a number of the interesting circuits. In fact, some of you who may have had building circuits as a hobby would have already done this, would have already used opamps. What we will do in this course is to lay a proper foundation for that. And then if you want to design new opamp circuits, how to go about doing that and how to analyze complicated opamp circuits, those things we will deal with.

Now, in terms of that, essentially, circuit analysis consists of, you will look at the circuit. Based on the circuit you come up with the number of equations and then you solve the equations. Now, if you, if your circuit has only resistors, then you will end up with the set of algebraic equations and you have to solve that. I think you already know how to do that.

In terms of that you can also make interesting circuits when you have capacitors and inductors. In those cases, you will end up with what are known as differential equations and some of them may know how to solve it. What we will do is go through the treatment of differential equations. The particular kind of differential equations, that is, constant, co-efficient, linear differential equations that we will use in this course, we will deal with that in some detail, so that you are familiar with the kind of solutions that can be present, ok.

Now, finally we will look at qualifier circuits. At least, some of you will be familiar with the three phase power transmission and all. So, we look at some of those things and see why those things are important and see how to analyze those circuits. Now, in this online version of the course we will not be dealing with magnetic circuits, but you can look at other resources to get some knowledge about those things.

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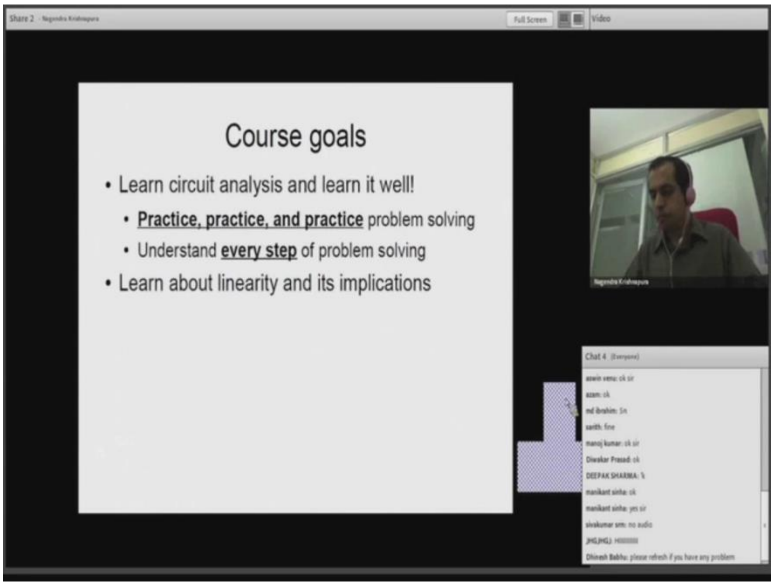

Now, as far as the goals of this course are concerned, it is very simple. We learn circuit analysis and learn how to do it well. And the way to do it well is to practice, practice and practice problem solving. Now, you practice problem solving for many different reasons. Sometimes you do it for competitive exams where you solve the same kind of problem many times. So, the next time the same type of problem comes up, you are not to think about it.

Now, here it is a little different. The reason for practicing solving a lot of problems is to be confident enough of solving any other problem. It maybe of the same type, it maybe of slightly modified type or even a completely different type. Any problem, that you have to solve, you have to be able to approach it with confidence and then solve it. So, that is why, you have to solve the number of different types of problems. And also, more importantly, when you solve any problem you have to understand every step of problem solving. It is not a depth of speed, but you have to know why you are doing what you are doing. So, whenever you solve any problem, please make it a habit to understand every step and then move on to the next step.

And a sort of secondary goal is to learn about linearity. What I mean by this will become clear, but a large number of circuit that we will analyze will turns out to be linear. What it means is, that you apply certain stimulus, you will get some response. You apply another stimulus, you get different response. And you combine the two stimuli, the response turns out to be the combination of the original responses.

Now, this simplified analysis is a great deal. It turns out, that you do not have to analyze the same circuit many times. You analyze it for one set of inputs, you will know the answer for many other sets of inputs. In fact, any other set of inputs. So, you have to become comfortable with this or implication of linearity, how to recognize linearity and exploit it while analyzing circuits.

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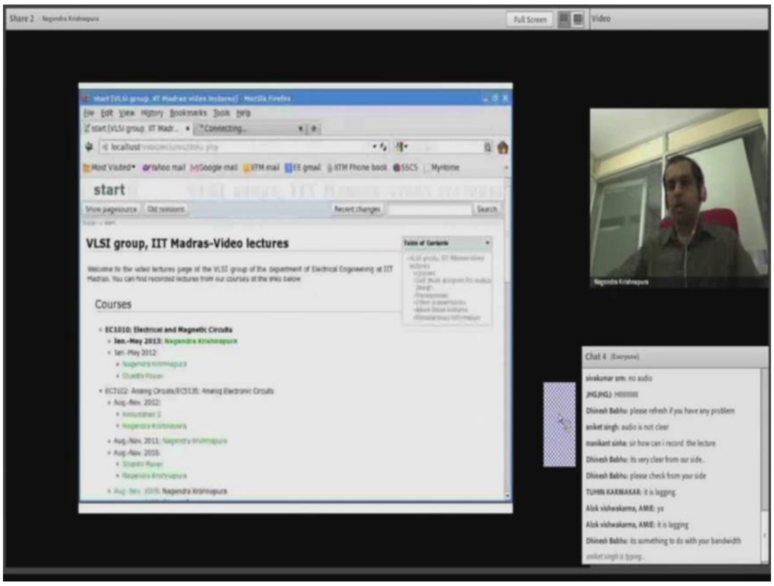

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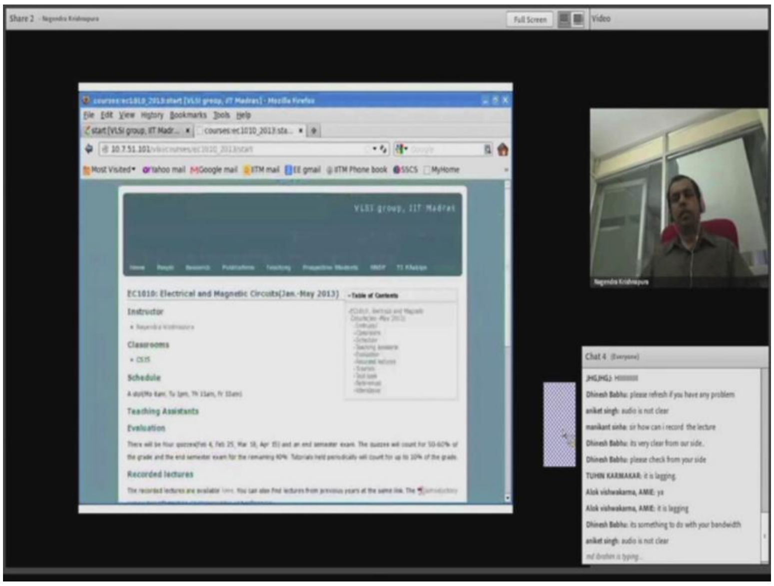

Now, we have some resources, that we can use, also called as, I think already mentioned to you, these lectures, these online sessions will be recorded and they will be made available to you. In addition to that you can make note of a URL that I will give you. Within our group we record our lectures and you can view those lectures and one of the resources that we have taught is this electrical and magnetic circuits. It has some overlap with the course that I am teaching now, but ((Refer Time: 11:09)) quick updates. So, you can view those lectures.

Those, of course, are familiar with NPTEL that is how we came to this course. So, NPTEL source are also very useful on specific topics. And the VLSI group homepage at IIT Madras, this is also something that we can use to further your knowledge of circuits. So, the entire diagram, perhaps we can get started.

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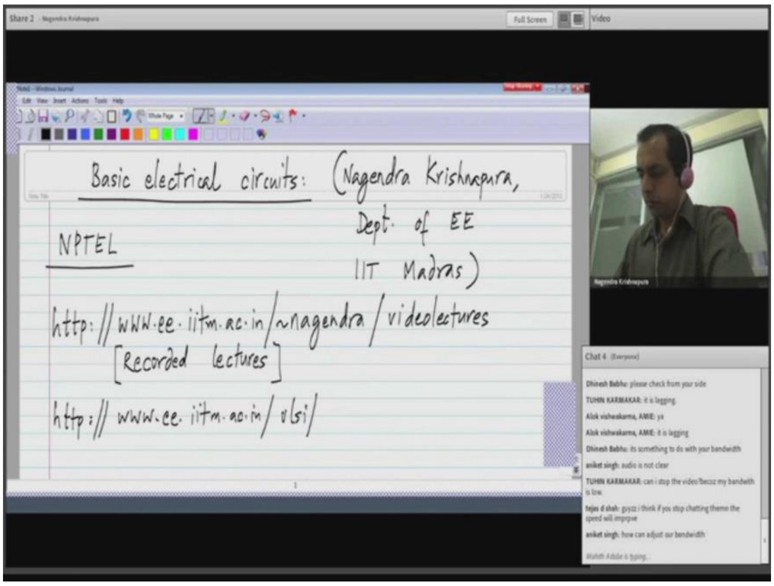

I am going to save the journal now. This, I mentioned some resources. I am going to write the URLs here. This has recoded lectures on various circuit related courses and you can also see. And finally, of course, all of you know that NPTEL.

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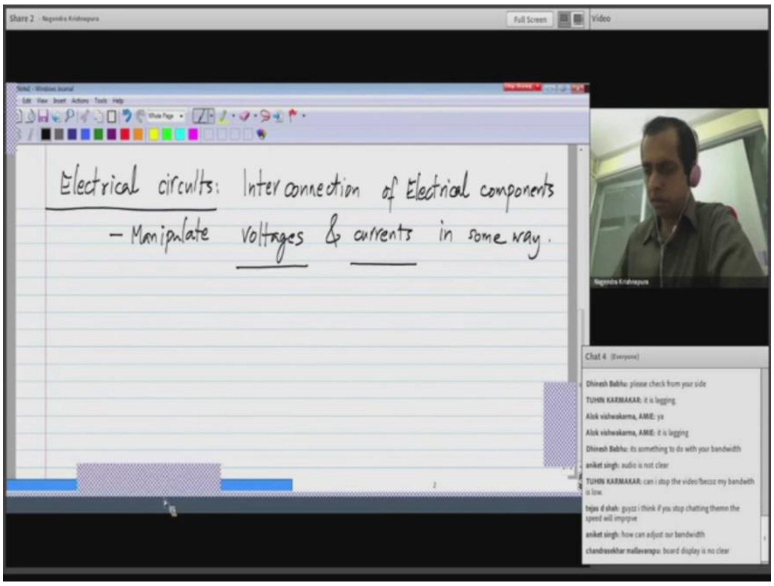

So, with that background we can get started with our course, electrical circuits or interconnections of electrical components and the manipulate voltages and currents in some way.

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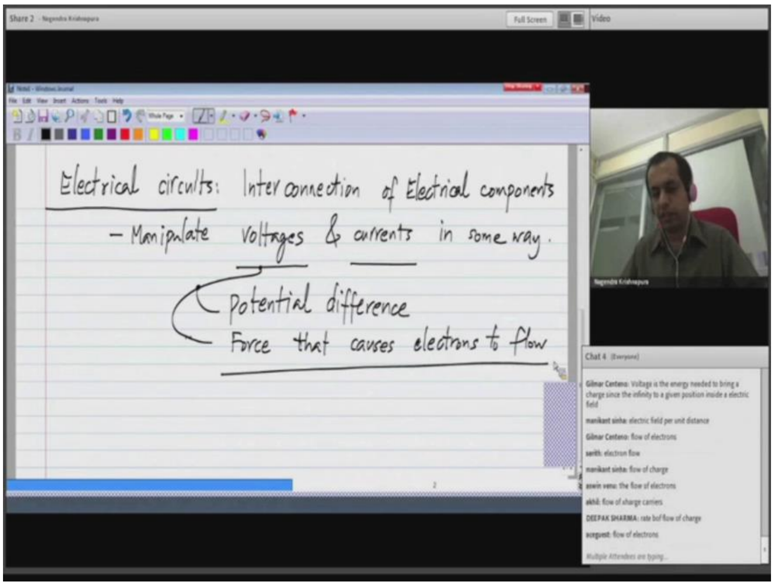

Now, I think all of you have heard of voltages and currents. I would like some responses from the participants what is a voltage or else, you can type it into the chat window. I have got a number of responses here, got a number of responses, and basically they kind of fall into two classes. There, you say that either the voltage is a potential difference or is related to some force, that causes current or that causes electrons to flow, ok.

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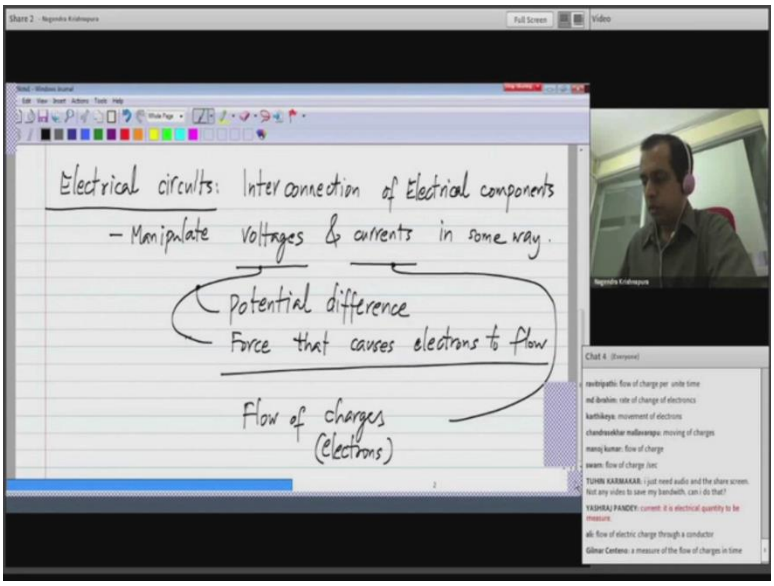

Now, both of these are of course, quite correct, and I will elaborate on these things. And similarly, I would like some responses on what is a current what is an electrical current. Again, now got a number of responses, which say, that current is basically flow of charges and some of you say electrons, which is quite correct, of course. And some of you have also said, that it is the rate of change of charges of, rate of flow of charges and these things is quite correct.

And in the definition for voltage, some of you also related it to the electric field, which is quite correct as well. Now, I think all of you know that all of you have at least heard of Maxwell's equations, which relates electric field and magnetic fields and charges. So, you have charges that can create electric fields and charges can move under the influence of electric field. They can move under the influence of the magnetic field and so on, ok.

Now, of course, those are the basic equations, which govern everything in electromagnetics including our circuits. As we also recall from electromagnetics, usually it is quite difficult to solve the problems, usually end ((Refer Time: 18:43)) lot of mathematics, but in ((Refer Time: 18:46)) are a lot simpler. There is an, I will explain properly, we are also dealing with electrical fields and magnetic fields and the flow of charges under the influence of either the electric field or the magnetic field, but there are some conditions that make our life a lot simpler. We can do things lot more easily and our primary variables will be voltages and currents and these will be related to the fields. But what we usually deal with are not the electric fields or the magnetic fields, but voltages and currents, ok.

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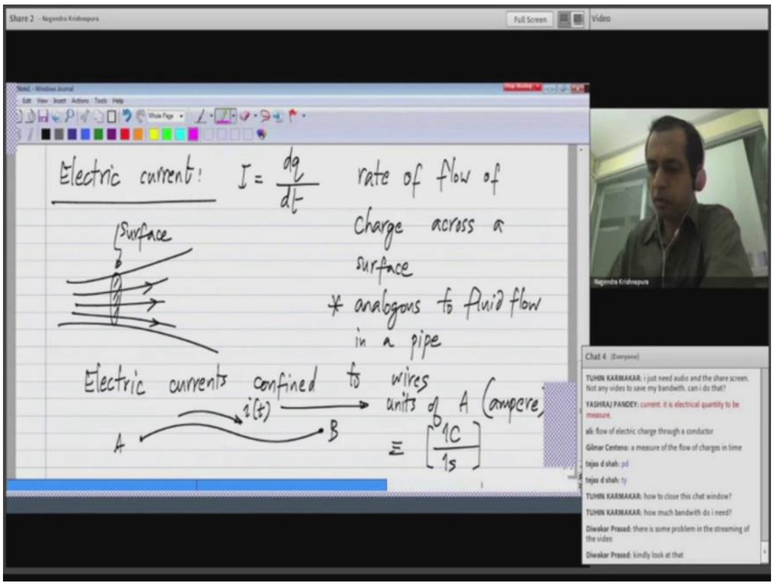

Now, first let me take an electric current, an electric current will be denoted by I, is the rate of flow of charge across some surface. So, if you could have some surface and showing some pipe like thing and you could have charges flowing this way and the rate of change of charge across the surface is the electric current through that surface, ok.

And a couple of things, I think all of you know, that it is electrons that do the flowing. It is the electrons, that flow and electrons are negative charge. So, what we are looking at, what is defined as the electric current as the flow of positive charges, it is really the negative of the flow electrons.

Now, as far as we are concerned, it is perfectly alright to think of positive charges of flowing, although it is electrons that is flowing. And the direction of flow of positive charges will be exactly opposite to the direction of flow of electrons, which are really the things that are flowing. It is ok for all purposes to think of currents as the rate of flow of positive charges through some surface.

And also, generally a very useful analysis for electric current is fluid flow. So, instead of charges that are flowing, you can think of fluids that are flowing in pipes and so on. And for a number of cases, which involves general rules about currents the fluid flow analogy works quite well.

Now, in our particular case, we will not be looking at charges flowing in arbitrary surfaces. We will be looking at currents, that are confined to a wire and a wire is a very good conductor. In fact, we will think of them as ideal conductors, which offer no resistance at all to the flow of current. So, we will be looking at currents that are confined to wires, which is one of the aspects that make our analysis quite simple. As we have charged this in field somewhere, it is not very easy to calculate the effect of field on charges, exactly how they move and so on. But we will be looking only at electric currents in a wire or through elements. So, our job is ((Refer Time: 22:18)), ok.

So, you may have some wire like that and it could have a current flowing from A to B. Now, as I said, many times this really consists of electrons flowing from B to A, but we can think of it as positive charges flowing from A to B if the current is in this direction. And we also do not worry about exactly how the charges are distributed across the surface of the wire. We will be only concerned with the total current flowing through the wire, ok.

And I think many of you know this already, the electric current has units of Ampere and this corresponds to starting a charge of 1 coulomb in 1 second. So, if 1 coulomb of positive charge flows from A to B in 1 second that constitutes a current of 1 Ampere from A to B.

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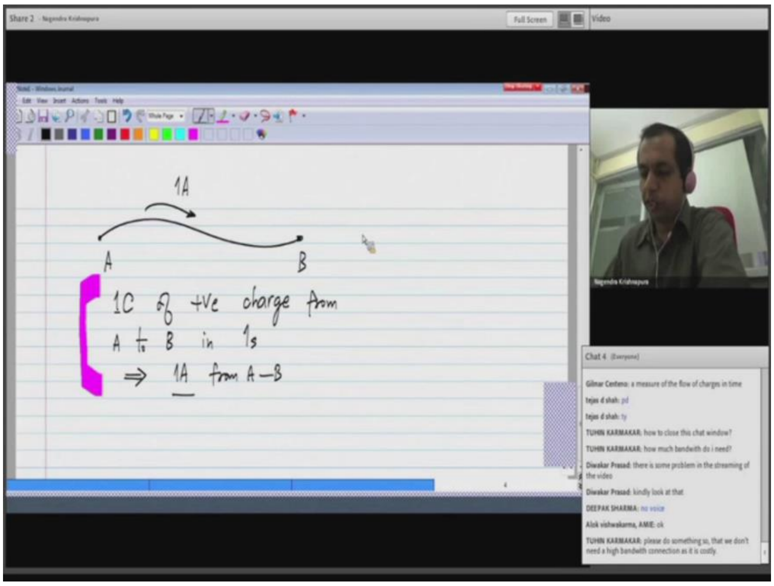

So, here I have shown a wire from A to B and I draw an arrow from A towards B. And I have marked 1 ampere and that is what this means, 1 coulomb of positive charge going this way. Now, I could also show the exact same situation. This is what the chat…

So, I believe, things were interrupted for a little while. What I was saying was, that a current of 1 Ampere means, that a charge of 1 Coulomb is carried over a duration of, I means, charge of 1 Coulomb is carried in 1 second.

Now, when I have a wire from A to B, as I have shown here, and mark an arrow from A towards B and write 1 ampere, that means, that a positive charge of 1 Coulomb has gone from A to B in 1 second. Now, the exact same situation can be depicted by having a wire with an arrow drawn from B towards A and put minus 1 ampere marked on it, ok.

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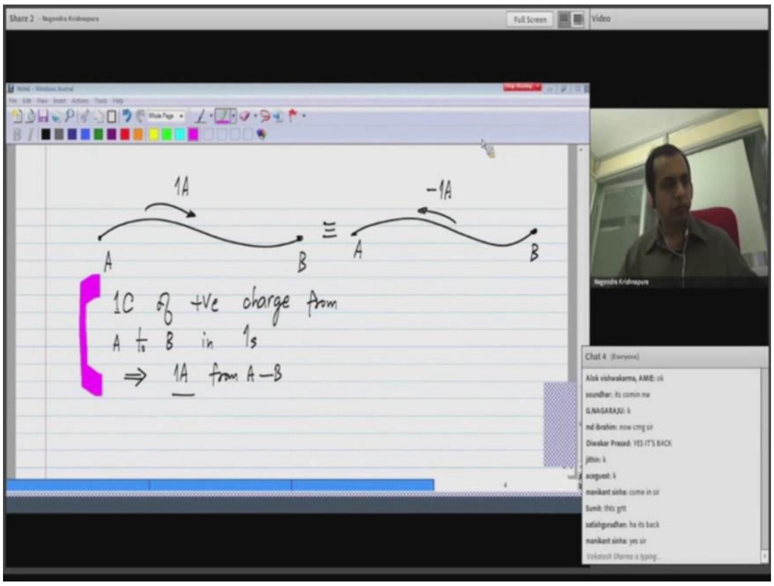

So, this is something that you have to get comfortable with. You can depict the current the same current as also 1 ampere going from this side to that side, or negative 1 Ampere going from that side to this side. Now, the reason, this is important, this looks rather trivial. The reason this is important is that when you solve the circuits, when you start solving the circuit, you do not know, which were the currents are, ok. We will assign some variable I and mark the direction of the currents and I could come out either positive or negative.

And in later cases we will see, that it could be even time living. For you to interpret these results correctly, you should become very familiar with the convention. What I want to emphasize is, that just because I have drawn a, drawn an arrow from B to A, does not mean, that current is actually flowing in that direction. It could change the negative of that also. Now, the value should become, by the value should come out either positive or negative, ok. So, that is about currents.

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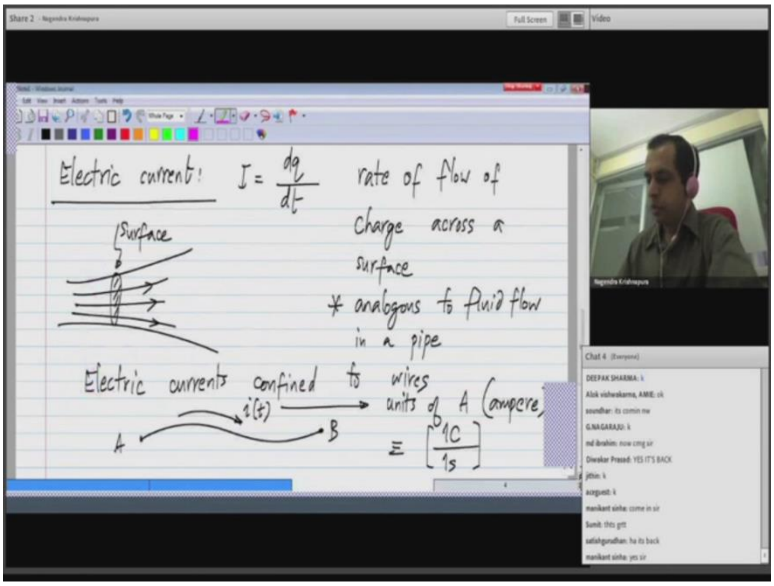

So, any questions or anything that is confusing about the definitions of currents and the convention of the sign. So, we will be talking about currents through wires. There were a few questions.

First one was, what is a coulomb? Coulomb is the unit of charge. You perhaps know, that electron has a charge of minus 1.6 times 10 to the power 90 coulombs. So, roughly speaking, you need 10 billion, billion electrons will be flowing to have 1 ampere of current in 1 second. You should, 10 billion, billon electrons flowing in 1 second to have 1 ampere of current. So, that is the unit of charge.

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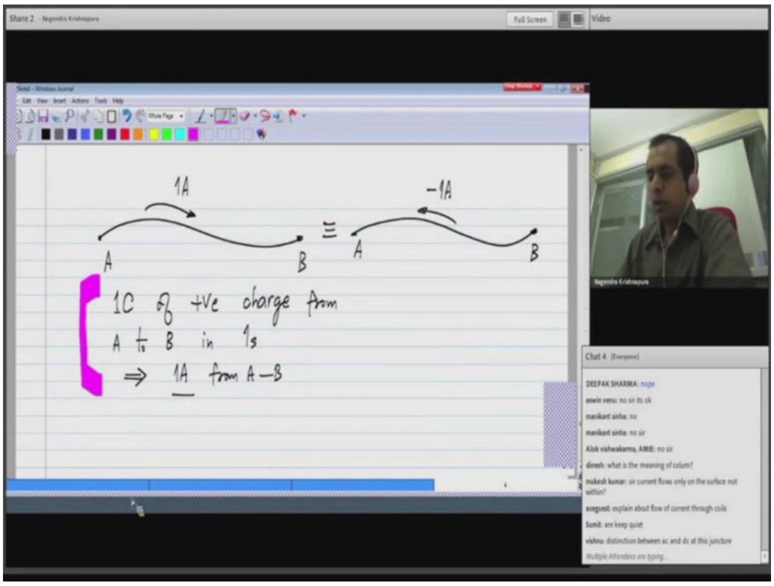

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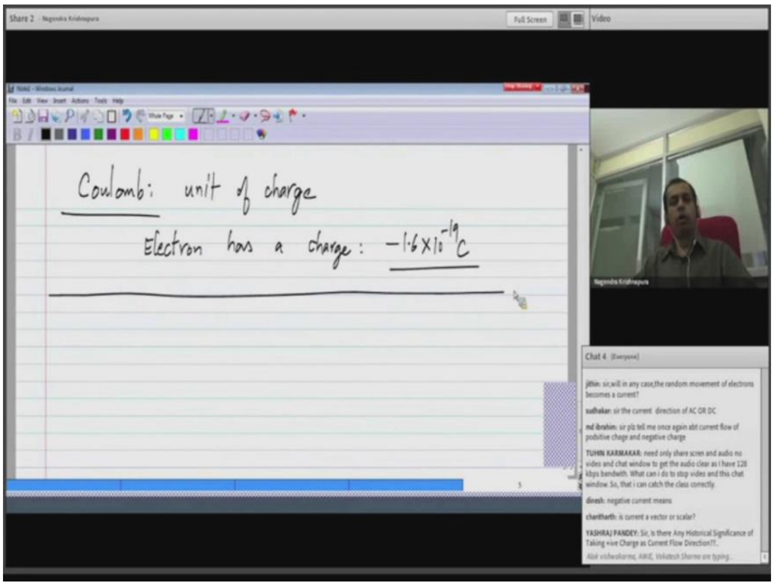

Now, there was another question, it was about, the current flows only on the surface of the conductor or not? Now, let us not worry about that. Now, in terms of that, I ((Refer Time: 29:16)) current flows uniformly through the surface of the wire. And as you go to higher frequencies, it tends to go towards the surface of, uniformly through the cross-section of the wire at low frequencies. And as you go to higher frequencies, it will be only towards the surface of the wire. But for us, those, those details are not important at all. We will be looking at the total current flowing through the wire.

And well, another question on flow of current through coils. Now, whether if a coil or not, current will flow through the wire, probably asking about what happens due to the current. There will be magnetic fields, but we will not be talking about it at this juncture. And someone else asked, whether any random moment of electrons becomes a current? Yes it does. In fact, electrons are moving randomly all the time and there is big field of study on noise, which is the electric current due to random moment of electrons. As long as the temperature is above absolute 0, this will keep happening.

Now, there is another question on positive charge, why we take it that way. So, this is something historical. I think, historically, people did experiments with electric currents on all kind of things when it was not known, that electrons are the, electrons are what carry current, ok. So, they are just, decided the direction of current and as the direction of flow of positive charges. And it should also be noted, that in certain chemical experiments it could be some positively charged ions that are actively flowing, ok. When we have wires, it is only negatively charged electrons that are pouring, that is what the case in every situation. So, it is an arbitrary thing, that is a historical convention and we will stick to that, ok.

Now, there is also question on AC and DC and so on. So, those things we will not worry about, that is just has to do with how the current changes over time. So, that is not something fundamental. And so that is about those things. And also, for us all conductors are perfect. So, as the conductor itself will not have any influence on the current. So, this is an idealization. And many of the wires that we use are made of copper, come fairly close to this ideal level. So, again we will not worry about the effect of wires at this point.

Now, let us, now let us move on to the other electrical quantity, which is the voltage or potential difference. Now, what is this? I think again an analogy could be made with gravitational field, you know, that if you have gravitational field, this is the earth, I am showing only a small area, so I am showing it as flat and you know, that there is gravitational field in this direction.

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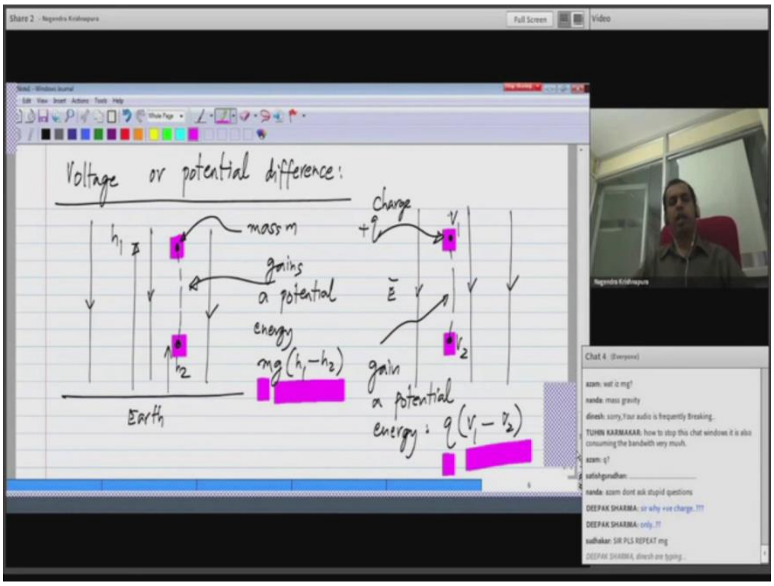

Now, if I place a mass m on a gravitational field, what will it do? Obviously, it will fall in some way towards the earth. In fact, the gravitational field could be due to anybody and it will always fall from a higher gravitational potential to a lower gravitational potential. And let us say, this was at a height h 2 above earth, the other one was at height h 1 above earth. But when it falls from h 1 to h 2, it gains the potential energy, which is m g time h 1 minus h 2, ok. So, it falls from a higher potential to a lower potential. And so while doing so it gains potential energy.

Now, similarly if you have an electric field, which ((Refer Time: 33:42)) denoted by that and then you place a charge q, it will, to be of course, the positive charge q, it will fall. I mean, here I use the word fall, not in the gravitational field, but in an electrical field, ok.

So, it will move from there to there, it will tend to go. And if it does that it will also gain a potential energy, which is q times, let us say, the potential. This electric potential is denoted by V and this is V 1, V 2 and V 1 minus V 2. So, you see, that the gravitational potential energy that is gained is proportional to the mass and the electrical potential energy that is gained, will be proportional to the charge. So, we leave out this.

If this charge and mass are property of the body that is falling and the rest of it is the property of the field and that is the potential difference, ok. So, the amount of energy gained is equal to the amount of charge times the potential difference between here and there and that is given V 1 minus v 2. Similarly, here in the gravitational case, the amount of potential energy gained is mass of the body that is falling times the potential here minus the potential there, which is 3 times minus h 1 minus h 2.

So, what I want to emphasize here is, that the potential makes sense only when measured as a difference of values between two points is, V 1 minus V 2. If you just say potential at this point is something that is not a very significant thing, ok. So, you always have to measure this voltage or potential difference between two points and this is flow of circuits as well. As usual, we are not looking at arbitrary fields that are distributed in space and charges falling in this, you are only looking at electrons moving in wires or charges moving in wires and the fields will be inside the wires.

So, the potential difference, the electrical potential difference is very much like the gravitational potential difference. The gravitational potential difference acts on the mass and the mass that falls on the gravitational field will gain some potential energy. Similarly, an electric field, electric charge that falls in an electric field will gain some potential energy. So, when we are talking about circuits, we will not worry about potential energy or electric field. We will talk only about the potential difference.

It looks like the connection have been broken for some people of the quality has been questionable. So, what I will do is, I will just pause the camera to cut down the bandwidth and hopefully, things would be better. You can give me feedback from other end. It is indeed better, ok.

What I was saying here is, that I was trying to make an analogy between voltages or potential differences ((Refer Time: 38:43)) we use, that is what, people said, ok, ok. So, the video is off now, by the way.

What I was saying here was, that I was trying to make an analogy between electrical potential and the gravitational potentials that you are familiar with here on the left side. I have shown the earth and the gravitational field pointing downwards and if you place a mass m somewhere, it will fall down in the direction of the gravitational field and it will gain potential energy. It will always fall from a region of high potential to a region of low potential.

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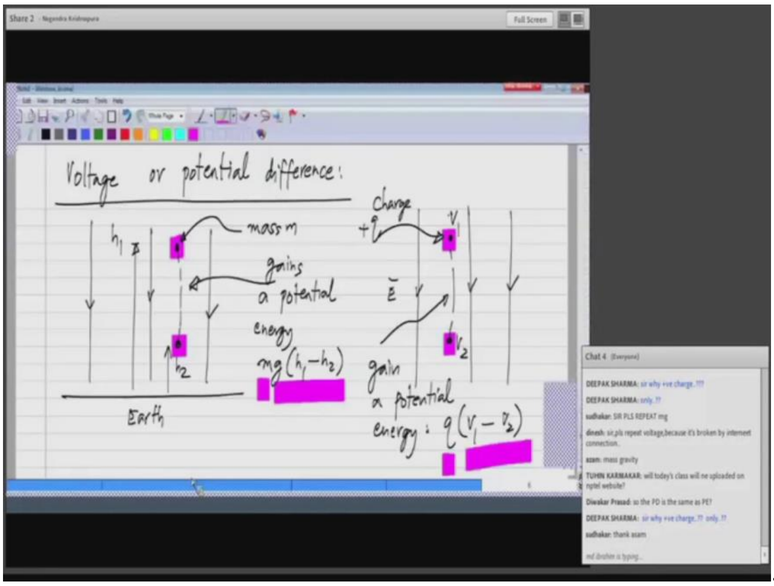

Let us say it falls from a height h 1 to a height h 2. It gains potential energy, which is m times z, gravitational acceleration, times h 1 minus h 2. Analogously, in an electric field here, I have shown on the right side, electric field pointing downwards. If you place a charge q somewhere, it will fall, that is, it will move in the direction of the electric field. And let us say, it falls from one point where I have marked the potential of V 1 to another point where I have marked the potential of V 2. It gains the potential energy, which is q times V 1 minus V 2, ok.

So, the amount of potential energy gained is proportional to the charge and it is charge times the potential difference, just like amount of gravitational potential energy we gained is mass times some difference. And it is the difference between some quantity at the initial point and some quantity at the final point.

So, what I want to emphasize here is, that the voltage or potential difference makes sense only when measured as difference between values at two different points. There is not much significance to say in, that the potential at particular point is one ((Refer Time: 40:42)) without saying with respect to what the potential is, ok. Or in other words, you have to say, that potential difference between point A and point B is something.

You know, you have to do something in circuits as well. The voltage is always measured between two points so. In fact, while you are discussing among yourselves or you are thinking about it, you always think of two points between which the voltage is measured.

Lot of confusion about voltage comes about because you forget that it is measured between two points.

So, any questions about the voltage? Any questions about voltage? There are a number of questions, one was related to electromotive force and voltage. These are basically different terms for the same thing. Electromotive force is somewhat old term and they use the term voltage now. And somebody asked, what happens to if the field is in opposite direction or if the charge is negative?

Now, if the field is in opposite direction, it will cause the potential in some different way. Now, as we said, as I said earlier, we will not worry about fields, we will only work with potentials. And if the charge is negative, whatever happens to the positive charge, exactly the opposite will happen to the negative charge. A positive charge falls from higher to lower potential and the negative charge falls from lower to higher potential, ok.

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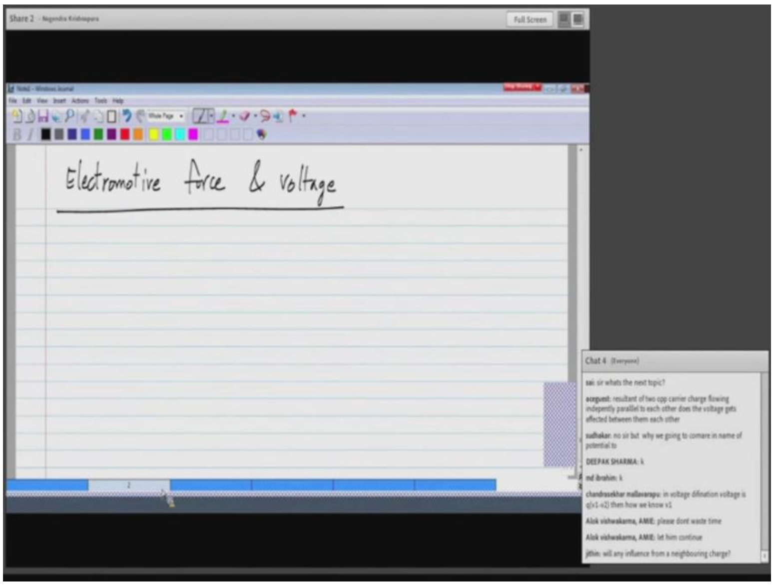

Now, one of the other questions is, I said that the potential energy gained is q times V 1 minus V 2. So, how do we know V 1? Now, when you talk about potentials in a field, we will measure V 1 with respect to infinity and it does not matter what it is measured with respect to, ok.

So, if V 1 and V 2 is changed by the same amount, it does not matter to anything. So, it is only with the value of V 1 minus V 2 that matters. Now, this has become more clear when we go on to discuss particular elements because we will only be discussing what is differences across the elements.

Now, there are also number of other questions on interactions between charges and fields that we will not worry about and we do not have to. Our goal here is to do circuit analysis. So, we can analyze circuits by staying at the level of voltages and currents without going into the fields.

Now, there are some laws that govern voltages and currents in the circuit. Now, as I said, I have not even put down what circuit it is. These are very general laws that apply to any circuit. These you can think of them as basic properties of voltages and currents, ok.

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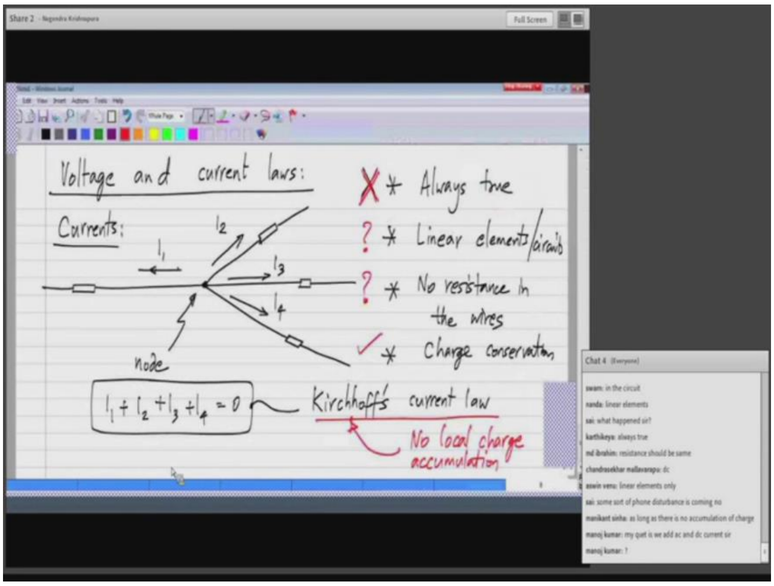

Now, one of these that talks about currents says, that here the number of branches, number of wires connected to a single point, such a point is known as a node. And these just do not have to be wires, they could be some elements, right. Now, we will not worry about them what they are, ok

Now, what this says is, that if you measure currents flowing out of the node, I will choose to measure the current in this direction, I call this I 1, I 2, I 3, I 4. So, very well. Now, that says, I 1 plus I 2 plus I 3 plus I 4 equals 0. Now, this has nothing to do with any particular circuit, but it is true for any circuit. And this, I think many of you already would know, this is known as Kirchhoff's current law.

Now, briefly could you tell me the conditions under which this is true, is always true under any circumstances or are there any conditions. There are a number of responses, I have broadly grouped them into always true and for linear elements or circuits. And somebody said something about no resistance in the wires and then somebody else said charge conservation or no charge accumulation and so on, ok.

Now, in terms of that, of course, this is not correct. If that is the reason, I ask the question, now this is a kind of funny answer because I do not even ((Refer Time: 49:15)) on what circuit it is. I have already said, that these are general properties of currents. It has absolutely nothing to do with what circuits we apply to, ok. So, this is something also important for a different reason. I think, whoever answered these things are mixing up some different concepts. Linearity refers to a voltage current relationship of different elements.

Now, the Kirchhoff's current laws, that I am discussing here, has nothing to do with what circuit it is. It is generally true of all circuits or with some conditions, as we will see. And again, this is also something similar. It says no resistance in the wires. Again, it has absolutely nothing to do with that because you could have wires. And it will have elements connected to it, which could be resistors because if you say no resistance at all, then such a law, such a theorem would not be very useful because it has to be useful for real circuits.

Now, finally, we come to the main point, which is, that if the charge is conserved, that is, charge is neither created nor destroyed. And more importantly, it is not just this that is important, there is no local charge accumulation, that is, you have currents flowing out of it. Now, if the sum is more than 0; that means, that the charge was depleting from this point and its sum is less than 0, charge is getting accumulated at this point. Neither of it is true. So, charged is conserved, of course, and also, a charge is not accumulated locally in any point, ok.

So, this is the reason why this is the assumption under which Kirchhoff's current law is true. In fact, there are conditions where it is not true. If there is time, we can discuss those things later, but now for a large number of circuits this is true and we can use Kirchhoff's current laws safely. So, that is true.

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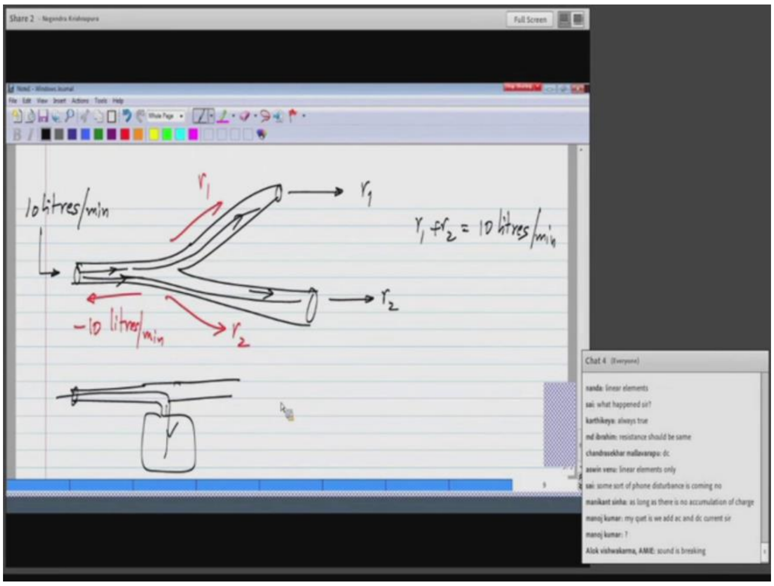

Again, as I mentioned earlier, very useful analogy for thinking about currents is fluid flow. So, if you have a pipe here and then it branches off into two pipes, it is very obvious, I mean, even without analyzing to most of you intuitively obvious, that if there is water flowing here and then it will branch off into two. And let us say, water flowing here at a rate of 10 liters per minute.

Now, whatever the rates here are, I mean, this type could be big and this could be small and all of that, so this is flowing at some rate r 1 and this is flowing at rate r 2, you know, that r 1 plus r 2 equals 10 liters per minute, ok. Or if I have to use convention in for currents, I took all the flow to be away from the node. So, I can also take r 1 liters per minute flowing that way, r 2 liters per minute flowing this way and this way it is minus 10 liters per minute, ok. It is a slightly lower way of saying it, but a useful way when you talk about currents.

I initially assumed, that the flow is that way, but it comes out the way from left to right. So, that means, from right to left minus 10 liters per minute of ((Refer Time: 52:53)). So, minus 10 plus r 1 plus r 2 will be 0. This is something that you intuitively feel is true even without knowing the great deal of fluid dynamics and so on.

And why does this happen? If this was not the case, water would be accumulating here or water would be drawn out of here if we had a tank here into which water is accumulating. This could not, this need not be true. For instance, I could have water and then flowing into a tank and then nothing coming out of it. Whatever is coming here, is going into the tank.

This is analogues to charge accumulation and we assume that such a thing is not happening. As long as it is not happening, the Kirchhoff's current law is true. The sum of all the current flowing out of the node or equivalently, sum of all currents flowing into a node will be 0, ok. A very useful thing and. In fact, a necessary thing to solve for circuits.

Similarly, there is something that governs voltages in general. So, let us say, you have an electrical circuit. Electrical circuit means, that there is some loop of electrical components. Now, they will not even discuss any element, but I will take some two terminal elements: 1, 2, 3, 4 and 5. And I will measure the voltage across each one, like I said, voltage is potential difference between two points. So, here I will measure V 1 in this direction and here, I will measure V 2 in this direction.

Please mind the directions in which I am writing this: V 3 here, V 4. You see, that I am taking all the differences in the same directions and V 5. Again, this has nothing to do with the specifics of the circuits and there is a law that says, that V 1 plus V 2 plus V 3 plus V 4 plus V 5 equals 0, ok. And this is known as Kirchhoff's.

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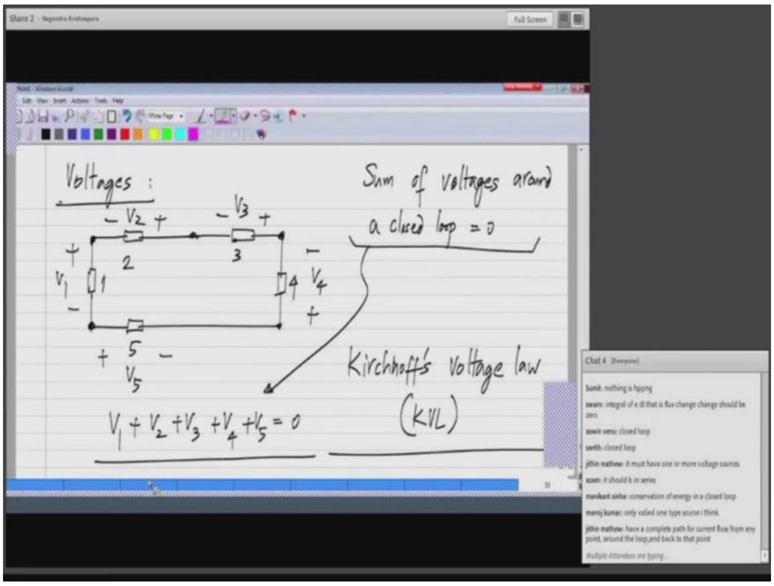

So, it appears, that the audio was broken. What I was talking about was the sum of voltages around the loop being 0. So, here I have shown it for this particular circuit, V 1 plus V 2 plus V 3 plus V 4 plus V 5 plus 0, that is, sum of voltages around this closed loop is 0 with all the voltages being defined with the consistent polarity. You see, that they are all in the same direction around the loop and this is known as Kirchhoff's voltage law.

The response I would like from participants is to tell me the conditions under which this is true. Again, I have a got a number of responses. Now, some of you have said, that it is true in a closed loop. Yes, of course, it is only a closed loop, that I am discussing, right. Here, I have written a loop and as I have written on the side, some of voltages around the closed loop equals 0. So, my question is, is that violated in some conditions, ok.

Now, in terms of that it can be violated if there is significant time varying magnetic field cutting this loop. So, this loop has certain area. So, this loop can enclose certain time varying magnetic fields. If there are time varying magnetic fields in the cutting the loop, then the sum of voltages does not have to be 0, ok.

So, again all the practical situations or most of the practical situations that we have encountered. The time varying magnetic fields cutting this loop will be small enough, cutting our loops will be small enough, that we can take the sum of voltages to be exactly 0. Again, this turns out to be true in practice in lot of cases. So, we can use the Kirchhoff's voltage law also safely.

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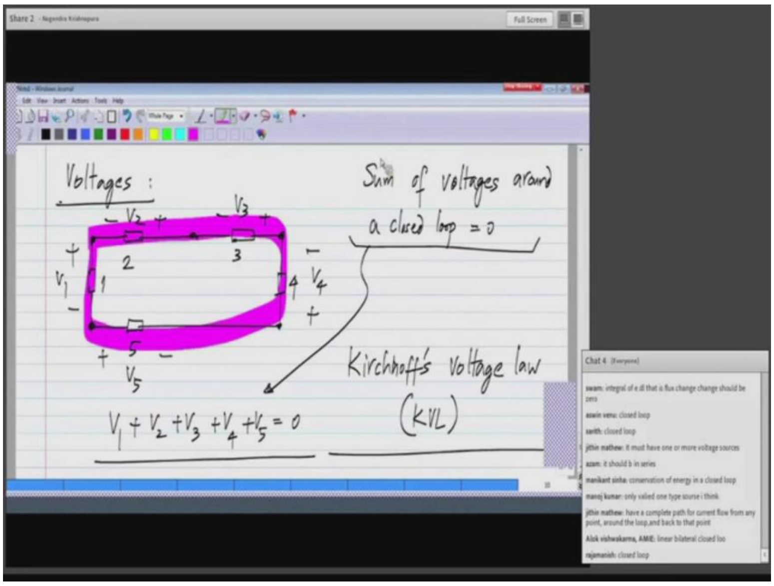

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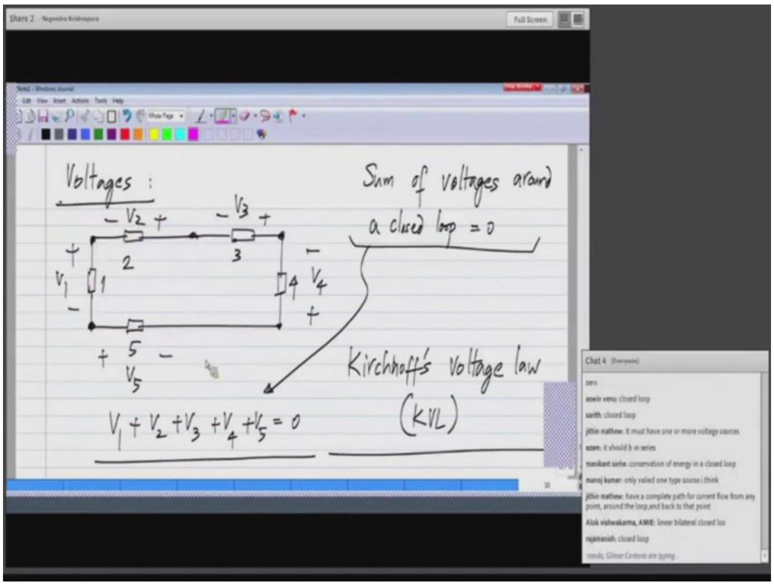

Now, there are some people asking questions on what happens if voltages are induced from other loops. That is exactly what I am saying, that if there are ((Refer Time: 59:20)) magnetic fields, there will be the sum of these things will not be 0. It will be related to the rate of change of magnetic field and the area of the loop. So, we will not consider those conditions. We will only consider the conditions where the flux is 0, that is, time varying flux cutting time varying magnetic field cutting the loop is 0, ok.

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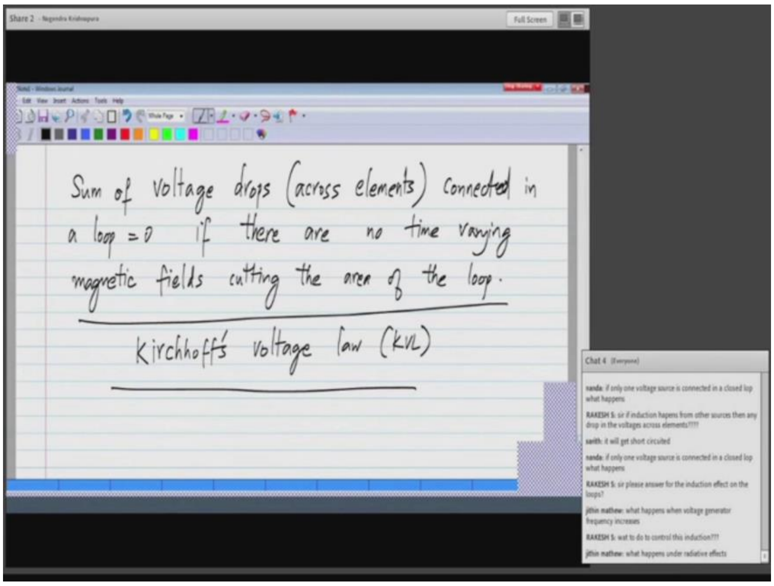

So, there are these two basic laws and Kirchhoff's, Kirchhoff's voltage law and Kirchhoff's current law, one relates to voltages in a loop and one relates to currents in loop. And one of the very important things while applying this is to apply it with a consistent polarity, ok.

So, we will have, here I will show a loop, the loop will have some elements, but I will not worry about those or maybe, I will show it with elements, so that there is no confusion. So, if you look at this, what I have done is to go this way. If I go in a proper loop, all this, I have minus first and plus next and so on in the direction, in this direction. ((Refer Time: 1:01:18)) going in this direction and then I sum all the voltages, it becomes 0.

Similarly, for Kirchhoff's current law at a node to sum of all currents, flowing out of a node is 0. So, I suggested right from the beginning, you adopt a consistent polarity because if you make a mistake with the polarity of these things, obviously you will get the wrong answer.

Now, one thing I had to mention about voltages, it is for currents, that is, I told you, that a current of 1 ampere flowing from A to B is exactly the same as a current of minus 1 ampere flowing that way. And similarly, if you have two points, let us say x and y, and having a one word difference in this direction, is exactly the same as x and y. And I will measure y with respect to x, the voltage in this direction being minus 1 volt, ok. So, this is just, so that you are comfortable with the sign convention.

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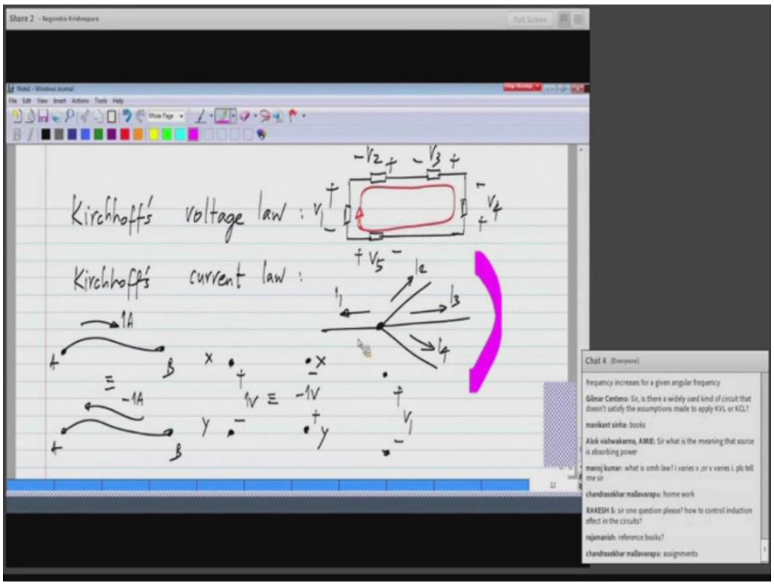

So, again for instance, I could have some two points and I will write even this way. This does not necessarily mean that this at higher potential than that it says that it is higher by v one and v one itself could be positive or negative.

So, I think, in today's lecture we have discussed a number of things, basically definitions of voltages and currents and the laws governing them, ok. Now, we will continue from here in the next lecture. There are a couple of more questions, some of them are related to frequency of the voltage and so on. I will not discuss those things here as they are not really relevant because even if, let us say, V 1, V 2, V 3, V 4 and V 5 are primary, Kirchhoff's voltage law says, that every instant of time the sum of those things has to be 0, ok.

Similarly, for the currents, now the sum of currents I 1, I 2, I 3, I 4 is 0 for this particular example here. Now, this is true. Even if those currents are time varying, they could in general be time varying. At every instant of time the sum has to be 0. So, that is the meaning of Kirchhoff's voltage and current law.

Now, there is one very interesting question, which is, what are the circuits, that do not, that do not obey Kirchhoff's voltage law or current law, as I have shown some examples.

Now, it turns out, that there are, there is, first of all, so there is one very common example, which is basically, if you are, if the dimensions of a circuit are very large. Now, by very large what do I mean? Very large compared to the wavelength of the signal, then these things do not hold good. We can perhaps elaborate on this later.

What I mean by that is, let us say, I have a very long wire, ok. And again, I think of positive charges flowing this way. Now, always we think of charges flowing infinitesimally, but we know, that it really moves at the speed of light. If it is limited to the speed of light, it probably moves slower than that.

Now, let us say, that to drive a current and you reverse the direction before the current can get from here to there because there is always some length to the wire. And then it takes some time to get from here to there and before that if you reverse the direction of the current. So, let us say, you are driving a current from one side. We will not worry about how to do it before it gets from here to there. The charge gets from here to there, you reverse it, then you look at different parts of the wire, they will be, they will be carrying different currents.

And a very common example of this is the antenna. I think all of you are familiar with antennas, which are just a single wire sticking out, could be sticking out of your radio or your car, it is just sticking out and you ((Refer Time: 1:06:10)) to it. It looks like it is just hanging in the air and then current is going into it.

So, clearly Kirchhoff's current law is not valid here. What really happens is, that the length of the antenna is comparable to the wavelength, that is before the current reaches from one end of the antenna to the other, the direction of the current driving it changes. And then so you have a consistent situation without Kirchhoff's current law being violated, ok.

Now, we will only be talking about those situations where the dimensions of the circuits are much smaller than the electrical wavelength of the signals that are driving it. So, in our cases, Kirchhoff's current law will be valid and similarly, for Kirchhoff's voltage law. So, in general, these things can be violated if you have a very large circuit and large relation to the electrical wavelength or in general, if you increase the frequencies of the signals.

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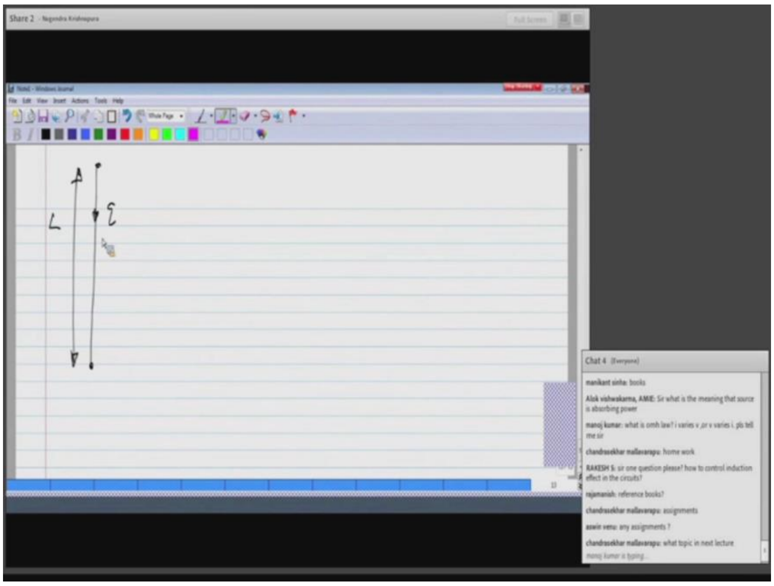

Any questions? So, there are, so there are some general questions, which we will deal with later. So, in the next lecture what we will do is, take some electrical circuit elements, which are commonly used. This is their relationship between voltages and currents. What we did today was to see general properties of voltages and currents and their definitions, ok.

So, in the next lecture we look at some elements and then in next some simple circuits out of them.

Thank you.

Can you tell them about website the online courses website, tell them that has the syllabus that will have the ((Refer Time: 1:07:48)) posted, that will have a discussion forum, that we can ask questions ((Refer Time: 1:07:51))?

And there is an announcement also. The online courses website will have the recorded lectures and it will have a forum for you to post questions where I can post answers or perhaps others can also do that and so on. And it will also have the syllabus and assignment and all of those things. So, please consult the online forum. So, and this class, this lecture was about some features. I think from the next lectures onwards things will be lot smoother.

Thank you.