Engineering Physics – II
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Module No. # 03
Lecture No. # 08

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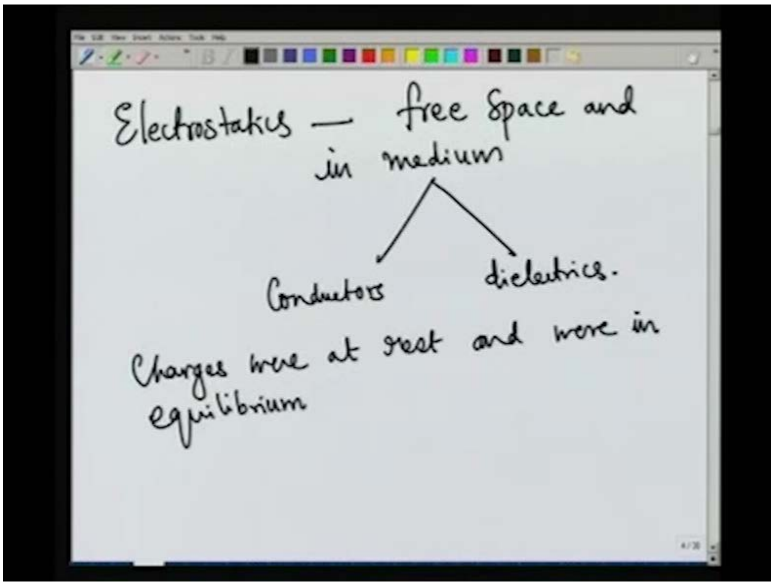

So so far, we had been looking at electrostatic phenomena, where the charges were at rest. So, what we did was to look at electrostatics both in free space and in medium. We considered broadly two kinds of media; so one was the class of conductors and the other one was dielectrics, and by taking the charges to be at rest and at equilibrium. So, what are the conditions that we put? The charges were at rest and were in equilibrium. If the charges are not in equilibrium or they do not reach in equilibrium state, then one cannot discuss electrostatics phenomena like for example, how does a dielectric material respond in electric field or how do the charges get redistributed, when I change my electric field?

So, we took charges to be at rest at an equilibrium, and we sort of covered the phenomena in the media namely; conductors and dielectrics, which covers most of the materials that we encounter in everyday life. What we now do is to look at charges in motion and that would be the subject matter of the so called currents. So, it is a fresh topic that we are going to begin right now; so let us call it as the physics of charges in motion. Now, when I am looking at charges in motion, obviously I would not like to consider the most general motion that is possible with all kinds of accelerations. To start with, we want to specialize ourselves to a very specific kind of motion.

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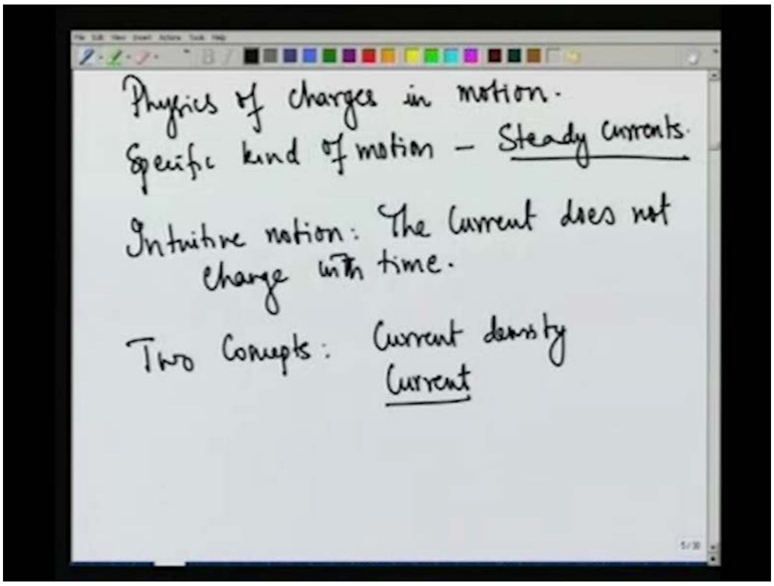

So, we want to look at a specific kind of motion, and it is this motion which gives rise to what is called as steady currents. In fact, today’s lecture will be largely devoted to an elucidation of the concept of what a steady current is and how it manifests itself in many situations. I have to define the notion of a steady current very, very carefully, and what I would request you as you listen to me is also to remember that you have studied a similar thing in your fluid dynamics course or you will be studying something very parallel to whatever I am telling you in your fluid dynamics course. Therefore, you should be able to sort of make some kind of a correspondence between the steady current that is being introduced here and what you study in the general subject matter of fluid dynamics.

Now, how do you define a steady current and what do we mean by that? The notion is intuitively clear. What we want to imagine is that the charges are all moving with uniform velocity and the current does not change with time. So, the intuitive notion is that the current does not change with time; of course, it can be quasi static or quasi steady by that we mean; it changes very slowly with time.

What are the situations that we encounter normally? For example, if I take a wire and connect it to a battery, I say there is this much current that is flowing. I know the resistance of the wire; I know the battery voltage. Let us say at 5 volts or whatever. So, these are examples of steady currents that we have intuitively. What we now want to do is to quantify it and make that notion precise. So, this intuitive notion of what a steady current is to be made precise. In doing so, we shall introduce two important concepts both of which you are familiar with; so two concepts is what I need required; one is that of current density and the next one is of the current itself.

Currents are of course are what we are most familiar with. We say this wire carries ten amperes current. There is a lightening which carries something like 20 thousand amperes etcetera, etcetera. Current density is something that we do not encounter normally. However, current density is absolutely fundamental. It is more basic then the notion of a current. So, what we shall do is to first of all introduce the concept of current density; introduce the concept of a current; state precisely what one means by a steady current. Study its properties, and then, go on to study the magnetic field produced by the currents. So, this is our plan of action for this lecture and probably the next lecture.

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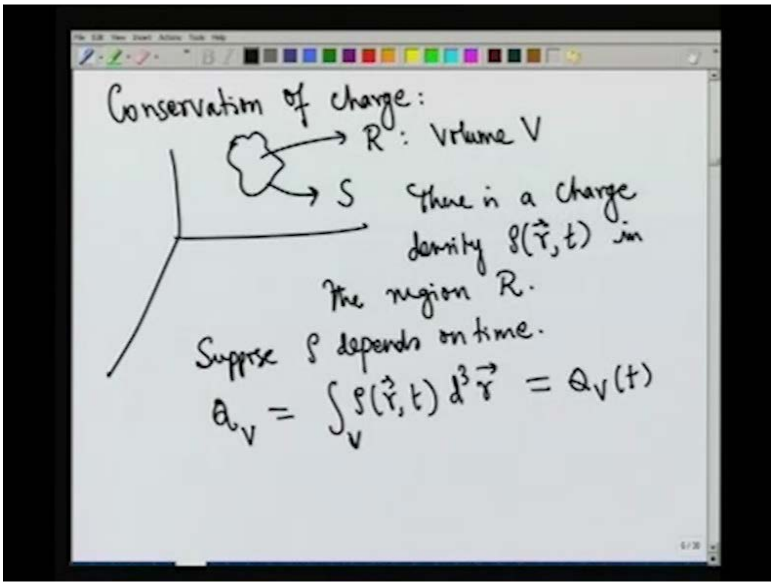

Now, in order to formulate the notion of a current, it is very important for us to remember the most fundamental law which governs all of electrodynamics phenomena and that is conservation of charge. So, let us start with that; long time back in my fifth or sixth lecture, I almost devoted an hour to elucidate the concept of the conservation of charge. What it means, how it can be verified, what is the evidence, so on and so forth. Shall I would now do is to take it for granted that we all accept that we all know that charge is conserved and use that in order to formulate the concept of a current. How shall we do that?

In order to do that, what we shall do is to look at a certain region in space. So, this is a certain region in space. So, let me call it as R and this region is bounded by a surface s. Now, in this region carries a volume V. The volume of this particular region is given by V and we shall ask what is that, that, we can say about the charge density in this region. So, what is the statement that I would like to make? I would like to say that there is a charge density rho of r, t. It can of course be a function of time in the region R. Now, if rho were independent of time, then I would say as far as this particular region is concerned, it is as good as electrostatics.

However, suppose rho is a function of time. So, suppose rho depends on time. What do we mean by that? By that we mean that as a function of time, the charge contained in this particular volume is going to change. Now, when I am speaking of rho depending on time, I do not mean simply redistribution of charges. So, let me make my concept even more precise. What I will do is to look at Q which is contained in the volume V, which is nothing but the integral rho of r t d cubed r.

So, I am looking at the total charge contained in this particular region, and I am asking how much is it? So, I make an integration over this certain volume; I have indicated this figure here and ask what is this Q V the charge contained, and we are asserting that this is a function of time. Now, if this is a function of time, we ask how is it that this charge can become a function of time.

Well, the answer is clear. The charge becomes a function of time not by sudden annihilation or creation of charges. I cannot say that an electron was born in this particular volume. Your proton got dead in this particular volume. It cannot be suddenly appearing; it cannot be vanishing, because remember, we said that our whole discussion will be based, will be pivoted on the fundamental law namely the law of conservation of charge. So, what is the statement that we want to make?

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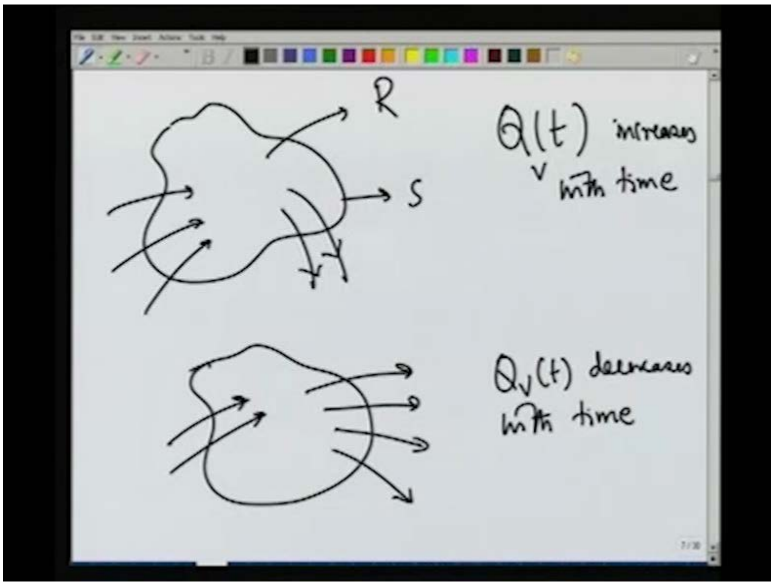

So, let me write that region here again. I am going to magnify that. So, this is my region r; this is my surface s and I am looking at charge contained in that particular volume V. So, if we say that the charge contained is changing as a function of time in this particular volume V, how is it possible? It is possible if and only if there is a net charge that flows into the volume or a net charge that flows out of the volume.

If Q V of t increases, there should be a net flow into the volume. So, let us indicate that. So, this is the line which indicates that the charge is flowing into the volume. These are the lines which indicate that the charge is flowing out of the volume. So, if my Q of t is an increasing function of time, I would say that such a thing happen because more charge flowed into the volume, then the charge flowed out of the volume.

If Q V of t is a decreasing function of time, I would say that more charge flowed out of the volume than inside the volume. So, in this case, Q of t increases with time. This is a schematic representation, whereas I can write the same situation of figure here, the same region. Let us say these two lines indicate the flow of the charge inside the volume and these four lines indicate the flow of the charges outside the volume. Here, Q V of t decreases with time.

So, we are asserting that the charge contained in the volume can change only because of the flow either into the region or outside the region. It cannot happen by annihilation or creation of individual charges. That is the statement that we are making. Now, it is perfectly possible that my charge does not change and yet there is a flow. So, how do I indicate that? The indication is clear.

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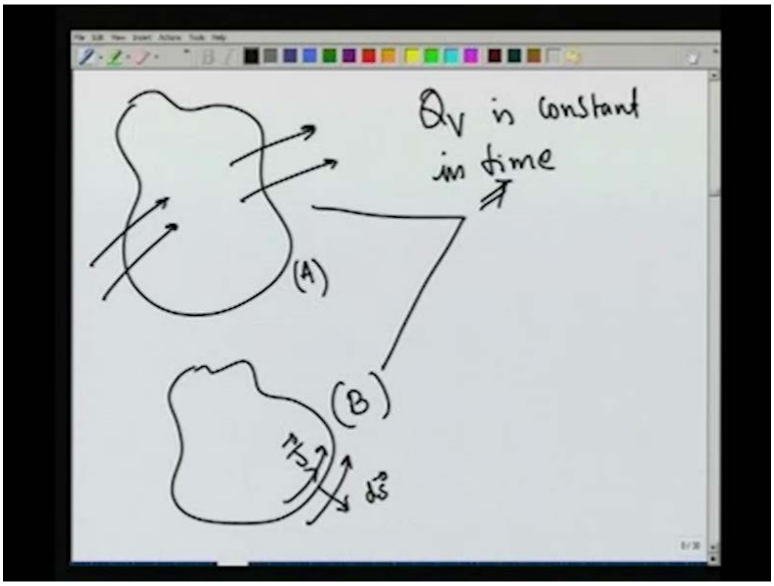

So, let me draw two figures to show you because this is an important concept. Schematically, I would draw two lines like this and two lines like this; that means here, Q V is constant in time. What is happening? There is a certain charge that enters this particular volume, but the same quantity of charge also leaves this volume. Therefore, Q V is constant in time. Is this the only possibility, because of the current that the charge is going to be constant in time? The answer is no. I can make one more schematic representation and that is the currents are of this nature.

Whatever charge is inside keeps flowing, there is no flux outside, but the flux is all parallel to the surface. Therefore, whether we look at this, let me call it as figure a or whether we look at this configuration, both of them imply for me that Q V is constant in time. So, the long and short of this story, the summary of whatever I am trying to convey through this cartoons, through these schematic representation is that the charge contained in a given volume will change because of the flow of the charges.

And what should be the nature of the flow of the charge? The flow of the charge should be such that there should be a net flux either inside or outside the surface. So, please notice the way I have drawn the arrow. These arrows have a component perpendicular to the surface. Now, my area vector is always perpendicular to the surface. Therefore, my current which represents the flow of the charges obviously should have a component parallel to the surface vector.

If the current vector, the flux vector does not have a component parallel to the surface vector like here, it is parallel to the surface, but perpendicular to the surface vector, then there is no change in the charge contained. So, in other words, the change in the charge contained is always, it is always it is invariably accompanied by an associated current.

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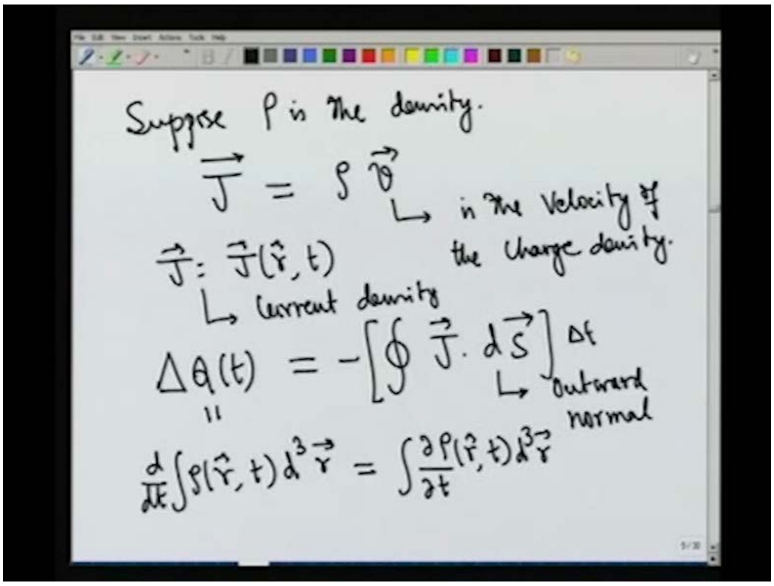

Now, what is the current that we want to say? Well, suppose rho is the charge density. Now, the current at any given point depends on two factors. How many charges are sitting in that unit volume, and what is the velocity with these those charges are moving. Therefore, the flux that I want to construct is naturally given by the quantity. This is my famous current density, which is nothing but rho into V, where V is the velocity of the small pocket of the charge this charge density.

So, obviously we are looking at a sufficiently small volume to take it for granted that all of them are moving in the same velocity. So, in general, J is a function of both place and time, and what we want to say is that it is because of this motion that there can be a change in the charge contained. Well, how do I write that? It is a very, very simple relation that we can write. We can write that delta Q of t. I am asking for the change in the charge contained that is simply given by minus surface integral J dot d s where J is given by rho V. So, let me record it. My J is nothing but the charge density, current density.

Now, if you feel like you can go back and look at all these pictures, integral J dot ds is equal to 0 here because whatever entered the surface exited through the other side of the surface. Integral J dot ds is equal to 0 here because J and ds were perpendicular to each other. This was your ds and this is your direction of J, and whereas if you go yet other previous figures, here integral J dot d s is greater than 0; here integral J dot ds is less than 0. Our surface area element the tractor is always outward normal and that is indeed the reason why I get this relation minus sign minus integral J dot ds, because we should remember this is always defined as outward normal.

J dot d s greater than 0 tells you that the charge is flowing out; that means, there is a in the charge contained that gives you the minus sign. J dot d s is less than 0 tells you that the charge is flowing inside the surface. There is a flow of the current within the surface. It is flowing into the volume. Therefore, this minus sign now ensures that there is an increase in the charge contained.

So, we are now able to quantify the qualitative notion of conservation of charge through this relation and all that remains for me is to write it as a nice algebraic relation, a differential equation. In order to do that, all that I have to do is to rewrite the left hand side, but what is delta Q of t? So, if I have rho of r, t, if I have an integral d cubed r, that is actually what the total charge contained.

Now, I am interested in how it is going to vary. So, I am going to write a d by dt. That is what I have here, and the derivative can be taken inside and I can write it as delta rho by delta t, that is, the ordinary derivative becomes the partial derivative r, t d cubed r. This delta Q of t was actually a function of time. I should have actually written it as d Q by dt. Otherwise, I would have to multiply this whole thing by a certain delta t that would be a more precise notion.

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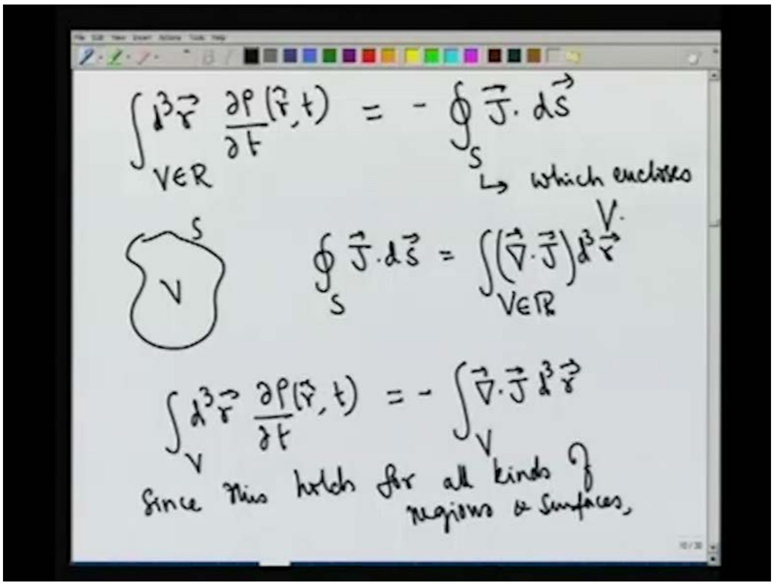

So, if we combine both the formula, what is the relation that I am going to get? I am going to get d cubed r delta rho by delta t r, t. In that volume V, whatever the volume is of your interest is nothing but minus integral J dot ds where there is a surface s which encloses, which bounds the volume V. So, we know the precise meaning of the symbols on the right hand side and the left hand side. I am performing a volume integral on the left hand side; I am performing a surface integral on the right hand side. This is a close surface, and what is that close surface? The close surface is indeed the surface that bounds that particular volume. So, let us never forget this figure. This is my total volume and this is my surface.

Now, all that we have to do is to actually invoke Gauss Divergence theorem, and what does gauss divergence theorem tell me? It tells me that integral J dot ds. Please remember it is a close surface. That is the reason why I am putting that circle is nothing but integral divergence J d cubed r. So, we are rewriting the surface integral on the right hand side as a volume integral, and of course, it is over the same volume contained in the region r. So, if you feel like I will write it as contained in the region r, so all we have is a volume integral on the left hand side; a volume integral on the right hand side.

So, let me write them now integral d cubed r delta rho by delta t of r, t over a given volume is equal to minus integral divergence J d cubed r over the same volume. So, we are almost home. All that we have to do is to look at the left hand side, look at the right hand side and ask whether we can get rid of the integral sign. Let me go through the argument slowly.

When I wrote this equality, I did not make any assumption about the nature of the volume. The volume can be large; the volume can be small. The surface can be of any shape. In other words, this relationship holds for arbitrary regions which are enclosed by arbitrary surfaces. Therefore, since this holds for all regions, all kinds of regions and surfaces, since we have made no assumption what so ever on the nature of the volume integral. We can conclude that this equality is possible if and only if the integrants are equal.

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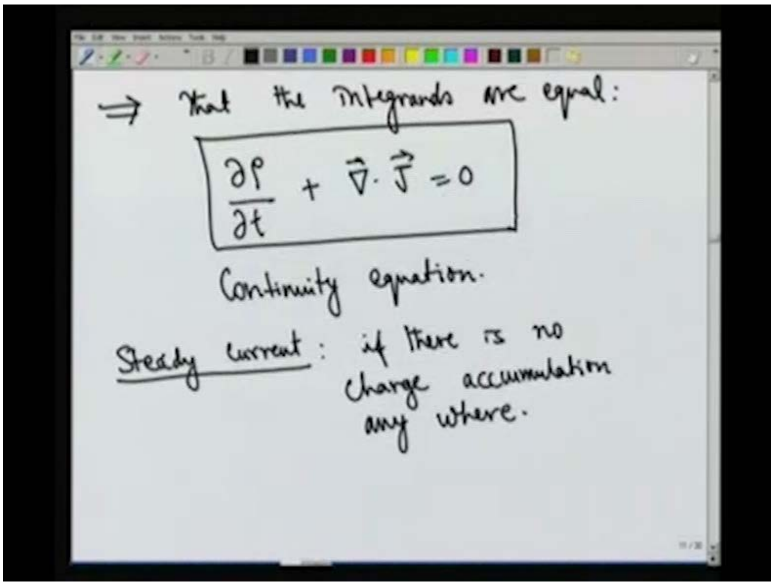

So, this is indeed the crux of the argument. Therefore, this implies that the integrants are equal. So, we have now got the required equation delta rho by delta t plus divergence J equal to 0. This if am I say so is the local version of the conservation of charge. Conservation of charge tells you that the total charge contained in any closed system is the same, but this local version is more powerful. It has more information than that statement because it tells you that, if I consider a certain region in space and if there is a change in the charge contained, as to how the charge contained change because there was a net in flux or out flux. Therefore, this is the local version of the conservation of charge.

Now, it is this local version of the conservation of charge that we are going to use, and by the way, this goes by a famous name. This is called the continuity equation, and as I told you at the beginning of this lecture, this is an equation which will encounter in many many situations. It is not necessarily specific to electric current. There can be a fluid which is flowing; there can be a gas which is flowing. The total mass will be conserved in such a situation that tells the place of the total charge.

So, in a variety of situation where there are conserved charges, conserved masses, conserved momentum, conserved energy, we write the appropriate continuity equations. Therefore, this is indeed a very, very important equation which will certainly encounter in your fluid dynamics course. Therefore, we should remember this.

So, what I would now like to do is to look at this continuity equation, this particular version of the conservation of charge, and now, define for you precisely what is steady current is. Let me first state the intuitive concept, and then go on to make it precise. Intuitively, I said that a current is steady if the current is the same everywhere. Now, what does it mean for us? A current is steady if there is no charge accumulation anywhere, charge accumulation anywhere. Let me give an example.

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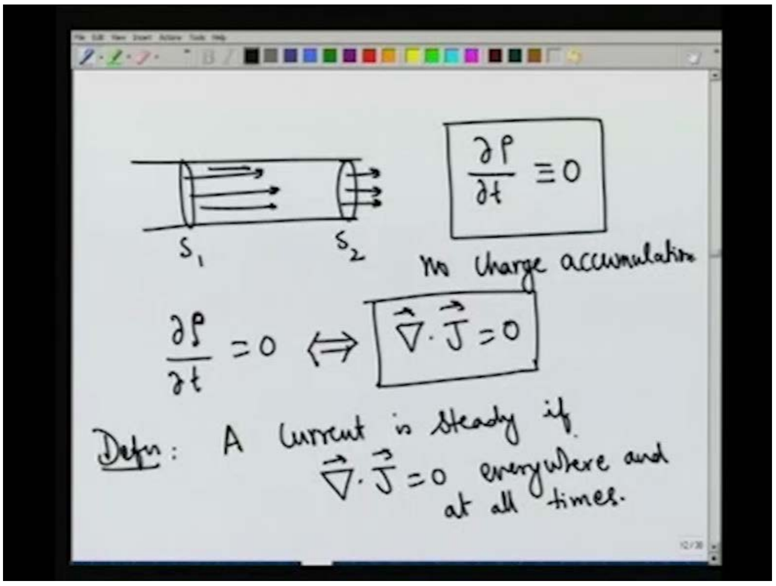

So, let me imagine a thick wire or it may be a thin wire which I have magnified and there is a current which is flowing. So, what I will do is, I will look at this surface s 1 cylindrical wire. So, this is a circular cross section and I will look at s 2 and ask is the same current flowing here and here. Well, if the same current is crossing the surface s 1 and also s 2, that means there is no accumulation of charge anywhere. That is the statement that we want to make; so, that means delta rho by delta t identically equal to 0.

This indeed is the statement of the idea, the intuitive notion that there is no charge accumulation. Very good, but what does the continuity equation tell me? Continuity equation tells me that delta rho by delta t is equal to 0 if and only if divergence J equal to 0, divergence J equal to 0, and this is what we are all the time going to use in order to discuss our quantify the notion of steady currents.

So, now, we have a definition. A current is steady if divergence J equal to 0 everywhere and at all times that is indeed what happens in your wire. When your d c current is flowing, divergence J is equal to 0, everywhere and at all times. So, if you come back to this example, you can easily see that there is a same current density at this point and at this point; the area of the cross section of the same. Therefore, the current is steady. So, what we have done so far is to actually define the concept of a current density.

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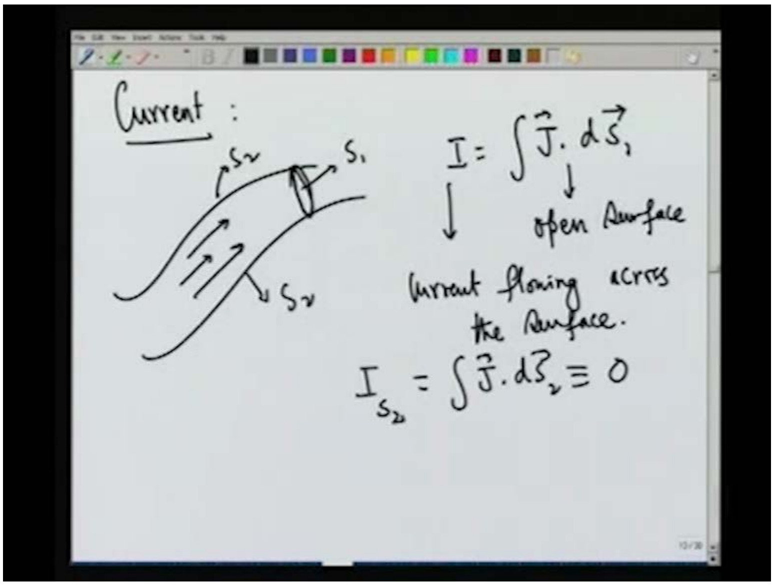

Now, let me take the opportunity to also define the concept of a current. As we saw current density is a vector quantity, whereas current is a scalar quantity. I say for example, a 10 amp switch, 20 amp switch, this fuse can support a maximum current of 20 amperes.

So, when I say that, I am not bothered about the direction in which the charge is flowing. So, I have to define a scalar quantity in terms of the fundamental vector quantity namely the current density and that is very simple. So, what we shall do is to imagine that the current is flowing. So, you can imagine that there is some kind of a pipe line and this is my surface. So, this is my surface s 1, and then there is also this surface, this cylindrical cross section. So, let me call this as s 2.

So, both of these line are parts of the surface s 2. We are looking at a cross section in the plane. Now, how is the current flowing? The current is flowing along this particular direction and we normally define the current to be total charge per unit time, but total per unit time of what? Per unit time flowing through this particular surface.

Therefore, I will define the current to be integral J dot ds. Please notice that this s not a close surface, but an open surface. That is very, very important. This is not a close surface but an open surface. I put an obstacle; I put a surface; I put some kind of a gaze and ask how many of the charges are passing per unit time - obviously for a given current density. Imagine the current density is constant throughout. Then as I keep on increasing my area, the current increases. As I keep on decreasing my area, my current decreases.

So, here is my fundamental quantity; the basic quantity namely the current density. If I dot it with the surface element, the surface vector d as an integrate that gives me the current flowing across the surface. So, this is the current flowing across the surface. Of course, if I ask what is the current flowing through this surface s 2 in this particular figure, I s 2 is equal to integral J dot d s 2. This is s 1 d s 1 identically equal to 0 because no charge is flowing. The charges are all flowing parallel to the surface of the wire. It is always the cross section which cuts the wire. That is what we have.

Therefore, we have now a precise concept of what is a current and what is a current density and we have also been able to define what one means by a steady flow. We should never forget that divergence J identically equal to 0. By the way, there is yet another notion that I would like to tell you at this particular point although I would not use it.

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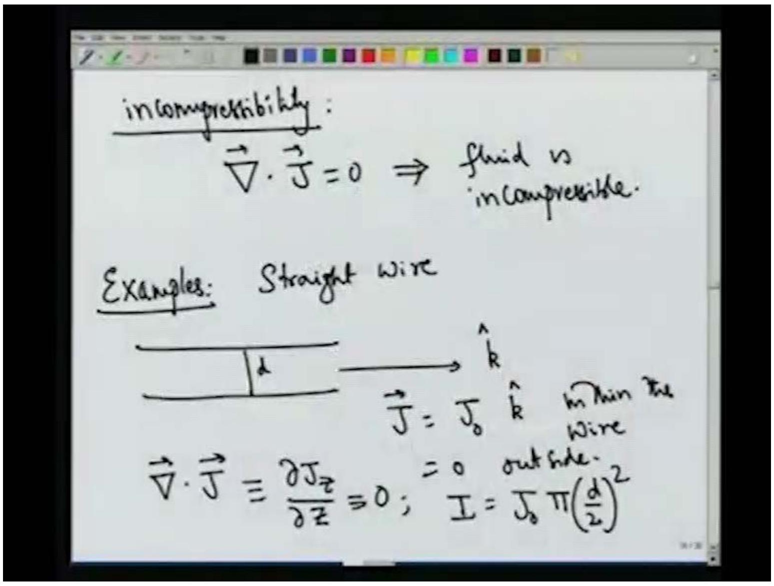

That is the idea of incompressibility. We can always imagine the flowing charge to be some kind of a fluid because it is a field, is that right? And all fields can be imagined to be some kinds of fluids whenever there is a velocity associated with it. So, divergence J equal to 0 means that fluid is incompressible; it cannot be compressed. For all reasonable pressures, water is an incompressible fluid and this again is intuitively possible to us, because if the fluid is not compressible, whatever enters should go out; that means there is no accumulation of charge. Therefore, this is also a statement of incompressibility.

Now, we should be very clear in understanding under what conditions, I would have an incompressible flow; under what conditions, I would have a compressible fluid, or even better under what conditions, I would have a steady current, and under what conditions, I will not have a steady current, and in order to illustrate that, let me give you the following examples. So, let us start with a few examples. We are proceeding rather slowly because although this might appear to be simple, grease light at the heart of all the electro dynamic phenomena the current phenomena that we are going to study. So, we might ask to be careful.

Now, a good Example is that of a straight wire, straight wire. So, let me say that it has a diameter d. Let me take the axis to the along the z direction. This is my z direction. My J is equal to J naught k within the wire equal to 0 outside. So, clearly if I did divergence J, this is nothing but delta J z by delta z identically equal to 0 because J naught is some number. This is the usual notion of a current that we have. In fact, my current is simply nothing but J naught into I gave a diameter d, so, pi r square which is d by 2 whole square. This is my current.

This is an example of a incompressible flow. The same amount of charge is passing through every cross section which is perpendicular to the axis of the wire. We have a constant current which flows and there is a constant density. So, the general notion, the intuitive notion what you expect is that, if there is a constant current that flows, well there better be a steady current, and therefore, divergence J must be equal to 0. One has to be however careful in dealing with this. So, what I shall do is to now look at another example. In fact, this is an elementary physical example.

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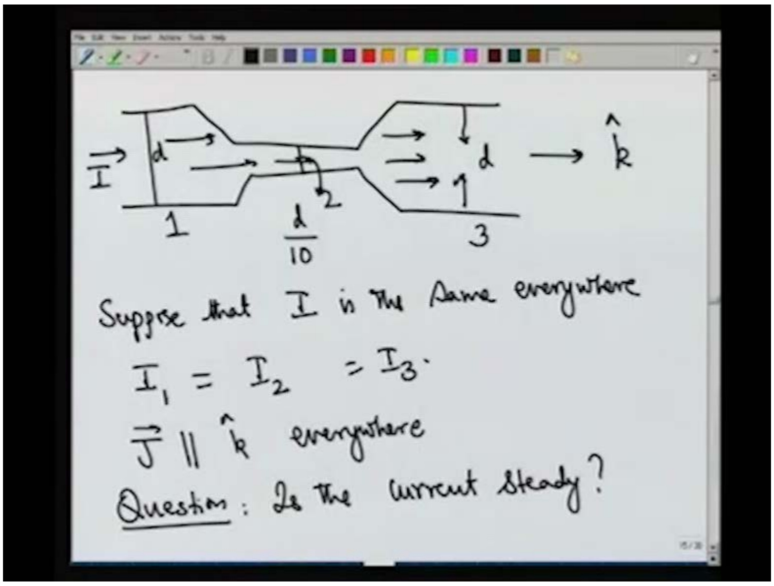

So, let me look at a wire whose cross section looks like this. It is a wire made of the same material. So, here, it has a diameter d. Here, it has a diameter let us say d by 10; it is some number that I am giving; here again I have a diameter d. This is in fact the principle behind the fuse what I do is that I take a wire and then taper it into a very very thin filament and then increase the thickness again.

So, if there is a current I which is flowing here, the same current I will have to flow here, but then, there is a change in the current density, and therefore, there is a corresponding larger heating which I will come to at a later stage. Therefore, what happens is that, as I keep on increasing my current, there will be a threshold value beyond which this part of the wire is going to melt and we say that the whole circuit has got fused.

Now, I do not want to solve this problem, I want to give it as a problem for you people to think. Suppose I assert, suppose that I is the same everywhere. The same current is flowing everywhere. So, let me call this as region one. Let me call this as section 2. This is the section 3 of that length of the wire. So, what we are saying is that I 1 is equal to I 2 is equal to I 3. Suppose I told you that. Suppose I also told you that J is parallel to the z axis. So, this is my z axis which I denote by unit vector k everywhere.

This is what you would imagine. There was a fluid or something which was flowing; it continue to flow straight; it continues to flow here. So, it continues to flow here. Except that here, it was distributed over a larger area here; it is distributed over a smaller area; again it gets distributed over a larger area. Now, the Question is, is the current steady? Well, I ask you to look at this figure carefully. I request you to evaluate the derivatives carefully; I request you to find out what would happen if J is everywhere and provide an answer.

The answer is that it is not a steady current, but as to how it is not steady, how the charge is going to accumulate that I will give as a problem. So, let us call it as a home work problem. We will return to this problem when I discuss the functioning of a fuse after I introduce the concepts of a resistance. But I would urge all of you to solve this problem before actually going on to discuss the other things. So, please take some time to solve this particular problem.

So, now, we have stated the concept of a steady current, and the next thing obviously is to immediately start discussing what should be the magnetic field produced by a current and what happens if a current is flowing in a wire so on and so forth. However, we have to be a little bit more careful here. We have to pause for a while and ask ourselves as to how many kinds of steady currents are there.

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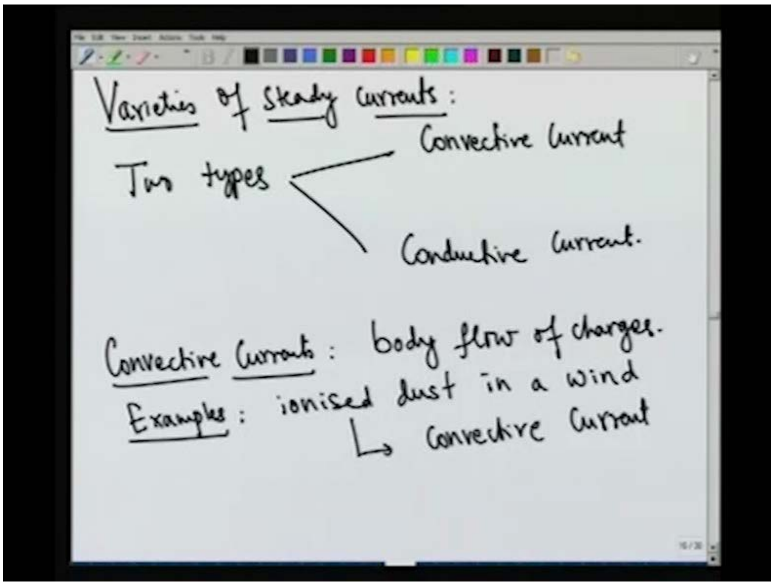

So, you shall now ask a slightly different question what are the varieties of steady currents, so, varieties of steady currents. I would like to give you several examples. In nature, which are different manifestations, which give you different kinds of steady currents, and therefore, we shall ask ourselves that whether all steady currents are the kind of currents that we see in a wire.

The answer is no. Actually there are two types. There are two types - one is what I call as convective current and the second is conducting type, conductive current, and most of the time when we deal with steady currents, magneto statics whatever you people studied in your twelfth standard, we deal with conductive currents, but conductive currents do not exhaust the phenomena of steady currents.

There is a lot of interesting physics even with currents which are not conducting and these are the convective currents. So, let us start studying Convective currents; convective currents arrives when there is a body flow of the currents. I will make this concept more precise body flow that is the charges flow. They do not simply transmit momentum to the neighboring charge, but the body flow of the charges, the charges move

So, what are the examples now like to give? Ionized dust. So, dust you know gets charged, and suppose there is a wind that is blowing in a wind; so when the wind is blowing, carries the dust, and when the dust is flowing, each dusts let us say carries a charge. It may tells about hundred electrons of per unit some peak of coulombs. But then, there will be a certain density of the dust. Each dust particle carries some peak of coulombs of charge and it will be moving along the direction which is the wind is blowing. So, this constitutes a Convective current.

So, if there is a steady wind, then there is a steady current and these currents of course exhibit a variety of phenomena. They will produce a magnetic field so on and so forth, but their behavior as per as the resistance properties are concerned are very, very different from what you would find in a conductive current.

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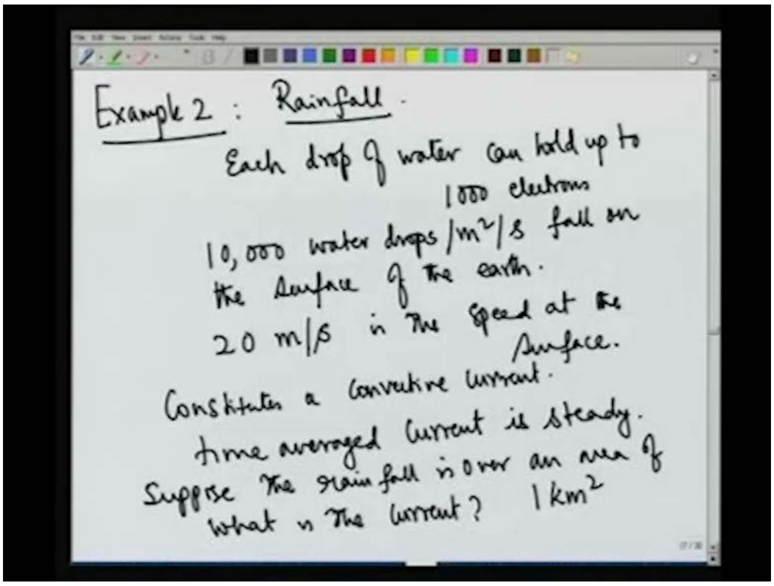

So, this is example one. Let me consider another example and this is a very familiar example, but not from view point of the current and that is rainfall. We are all told that rain water is the purest form of water so on and so forth. But actually in reality, the water molecules, the water drops which fall actually can carry a charge. So, let me give you some tit bits of information. So, typically each drop of water can hold up to thousand electrons, and how many water drops? Do you expect to fall per meter square about ten thousand water drops let us say. I am speaking of normal rain not a very, very heavy Rainfall or anything per meter square per second fall on the surface of the earth.

What is the speed with which they move? Well, at the surface, it will be about 20 meters per second. Not a very fast, it could be 10 20, 25. It really does not matter. So, as I told you these are some typical values, 20 meter per second is the speed, vertical speed at the surface. So, if you imagine that each drop is carrying about thousand electrons, there are ten thousand water drops per meter square per second and there is a certain velocity 20 meters per second. This constitutes a Convective current.

Of course, the total number of electrons might fluctuate from particle to particle, but if I consider for example a centimeter square of area or whatever, the fluctuations average out. There will be on an average 1000 electrons per water drop. On an average, there are ten thousand water drops per meter square. The average speed is about ten feet meters per second. Therefore, the time averaged current, and remember, we already discussed the notion of a macroscopic field a macroscopic charge density and a macroscopic current.

So, the time averaged current is steady, and obviously, you people should be imagining that there is going to be a problem. So, let us say that the Rainfall is over an area of, let us say suppose the Rainfall is over area of 1 kilometer square. What is the current? So, I invite you to do this calculation and then convince yourself that you have got your numbers right. Get the estimate of the current and compare it with the typical currents that flow in your wires at home or in your laboratories and ask yourself whether this is a large current or a small current. Obviously, the current should not be too large. So, I will leave it for you people to ponder about and work it out.

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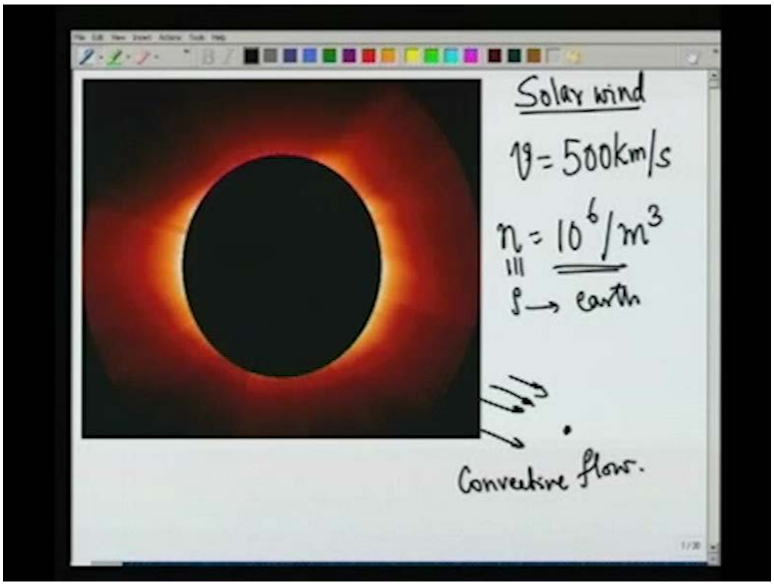

So, what I shall now do is to look at the next example. This is indeed an example of what is called as a Solar wind. So, we have looked at two examples which come from the terrestrial phenomena for the convictive flow. The first one was the dust particles which are carried by the wind. The dust particles were naturally charged because of confliction or whatever.

The second example was that of the rainfall. The third example is now astronomical we are going beyond the realm of the earth and this is what is called as the Solar wind. Now, what is a Solar wind? If you can look at this accompanying picture, this is what is called as a corona, and in the corona what happens is that, it is enormous number of charge particles which are thrown out by the sun. These are called the solar flares and these charge particles travel enormous distances.

Now, I have written down some typical numbers here. The speed with which the charge particles are thrown out are something like 500 kilometers per second. The corona is at a very very large temperature. It is of the order of something like a million Kelvin or so. So, these are all predominantly protons not electrons.

So, they have thrown out at a speed of 500 kilometers per second, and then they travels through what? They travels through the planetary system and they reach the surface of the earth. Now, as they move further and further away from the sun, their density increases. And then they reach the planetary orbit. So, this is near the earth. When they reach the earth and you know earth is about seven light minutes away from the sun, that is, light takes about seven minutes to reach the earth from the sun and light travels with a speed of 300, 000 kilometers per second. Therefore, you can find out what is the distance between the earth and the sun. When they reach there is a flux of about ten to the power of, their density of the protons is about ten to the power of 6 meter per cube.

So, if this is the sun and if you imagine that there is an earth here, so you can imagine that there is a flux of the incoming proton. This again is an example of the Convective flow. By the way, this is a phenomenon which is a branch of an extraordinarily interesting subject called the magneto hydro dynamics because these moving charges produced a magnetic field. In fact, the magnetic flux lines are attached to the charge particles.

And because they are charged, they are also going to produce an electric field. So, there is a lot of study that goes on to study the solar wind, because it will give us lot of information about the sun, but that does not matter, but we see that at the astrophysical level at the, sorry, at the astronomical level, again there are phenomena involving with the conductive flows and that is indeed the familiar, the beautiful example of the Solar wind.

Again, I would like you to estimate what the current is because I have given you the number density; I have given you the velocity. The last example that I would like to give you is a very, very practical example. Except that, unfortunately in this case, I do not have the numbers. Therefore, probably you should talk to your faculty members to your teachers in your colleges and find out.

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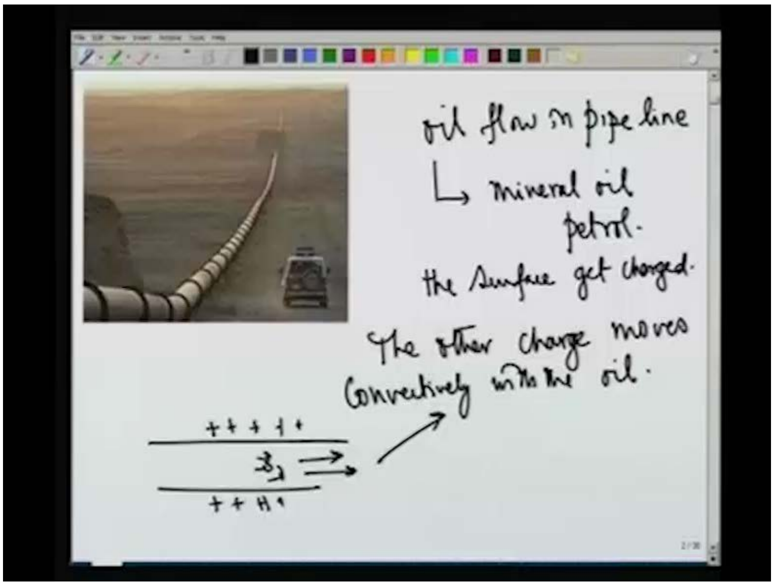

This is oil flowing pipeline and we know that oil flows through enormously long distances through pipelines, and what is the oil that we have in mind? The mineral oil or petrol let us say. Now, what happens when petrol flows through this pipeline and this is a picture of a long pipeline? The, because of the friction between the surface of the pipe and the oil, the surface gets charged. So, let us say positively if the surface gets charged, oil is over all neutral, the other charge moves convectively with the fluid with the oil and this has lots of in terrestrial implications for better and for worse.

So, even here, you see that what is happening is that, if I am going to show you a pipe, the positive charges adhere to the surface and the negative charges stick to the molecules and their flow and this causes gives rise to the convective flow of the oil and there is a steady current that is produced.

So, be it dusts or rainfall or a solar wind or the flow of oil in a pipe, all of them give us the notion are examples of steady currents, and what I would like you people to remember is that the physics of this steady currents of this phenomena is very different from what you get when you look at the steady currents coming from the conductive phenomena and we shall look at that in your next time.

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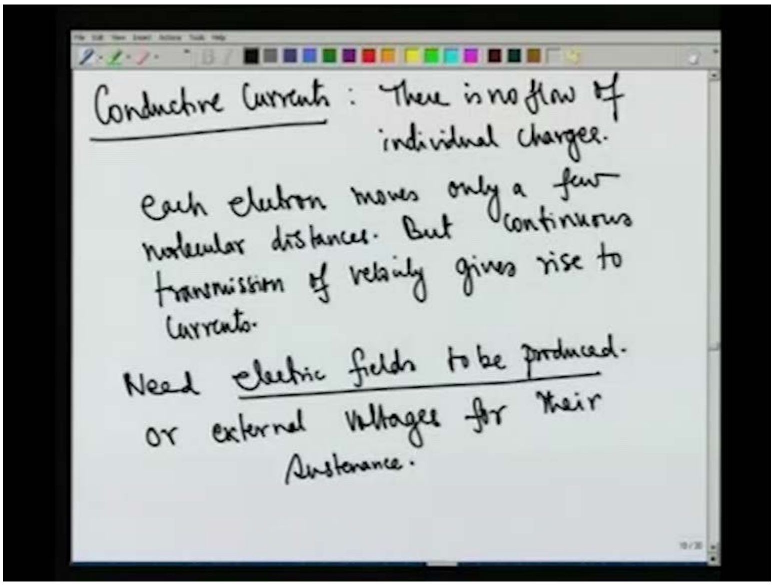

So, now, what we shall do is to look at conductive currents, and this is what we are familiar with in our day to day example of electro dynamics. In the phenomenal of conduction, there is no flow of individual charges. What happens here is that there is a large number of charge particles and you keep on transmitting momentum to your neighboring charge. So, each charge let us say electron one moves only a few molecular distances, moves only a few molecular distances.

But then it moves, it transmits all its momentum to the neighboring electron. Meanwhile the electron behind it again transmits the momentum, and because of which, there is a net current, but continuous transmission, continuous transmission, of momentum velocity gives rise to currents. So, how do I produce a current? The way I produce a current for continuous transmission of momentum is that I have to apply an electric field. So, conductive currents need electric fields to be produced. Please notice that when we looked at the conductive currents, there was no concept of an electric field.

In the case of the wind, it was the kinetic energy of the wind that produced the current. In the case of the rainfall, it was the gravitational field. There is no electric field; there is no voltage difference, and in particular, there is no Ohm's law. But here, in the case of the conductive fields, you should remember whatever I told you when I was discussing the difference between the concepts of a conductor and a insulator, I told you that in conductors there are about 10 to the power of 28 electrons per meter cube. There are that many of them. They keep on transmitting energy because of an applied external field.

They need electric fields to be produced, and therefore, there is a natural dissipation. They give rise to Ohm's law and this we shall study a little bit carefully because that is at the heart of all circuit theory. So that means, they need electric fields or external voltages, for their sustenance, and how are these voltages produced? That is the question that we have to ask.

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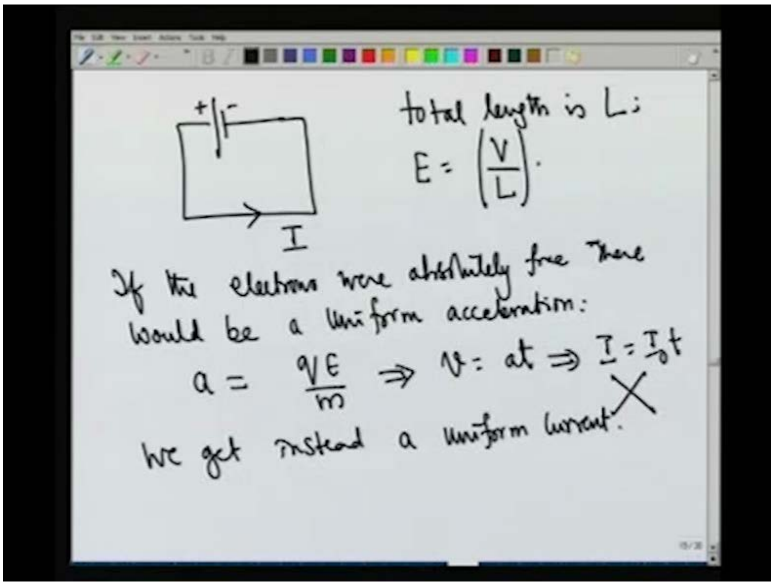

The whole thing is kinetically shown. So, this is my voltage source – positive, negative, and there is a current that is flowing through this. This has a thin filament wire. We do not worry about the thickness etcetera, etcetera, at this particular point. It is carrying a current I, and what is this voltage doing? It is going to produce an electronic field. So, let us say that the total length is L through of the wire is L. Then my electric field is nothing but V by l. You can imagine that there is a source and there is a drain, and then, the total electric field is simply given by V by L. Now, what is the phenomenal unit to the conduction electron? Although we use the language of free electrons in order to describe, this cannot be absolutely free, because if they were absolutely free, a uniform electric field would have produced a uniform acceleration.

If the electrons were absolutely free, there would be a uniform acceleration. This is child's play to all of you how to solve this. You would write acceleration is nothing but what? q E by m which is uniform, which implies V is equal to a t. Even if they were at rest, this implies I is equal to some I naught t because the current keeps on increasing with time, but this is not what happens we get instead a uniform current.

So, the interest in questionnaire is that, how I write that a constant force does not produce a constant acceleration but a constant velocity. The answer to that is obviously that there are lot of coalitions that are taking place. There are frictional forces, and what eventually happens is that the charge particles attain a terminal velocity like you have studied in your dynamics and that is what constitutes a uniform current. So that means that although there is a constant force that is being applied on the electrons, the electrons only move with a constant velocity; that means all the work that is being done should be dissipated away. How does it get dissipated away?

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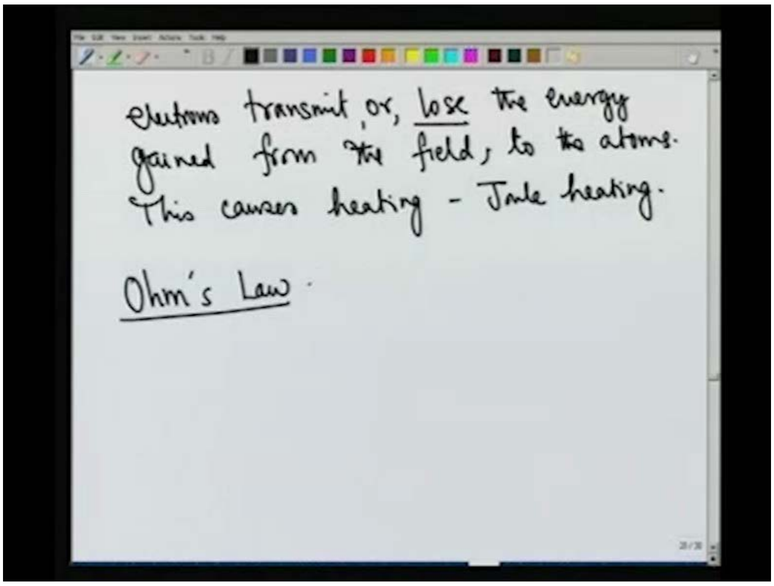

The electrons transmit or lose. That is a better word. The energy gained from the field, gained from the field, to the atoms to the atoms, and what the atoms do? The atoms get heated up and they will dissipate. So, this causes heating, the famous joule heating. So, it is this heating that is phenomenological very beautifully summarize in what we call as Ohm’s law. Therefore, now you should be in a position to appreciate why I took so much time to make a distinction between the convective current and the conductive current. In a convective flow, the charge particles move with uniform velocity, but there is no accompanying dissipation because there are no accompanying coalitions; there is no external related field, whereas here there is a certain joule heating. So, what we shall now do is to study the phenomenon of this joule heating and that takes us to the famous Ohm’s law. So, we shall take up the study of the Ohm’s law and its applications and ramifications in the next lecture.