Engineering Physics -II

Prof. V. Ravishanker

Indian Institute of Technology, Kanpur

Module No. # 03

Lecture No. # 03

In the last lecture we were discussing the concept of the potential, I looked at a very interesting idea due to Lorentz. What Lorentz did was to look at the energy the electro static energy in a spherical char distribution.

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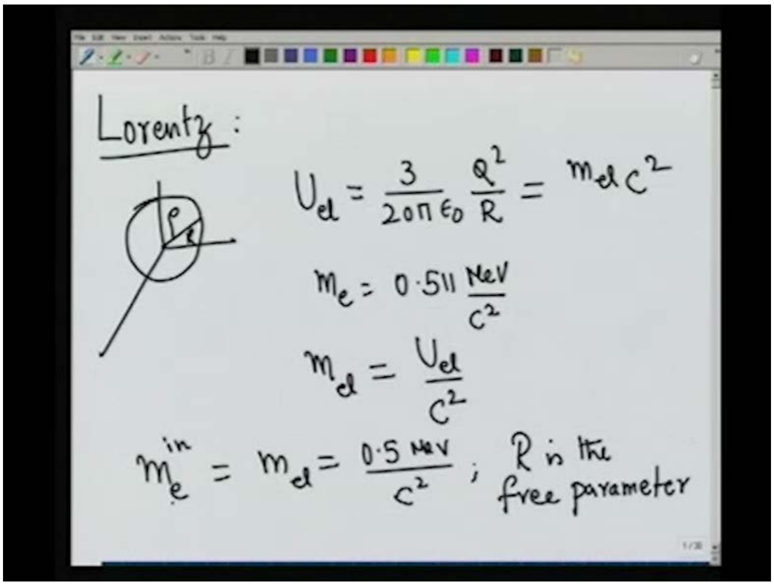

So, what is it that I have is a char density Rho in a sphere of Radius R, we compute at that in the previous lecture. And we form that the electro static energy is given by 3 over 20 phi epsilon naught Q squared by R, where R is the radius of the sphere. So, we are imagining that there is a certain material, of a certain radius R in which the total charge cube is uniformly distributed, that is how we wrote this expression rho is a constant. And in the previous lecture, we derived the expression that the electro static energy is given by this quantity 3 over 20 phi epsilon naught Q squared by R.

Now, during the time of Lorentz the only elementary particle that was known was the electron and people believed that all kinds of charges will be built out of the electron. Of course, there is the nucleus which is made of the proton and things like that we do not have to worry about that, let us concentrate on the Electron. So, what Lorentz did was to argue that, if I consider my object to be not any object but an electron then, we know that my electron also has a mass which is given by 0.511 MeV by C Square.

But, on the other hand from relativity we know that, associated with every energy there is a certain mass, I shall call it as the electromagnetic mass; because I am looking at the electro static energy. Therefore it is the electrostatic mass which is nothing but Mel into C square. Therefore, I have another kind of mass, the electrostatic mass which is given by Uel by C square.

The question, the important question that Lorentz asked was, why should the inertial mass given by 0.5 MeV by C squared be different from the electromagnetic mass. After all, if I subject my electron to an external field my electron moves, as it moves the whole charge moves. Therefore, my electrostatic energy also moves along with it therefore, Lorentz found it very tempting to identify me. The standard inertial mass of the electron with the electromagnetic mass, which is given by point 0.5 MeV by C squared.

This was indeed the temptation that Lorentz had and therefore, Lorentz postulated that perhaps all the mass of the Electron is, because of the char distribution over a certain radius R, in a sphere of a certain radius R. Now, this is indeed a very bold physics and as I said it is a stroke of genius Because now we are actually trying to derive the mechanical properties of an object through it is electromagnetic properties this is a very bold concept.

So, let us go back and look at what the meaning of this identification is if you look at the electrostatic energy know the charge of the electron the value of the epsilon naught is fixed. And on the other hand if you look at the inertial mass the mass is known 0.5 MeV by C squared, therefore the only free parameter is the radius of the electron R is the free parameter. R is the free parameter in the U electrostatic and that gets fixed by identifying my M electrostatic with the M inertia, so this is indeed what Lorentz did…

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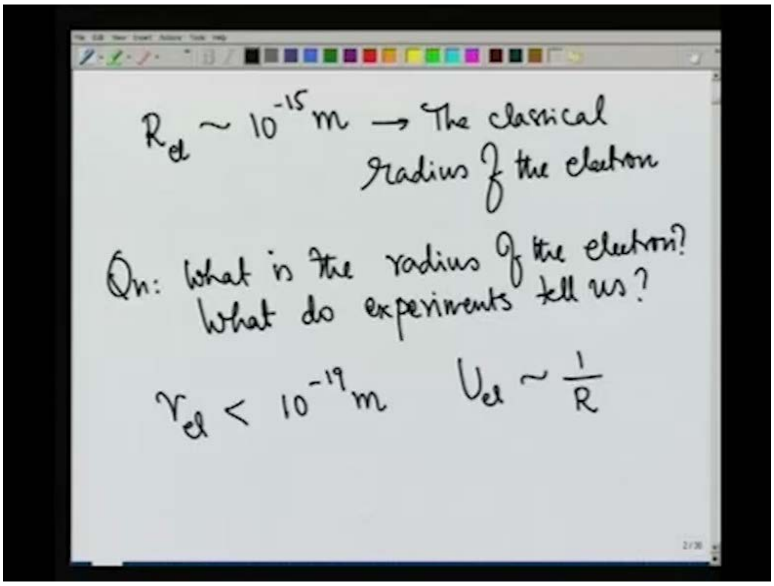

Now, we know all the values invite you people to pick up your paper and pencil and plug it, if you did that you will find that R electromagnetic or electrostatic. Let me call it turns out to be of the order of 10 to the power of minus 15 meters. So, if indeed the mass of the electron arose, because of the electrostatic energy of the electron, it is a different matter as to how this charges are held together, let us not ask ourselves that questions.

Then my Electron should carry a radius of 10 to the power of minus 15 meters of around 10 to the power of minus 15 meters our concentrations are completely classical. Therefore, it is also called the classical radius, the classical radius of the electron. Classical electromagnetic radius of the electron, that is what we should call, if it is correct then I should be able to perform an independent measurement and then measure the radius independently and ask whether it agrees with 10 to the power of minus 15 meters therefore, the question is what is the radius of the electron? What do experiments tell us? Tell us...

The answer to that comes from the, so called scattering measurements and I did I already told you at the beginning of this course. Let me repeat we know that, the radius of the Electron is known to be less than 10 to the power of minus 19 meters. Please notice that 10 to the power of minus 19 meters is the upper limit on the radius of the electron. What is the statement that we are making, if at all the electron has a radius it has to be less than

10 to the power of minus 19, perhaps it is 10 to the power of minus 20, perhaps it is 10 to the power of minus 30, perhaps it is 0.

In fact, all known Experiments today, which have proved lengths to very short distances tell us that, it is convenient to assume, that my electron is a point particle. However, if you look at the expression for U electrostatic, we find that the energy goes like one over R that is the electrostatic energy of the charged distribution increases indefinitely. It diverge the one over R though therefore, as R goes to 0, U electron goes to infinity. This is a major problem and it clearly tells us, that the idea of Lorentz's not going to work.

If this idea is not going to work, why did then said that Lorentz had a stroke of genius, it was an act of genius, to get a complete answer to this question you have to wait for a while. In the second part of the course, you people will study a little bit of modern physics a little bit of quantum mechanics and one thing that you people will realize is that this so, called classical radius of the electron demark it to different regions.

If you are looking at physics in Lorentz greater than 10 to the power of minus 15 meter, you can actually use classical mechanics, as far as the dynamics of the electron is concerned. but if you are looking at phenomena less than 10 to the power of minus 15 meter then, you should use quantum mechanics. Therefore, although this idea might not have worked out this idea is not useless, in fact, it is quite useful provided we combine this idea with ideas of modern physics namely quantum mechanics. So, this is something that we learnt by a little bit of extrapolation from our standards electrostatics.

Before I conclude my discussion, I am tempted to work out two more examples, I will not work out the problems completely, I will indicate to you as to how to solve these problems. but I would urge all of you to solve both these problems because we will gain experience in finding out the interaction energy and also these are interesting problems from the view point of electrostatics. Now, so far I looked at two concentric circle or spherical distributions or a single spherical distribution.

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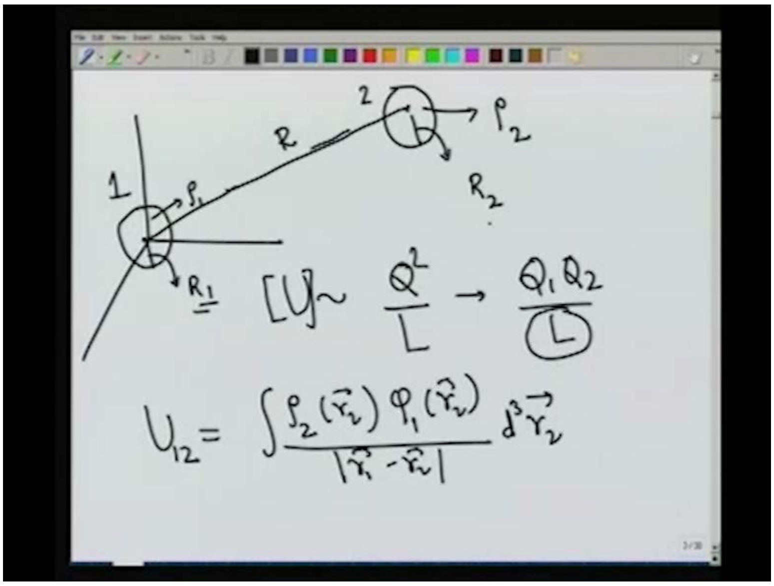

Now let me look at another case, where I have one spherical distribution of charge here. So, this as radius R 1 and the char density is Rho 1, this is my system 1, now at a certain distance, I have another spherical char distribution. Now this spherical char distribution has a Radius R 2, there is a density rho 1 which is sitting here, the two sphere is displaced with respect to each other.

Now earlier one sphere was envelop in the other sphere, when I looked at the surface charge densities, now they are displaced with respect to each other, and there is no overlap of the charge densities. And if I want to draw a line connecting the two center the distance between the two centers is given by R. So, how many landscapes is there, the radius of the sphere 1 that is R 1 the radius of sphere 2 that is R 2; the distance between the two centers R, these are the three length scales that I have and of course I have the Rho 1 and I have the Rho 2.

Now, I ask myself what the interaction energy between these two spherical charge distributions, this problem is not without interest, if you remember what Newton had to do in the similar context of gravitation. Newton could not straight away make use of the idea, that the sum can be treated as a point particle, because for a long time he could not prove that the potential produce by a spherical distribution is the same as the potential produce by a point mass all concentrated at the center of the sphere. So, long as you look at the point outside the sphere.

Today we are able to prove energy free in a minute by making use of Gauss's law. But Newton did not possess Gauss's law; therefore, he had to invent methods integral calculus in order to explicitly evaluate it. And historian can ask that it took him more than 20 years to prove that result and he postponed the publication of principia mathematical by that many years.

Now, what we doing are to slightly complicate the problem, we are not looking at a point mass moving in the field of the spherical char distribution. In the case of gravitation, it would have be spherical mass distribution, mind you in planetary motion; we assume the planets to be a point mass. Here, we are looking at two spherical char distributions, two spherical distributions and we are not making any assumption on the values of R 1 and R 2 and I am asking is it possible for me to compute the interaction Energy.

Now, I know one thing that dimensionally my energy should look like Q squared over L. So, Q square that means, it should look like Q 1 Q 2 divided by L except that there are lengths case R 1 R 2 and R. And how are we going to argue what kind of a combination of R 1 R 2 and R are going to contribute to this my L, so what we are interested is in the dimensional analysis that is what we are trying to do.

However a little bit of star tells you that, this problem is in fact very, very simple except that in order to perform this integration, do not look at the field, do not look at the charge densities. but write the expression my U is simply given by integral rho, let me say 2 of (r 2) this is what I have, then phi 1 of (r 2) divided by mod r 1 minus r 2 d cubed r 2. So, I am writing the interaction energy, so perhaps I should change my symbol here, what I will do is, I will replace U by U 1 2, that is what I shall do.

Now, because my charge distribution one is a spherical charge distribution, I know that the potential produced by this charge distribution is as if all the charge were concentrated at the origin. In other words, phi 1 of r 2 is independent of r 1, if phi 1 of r 2 is independent of the radius r 1, which means if at all this U 1 2 has to depend on some parameter, it has to depend on the distance R and the radius r 2. but then we know that this expression is symmetric between the potential and the charge distribution.

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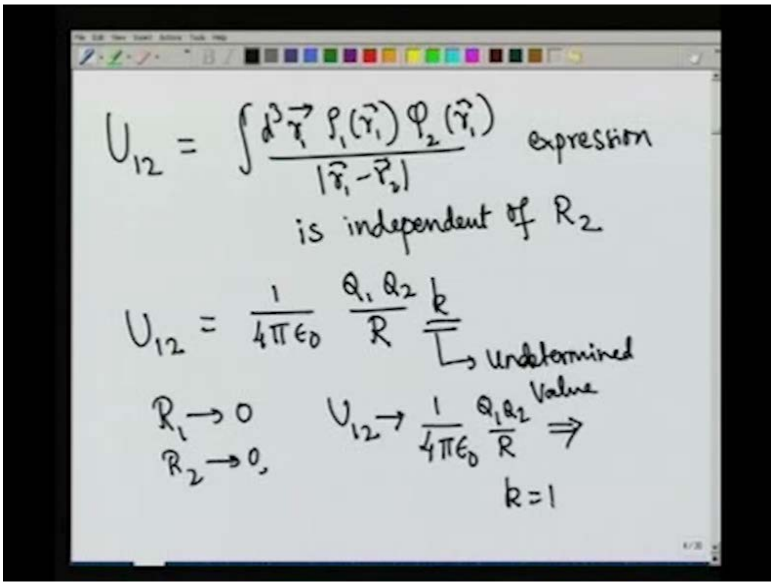

Therefore let me write one more expression now, I will say my U 1 2 is simply given by integral d cubed r 1, now I will integrate over the first charge distribution which I had written around the origin. Now I will write rho 1 of R 1 phi 2 of r 1 divided by mod r 1 minus r 2, this is the equivalent expression. So, we are calculating the potential coming from the second spherical charge distribution, which was displaced with respect to the first one and they are asking ourselves the questions what it is, again we will find that this expression is independent of independent of R 2.

My previous expression told me that, it is independent of R 1, this expression is telling me is independent of R 2 and therefore I conclude that my U 1 2 must be simply 1 over 4 phi epsilon naught Q1 Q 2 divided by R. Of course, this is not the end of the story and some number, which I shall denote it as k which is yet undetermined. So, except for an overall multiplying factor we have been able to write down the potential energy between two spherical charge distributions. It is exactly the same as the potential energy of two point masses, except an undetermined k, undetermined k value.

Now, it is a pretty simple matter to determine the value of k, because we know k cannot depend on R 1 R 2 or R; all the dependences have been exhausted. Therefore, we shall take the limiting case when R 1 goes to 0, R 2 goes to 0. When both of them goes to 0, we know that U 1 2 goes to 1 over 4 phi epsilon naught Q 1 Q 2 by R but then this should come as a limit of this particular case, this implies k is equal to 1.

So, by intelligently making use of Gauss's law, and the fact that I have used spherical charge distributions. We have found that the potential Energy of two spherical charge distributions is exactly the same as an equivalent potential energy of the charges, concentrated at the centers of the respective spheres.

This argument would of course hold even in the case of gravitation. Therefore, if you take earth to be completely spherical, if you take sun to be exactly spherical, then all that you need to know is what the distance between the centers of the sun and the center of the earth and that will simply give you the interaction Energy. So, long as we can ignore we can neglect the rotational motion either of the sun or of the Earth; so this is an interesting lesson that we have learnt.

Now, what I would like you people is to actually convince yourself, that my previous argument was right by doing an explicit calculation. That calculation is not difficult to perform, all that you have to do is to simple integration there are similar integration which are found in books like graphics, you may look them up, and I would like you to do that.

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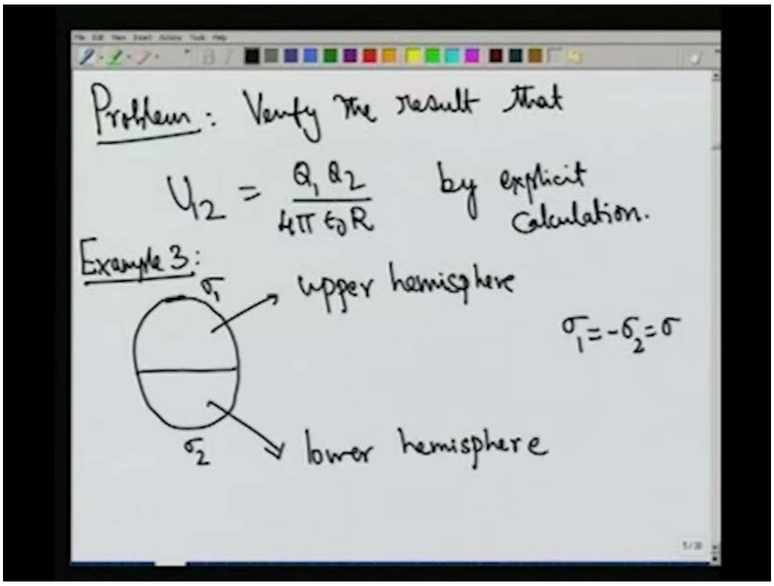

So, let me give you the problem, the problem for you is that verify the result that U 1 2 is nothing but Q 1 Q 2 over 4 phi epsilon naught R by explicit calculation that will give you some experience. So, let me give you this problem and then go to the final example before I go on to discuss certain interesting aspects of electrostatics.

The next problem is quite interesting, what is to again consider a sphere and make a distinction between the upper hemisphere upper hemisphere, and the lower hemisphere. So, here is the last example which I am working, may be example 3, if I am remember right, what I shall do is to paste a uniform surface charge density sigma 1 on the upper hemisphere and the uniform surface charge density sigma 2 on the lower hemisphere.

Now, the way that I have done this, I have constructed a sphere looked at the equatorial plane, there is a sigma 1 on the upper hemisphere, there is a surface charge density sigma 2 on the lower hemisphere. And in order to make my life simple, if you want although it is not necessary for calculation, you can choose sigma 1 equal to minus sigma 2 equal to sigma can be taken to be greater than 0. So, obviously what is the question of interest for me, the question of interest for me is the interaction energy the potential energy between the upper hemisphere and the lower hemisphere.

Now, this is an interesting example in integration using spherical polar coordinates. So, let me write down the expression for you but I will not work out all the steps, I will ask you to fill in the gap.

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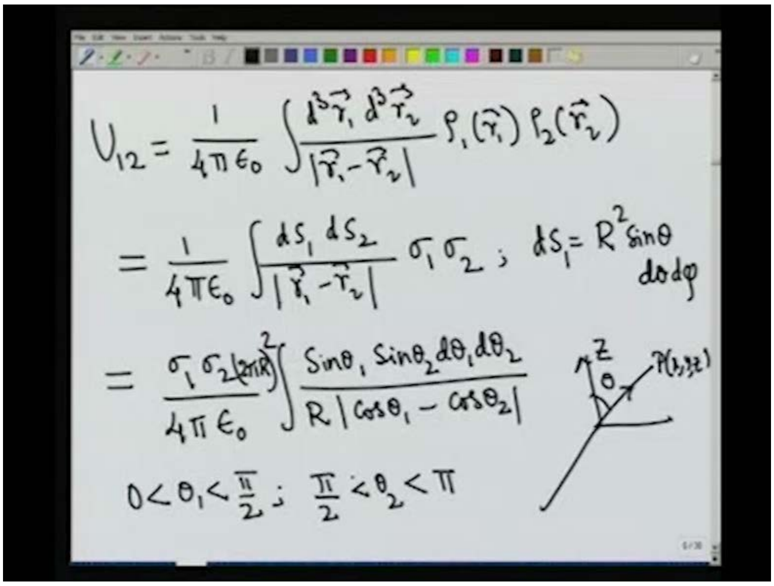

So, how does the expression look like, in order to evaluate this expression, I will now employ the expression for the energy as given in terms of the two charged density.

So, mind you what have I done in one case, I looked at the expression for the field E 1 dot E 2; in another case, I extruded the expression in terms of the charged density and the potential. Now I am using the third equivalent form namely the interaction energy Return in terms of the two charge densities and that is nothing but 1 over 4 phi epsilon naught integral d cubed r 1 d cubed r 2 mod r 1 minus r 2 is what I have rho 1 of r 1 rho 1 of r 2.

Rho 1 of (r 1) corresponds to a charged density on the upper hemisphere, rho 1 of r 2 corresponds to charged densities on the lower hemisphere. Mod R 1 minus R 2 gives you the distance between a charge distribution in the upper hemisphere and the charge distribution in the lower hemisphere and we would like to evaluate that.

Now, the first exercise that you have to do is to learn to write my surface char density in terms of the volume charge density. So, you people should convince yourself that this expression is nothing but 1 over 4 phi epsilon naught into, I am not interested in what, the volume charge density but the surface char density. Therefore, I will write d s 1 d s 2 this are indeed, what the surface elements, then I have mod R 1 minus R 2 into sigma 1 into sigma 2.

I have taken sigma 1 to be constant and sigma 2 to be constant; therefore, I have a d s 1 d s 2 mod r 1 minus r 2. This is my expression for the energy and you people should convince yourself that, it has the right dimension, sigma 1 d s 1 gives you, one charge sigma 2 d s 2 gives you another charge. Therefore, it has the dimension of Q 1 Q 2 by R with the factor 1 over 4 phi epsilon naught and that is indeed the correct expression.

Now, since sigma 1 and sigma 2 are constants and since we have said that it is equal charge, actually it need not be at this particular point, how do I write that. Let me bring it out as the first step, I will write it as sigma 1 sigma 2 over 4 phi epsilon naught and now we are going to write the expression for d s 1 and d s 2. If my sphere has a radius R obviously, I am going to get a factor 2 pi R whole square; let us understand where it comes from.

The factor 2 pi comes from an integration over the phi degree of freedom and the surface element is what R square d omega and d omega is sin theta d theta d phi. So, let me write that d s 1 is nothing but R squared sin theta d theta d phi. I have performed an integration over d phi will get a 2 pi, 2 pi R square, it is what I am going to get. And then I get another 2 pi R squared, so that together will I 2 pi R squared whole squared and that is this expression.

Now, we are left with the integration over sin theta 1 sin theta 2, so let me write it here sin theta 1 sin theta 2 d theta 1 d theta 2 is what I have and I have to write my Expression for R. And you people can convince yourself that, this expression mod r 1 minus r 2 is nothing but R mod cos theta 1 minus cos theta 2.

So, why am Employing my spherical polar coordinate system here, so if I have a point p (x, y, z), this angle theta is what the radius vector makes with respect to z axis that is what I have. The only thing that they have to be careful is to fix the Range for the integration theta 1 and theta 2. Now this on the upper hemisphere theta 1 will go from 0 to pi, 0 less than theta 1 less than pi by 2, is the range for theta 1, pi by 2 less than theta 2, less than pi, and is the range for theta 2.

You have a cos theta here, you have a sin theta d theta and sin theta d theta is nothing but d of cos theta. Therefore, what invite you people to do is to integrate this expression. If you integrate this expression you people can see, that you will get an expression d t 1 d t 2 divided by t 1 minus t 2. Therefore, how does your expression for the charge look like.

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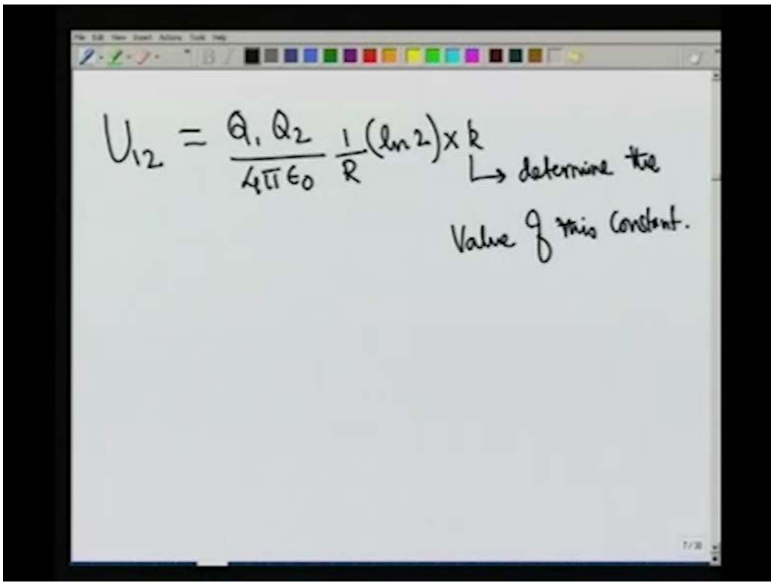

The Expression for the Energy density will roughly look like, let me give you the answer I will get a Q 1 Q 2 4 phi epsilon naught with a 1 over R, some number of the order of one and a number of the order of 2 into some constant.

So, what I ask you people is to determine the value of this constant, so this is the next problem for you. And remember, this result Because this can be used to actually determine other quantities at later stage, if I make it into a conductor or some setting although it would not be entirely correct to do that. So, let me leave it as the last example last problem for you in terms of the potentials, and now what I shall do is to go on to study other properties the real properties of real materials.

So, in some sense all this time I have been looking at what I will call as text book problems or problems of academic interest. However, the big question that arises is where is electrostatic important? Electrostatic is important for me in real life, we know that electrostatics phenomena was first discovered probably 1000 of years ago, when one of the ladies was combing her hair or when they rubbed hammer against something else. but today are these electrostatic phenomena merely of some interest, because it is there in our syllabus or do they have any practical significances, that is the question that we have to ask ourselves.

The answer to that is provided by looking by around everyday phenomena and one thing we should know is that modern civilization today is dominated by electromagnetic. In fact, apparently when Faraday found induction law, discovered his famous induction law it tells you that, whenever there is a change in magnetic flux there is a corresponding induced e m f. Some politician ask them what is the use and Faraday told him as of today I do not know what its uses, but let me assure you, we are certainly going to collect taxes based on that.

In a similar manner, we have to ask ourselves Coulomb gave us the Coulomb law, we have been able to write it in a very sophisticated form divergence E equal to rho by epsilon naught cur of E equal to 0. but what is the impact, what is the import of this electrostatic phenomenon on our daily life for better or for worse.

The answer to this question actually goes back to first of all trying to asking the question, what kind of charges can be carried by various objects. If I am going to say look here I charged a body and 2 electrons sat on it or 3 electrons sat on it, that is not of much use, we should first of all ask ourselves what kind of a voltage is developed when I produced.

For example, electrostatic charge distribution by friction or some other means, therefore first of all, let us look at real life examples what kinds of voltage are produced. And then go onto ask what kind of effect they can have that is indeed the proper way of looking at all these things. So, let me start looking at the some of the examples, so the first example is constructed in this particular table and let me look at the first example, what I want is this example.

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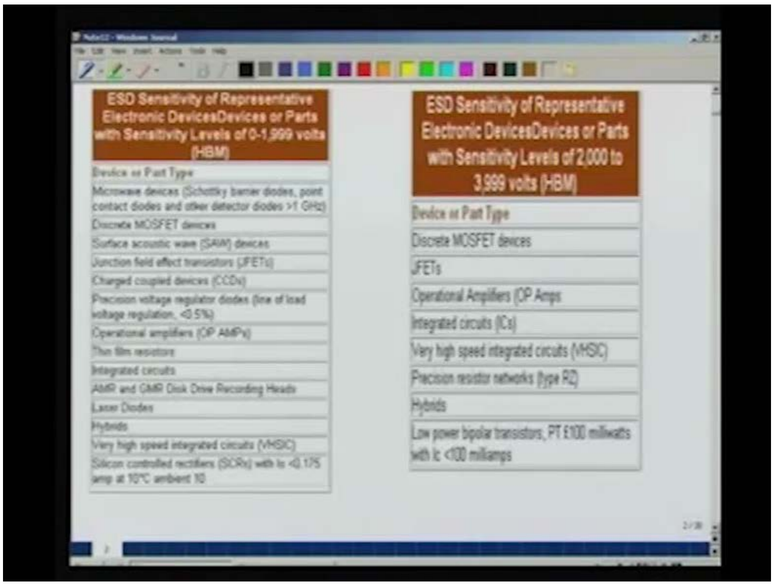

And the most important that we have to notice is that electrostatic phenomena in everyday life involve very high voltages, we have five volt batteries. And we connect two of them and three of them and we perform experiments, no that is not the kind of voltage that we are interested in. And here is a table which tells you the kind of charge and the kind of voltage that you can pick up.

Of course, it depends on a variety of conditions, what kind of a dress you are wearing, what kind of shoes you are wearing, the kind of surface on which you are walking, what kind of a humidity it is and look at this table. This table tells us that, if you walk across a carpet and if there is very little humidity, what is the humidity? Relative humidity the humidity in the atmosphere as far as we are concerned who can pick up an enormous voltage, a voltage as large as 10 to 35,000 volts which is not a small volt at all. If you look at A C voltage source it is 230 volts that is what we have you can pick up an enormous voltage.

However, if you are lucky that the atmosphere has lot of humidity imagine, that it is a rainy day or you are in a coastal area where there is always a lot of humidity then, the humid air will take away lot of charge from you. It will be down by many orders of magnitude, because it is almost ten orders of magnitude and will turn out to be 1500 volts this is walking on a carpet, this is a highly insulating material and when you walk there is a friction between your shoes and the carpet that causes a charge transfer.

If you decide not to walk on a carpet but on a modern house in modern houses, we put winery tiles all over the place, because we look we want our houses to look very nice. If you did that you would not pick up something 35000 volts, but you pick up something like 12,000 volts.

What about a worker at a bench? A worker at a bench will be hammering will be working on a lathe or he might be doing carpentry. Again there is a lot of friction and experts who have made measurement say that, you can pick up actually voltage up to 6000 volts. If you are working under there is some polythene bag, which is a very good insulator and you see that if you did that a voltage can be as large as 20000 volts. And of course, we all have our modern chairs we do not sit on gored chairs or wooden chairs, we have these gratin formed chairs right nice fancy chairs which companies like gore makes you can pick up a volt like 18000 volts.

So, seemingly in or near actions on our part seem to be producing voltages of enormous values all the way going from something like 6000 volts to 18000 volts. As I told you, if the humidity is very, very large it goes down correspondingly, but please notice that even these numbers 15000, 2500, 1200, 1500 are not small numbers therefore, we have to treat them with respect.

So, imagine that I have actually walked along a carpet or picked up a poly bag or rubbed myself against something else, this way of transferring the charge is what is called as tribo electricity. Tribo is a word which is used for friction by friction; I have been able to transfer the charge. Now I ask I go and try to switch on an electronic equipment I straight and sit in front of a computer or I open the computer and look at the lead which is connecting to my hard disc etcetera.

And I ask how much of voltage can actually be taken up by this materials. If the threshold voltage at which they work is much smaller than the voltage carried by me the minute, I discharge that much electricity to those equipment they may break.

So, again this electrostatic discharged centimeter has been shown in this table, the first table tells you the sensitivity up to 0 to 1000 volts and mind you these are devices which are used in everyday life. The first one gives you microwave devices, the second one is MOSFET which you people will encounter in your laboratory; then you have CCD's Charged Couple Devices, which are used everywhere. Operational amplifiers which are all in your electronics, laser diodes and look at this you have the G M R disc driving record, which are there in your computers.

So, you better be careful to discharge all your voltage before you touch the sensitive equipment. And mind you these voltages are not too large Because I told you that you can pick up as much as 20,000 volts 30,000 volts by simply walking.

In fact, you do not even have to look at the here examples, if you are a person you can give shock to another person also that is a different matter altogether. There are also devices which are slightly higher than this; so for example, you have again certain integrated circuits, hybrids, transistors, etcetera, which have a sensitive level up to 4000 volts. Therefore, all the way from 0 to 4000 volts we have a large number of a plethora of a circuit of electronic equipment which can break down.

Experts who studied this in fact, there are whole organizations called what electrostatic discharge societies there are generals devoted to that. You can go to internet and you can find out or you should go and ask one of your teachers, who may be working this area they tell us that, we should be very careful in handling this equipment, because they may break down.

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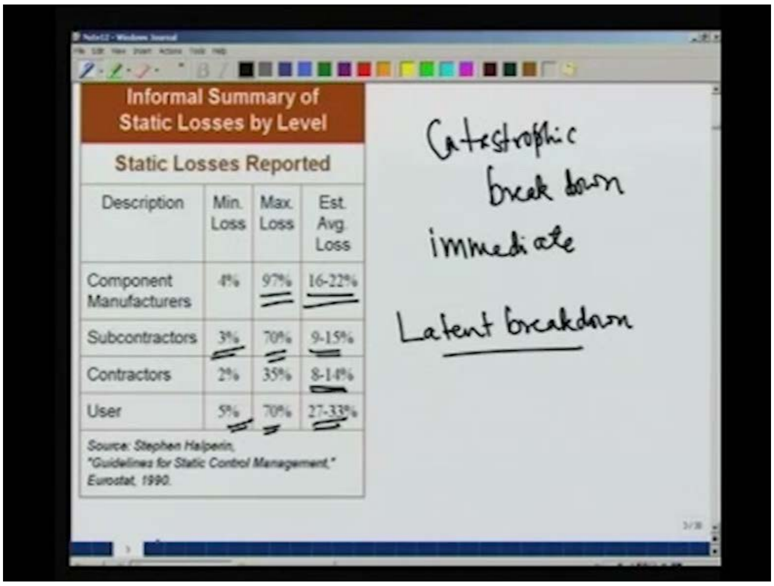

And there are one kinds of break down apparently one is called catastrophic breakdown, catastrophic breakdown where the breakdown takes place immediately. So, I charge myself and I try to open up my computer or some other electronic equipment my hi-fi system it breaks may be blaming my manufacturer actually the culprit may be my walking on the carpet. So, we should be very careful before we blame the manufacturer, if it breaks down immediately it is called catastrophic breakdown, here the breakdown is immediate.

But, on the other hand, the more dangerous the more (( )) where is not easy to trace the origin is what is called the latent breakdown. In the latent breakdown what happens is that there is not a complete breakdown but the efficiency of your component goes down and then after repeated such usages one day it will break down. And that day you might think look here this was a perfectly humid a I did not carry any charge then spite of it broke down therefore, it might be the manufacturer's mistake.

Now, please be careful there may be a latent breakdown and that can also be cast by this equipment. Indeed, if the user can cause a breakdown perhaps breaks down they are take place at all levels when there is a manufacturer, when it goes to a contractor, when it is packaging and things like that. And here is a table which the engineering experts have actually compelled, you see that the component manufacturers themselves spoiled the equipment sometimes up to 97 percent. On an average 20 percent of what the manufacturer manufactures is lost to us, because of the electrostatic discharge.

Then, there are subcontractors who buy this equipment and assemble them like various computer forms that we have in our country, there the loss goes from 3 percent to 70 percent with a mean of about 9 to 15 percent. Then there are contractors who probably package them and all that, there the mean breakage is about 8 to 14 percent. And the users are there who can cause a loss from 5 percent to 70 percent with a mean of 27 to 33 percent.

So, what is the lesson that you have learnt, the lesson that you have learnt is electrostatic discharge is of nuisance value is the part, at least, so far what we are seeing is this that it is a nuisance value. So, we started with a glorious subject called electrostatics we did lot of vector analysis vector algebra, we wrote it in a sophisticated form only to conclude that it is acting as a nuisance trying to spoil my equipment is it indeed so. The answer is no if the electrostatic discharge has a flop side it also has a flip side and where does the flip side occur.

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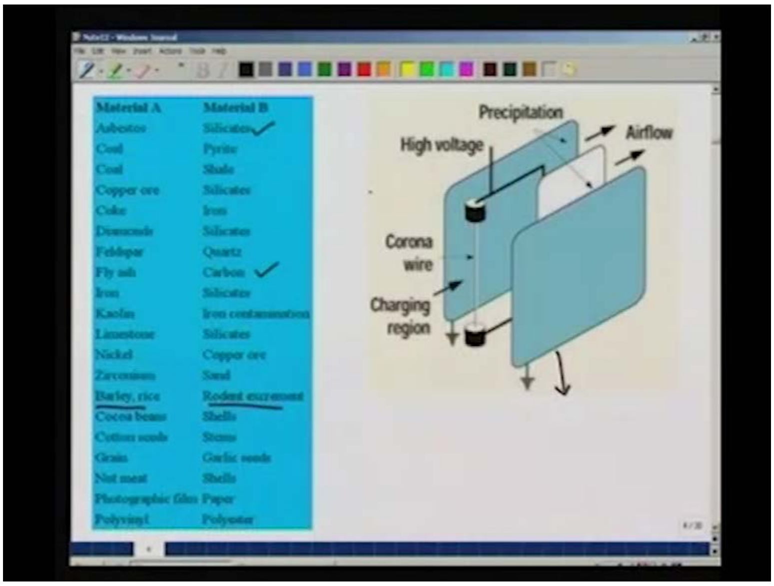

Here is a representative picture, which you how electrostatic discharge can actually be use and when is in the supersession of a material, if I have an anode and a cathode which I have shown here, there is a high voltage. So, called a corona wire which causes a voltage difference between the two plates, then the voltage difference that I create between the two plates can actually be used to separate material.

The figure on the right hand side tells you, how to actually purify your air, my air can have lot of ions which carry a charge and it is not very good for us to inhale this ionized gas. So, what we have to do is to actually neutralize trap all ions and get the neutral air, where does it occur in factory for example, where the lot of production is taking place in open air equipment the air can get ionize it is essential to purify the air before it is let out and that is where the separators are useful.

Or for that matter if you look at your stove in your house it produces a shoot of course there is a steam, there is a smoke, that is coming out it carries a lot of shoot, that will be ionize. And what you do nowadays you put sophisticated chimneys, which attract all those shoot, that also uses the principle of electrostatic discharge. Because the shoot is ionized it goes and settles on to the metal plane which is at a certain potential attractive potential.

Now, there are many, many materials which you would like to re separate asbestos might be mixed with silicates, this is one particular example; fly ash may be mixed with carbon we know that fly ashes use made use of in making very good cement. Nowadays in thermo electric plants then of course all of us have to view and all of us have to eat in order to live. Either I may have to separate barley and rice from rodent experiment rodent is there, because of the pests and that is very bad for the health nobody wants to eat them.

Or I might like to separate coco beans from the sheaf, coco beans are used for making chocolates, which we all like, I will like to separate grain from garlic seeds so, on and so, forth. Or photographic film paper polybrene from polyesther all these can be done by using the separation method.

Not only that, earlier you see that people whenever they wanted to paint surfaces, the painter will take a brush and paint it. but nowadays we have what is called as a spray painting or if you look at your chairs or if you look at your trays in your house in your microwave or your baking oven they are all powder coated. What is the principal behind microwave coated may be this powder coating or the spray coating, the spray painting and the powder coating are again based on the electrostatic voltage difference.

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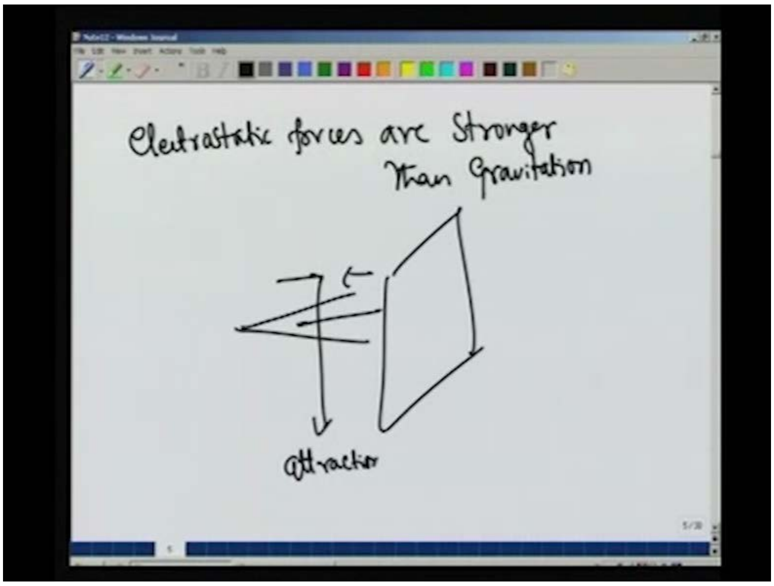

What is the great advantage in this, the great advantage in this is that electrostatic forces electrostatic forces are stronger than gravitation. So, suppose I have a plate here and there is a spray gun which is sending the paint, if I am paint holding it like I am painting it. I can ignore the effect of the gravitational force, because the electrostatic force is much, much stronger, the electrostatic attraction is much, much stronger. So, what is the principle behind this spray painting or the powder coating let me list them.

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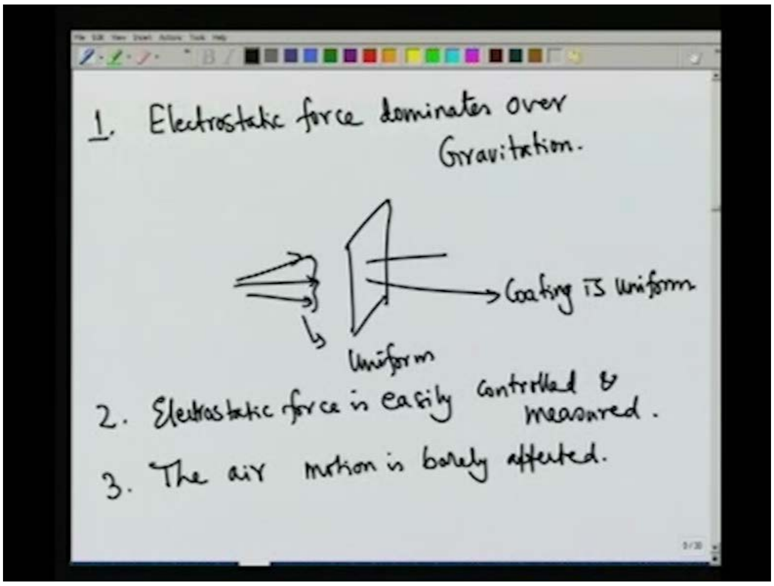

The first thing is that electrostatic force dominates over gravitation, so, I have a plate which has to be powder coated or painted I hold it as a certain voltage. And if I have a gun and if I spray it the effect of gravitation is negligible and so long as this is uniform the coating is also uniform. Secondly, the voltage difference that I apply is easily measurable, unlike gravitational force which is very weak this is easily measurable, so dominates over gravitation.

Number 2 electrostatic force is easily controlled and measured that is the next advantage and the third one is I am sending this in the air does it affect the air motion. The air motion is barely affected, so that we are not affecting the environment all this go to make it into your plus point. And therefore, you see you want to separate, you want to coat, you want to paint, all these situations it is much better to use electrostatic principles, rather than the volt brush and the paint.

So, to summarize my discussion of the impact of electrostatic forces on our modern day life for better or for worse it has a dominant role. As I told you, we are living in a sea of electromagnetic phenomenon of which electrostatic phenomena are also a part therefore, if we are careful, if you are wise, if you are intelligent. Then we should actually be able to make use of electrostatic phenomena to our advantage rather than to our disadvantage.

This brings us to the next question as to how; I actually employ electrostatic phenomena to my advantage. You see I made a statement that if I want to walk on the carpet, I pick up a voltage of up to 35000 volts who walks on the carpet. Now there is a great distinction between a child walking on a carpet or a dog walking on a carpet or a fully grown person walking on the carpet, what kind of a shoe am I wearing and what kind of a humidity etcetera, etcetera.

In other words whereas, all this time we imagined charges to be abstract and are given at will because we wanted to solve a few text book problems, now we have to actually study properties of the materials. So, now what I am going to do is to start a new topic. Let us remember, we want to start this new topic, because we want to understand the electromagnetic phenomena in media.

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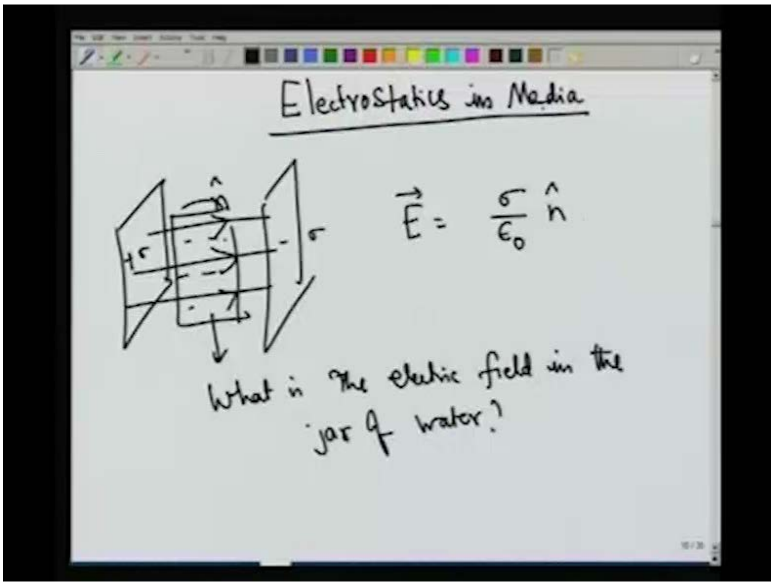

So, this I shall call as electrostatics in media, in media a subject which was again started by Maxwell and sought of put on a very form by Lorentz. That is what we want to study and ask how certain objects respond in a certain way to external environment consisting of the electric fields. So, what am I trying to say, now my purpose is more ambitious I am not interested in Coulomb law anymore only in free space, I am also interested in Coulomb law in a medium, so imagine that I have a parallel plate capacitor.

So, I have two plates this carries a surface charge density sigma, this carries a surface charge density minus sigma and it produces an electric field, it produces a uniform electric field. And Gauss's law tells us that, my electric field is simply given by sigma by epsilon naught is that right. Sigma by epsilon naught is what we are going to get that is what gauss's law tells us and of course, if I call this as the direction n this is what it is.

Now, a kind of question that you want ask is suppose I put a jar of water containing in this. So, I put my water in this, what is the electric field here in the jar of water or perhaps wood or perhaps mica or perhaps a metal is that or perhaps a very something like a super conductor. So, now, you see I am using many words, I use the word like metal, I use the word like super conductor.

So, in short the question that we are asking is, how do different materials respond to external electric fields and how do they modify, because of that response the field within and the field without. And that goes by the subject matter of electrostatics in media, this indeed is extraordinarily important subject for all of engineering.

So, I am going to go very slowly very carefully, let us set some time but before we do that, before we try to ask questions like what is the electric field or what is the magnetic field in the presence of media; we have to make a fundamental distinction between what I call as a microscopic field and a macroscopic field. In fact, I have a suspicion that the next 15, 20 minutes also will be taken up by this discussion, but never mind let us go along slowly, because this is important.

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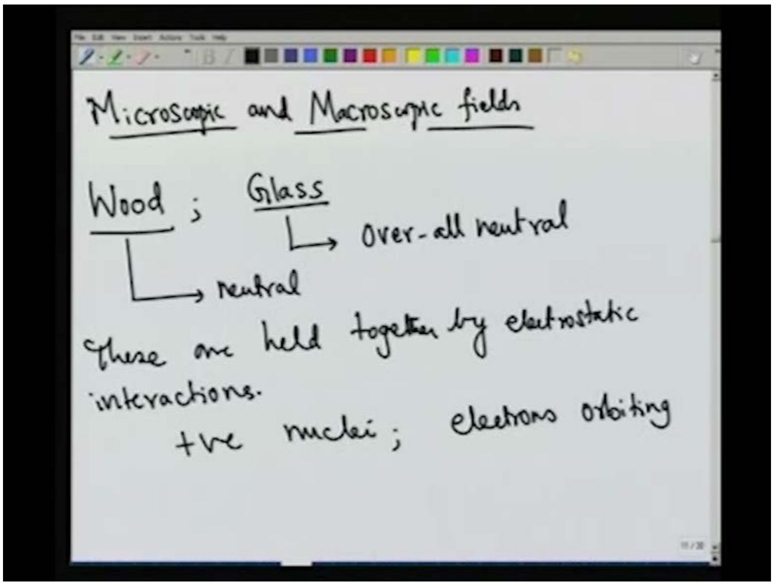

So, let us try to understand the distinction between microscopic and macroscopic fields. And those of you who have been following all the lectures will remember that, sometime in the fifth or the sixth lecture I evolved a procedure; I taught to how to average over charge densities, that is indeed the concept that, I am going to introduce at this particular point.

So, in order to make my example concrete, let me consider a material like wood or a material like glass, we know glass is overall neutral glass is overall neutral. So, take a piece of glass and bring an electroscope near that it is not going to respond that is what we have. However, what is glass made of, glass is made up of a large number of atoms and all these atoms are bound by electromagnetic interactions. So, all though this is neutral this is neutral these are held together held together by electrostatic interactions.

So, what do I have if I consider any material there are the positive nuclei positive nuclei positively charged nuclei and there are Electrons orbiting around they form an atom, one atom interacts with the next atoms they get bound together and that is how these are held therefore, if I want to try to draw a profile of an Electric field how will it look like.

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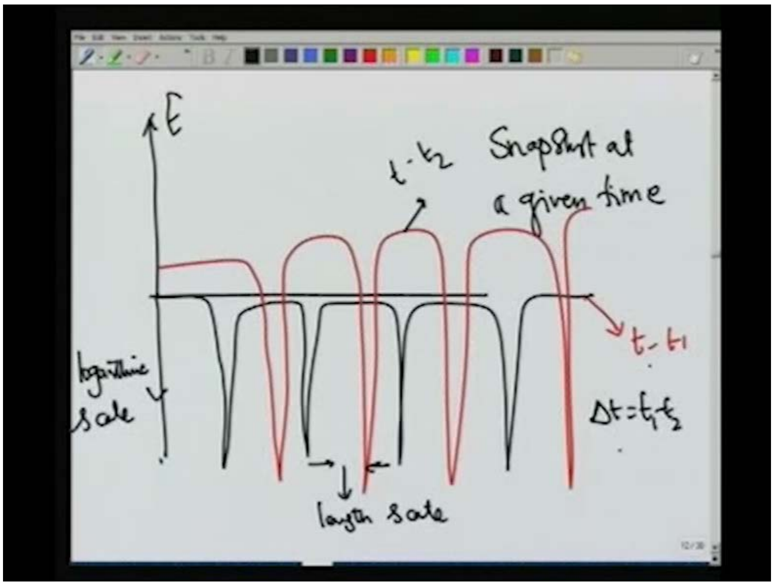

So, let me make a cartoon of a picture and show how it looks like. So, imagine that there is an atom and at the center there is a nucleus and there is an electron. And let me imagine that my I am going to ignore the field due to which the positively charged nucleus, let me concentrate only on the field due to the Electron. So, as I approach the electron my field goes to negative infinity is that right very close it goes to negative infinity. As I go up it goes to 0 as I go farther away, it again goes up, again it goes up therefore, this is the kind of figure that we are going to get.

So, it fluctuates to very large value, if you feel like this is something of logarithm scale this is my electric field and over atomic distances my field is going to change; this is a snapshot at a given time at a given time. However, we know that my electrons are not at rest they are going round and round the positive nucleus and the next instant the atomic is in a different position. So, in the next instant probably I can use a different color how will it look like, it may look like this is the next snapshot.

So, this is at t Equal to t 1 and this is at t equal to t 2, so as a function of time my electric field profile is changing, as a function of space my electric field profile is changing.

Now, the natural question to ask is what is the length scale here, and what is the time scale. This is t equals to t 1, what is t equal to t 2, what is delta t equal to t 1 minus t 2 equal to 1, what decides the scales. The answer to that is very clear the length scale is given by the molecules operation atomic of the molecules operation, whereas the time scale is given by the periods of the electrons let me write it down.

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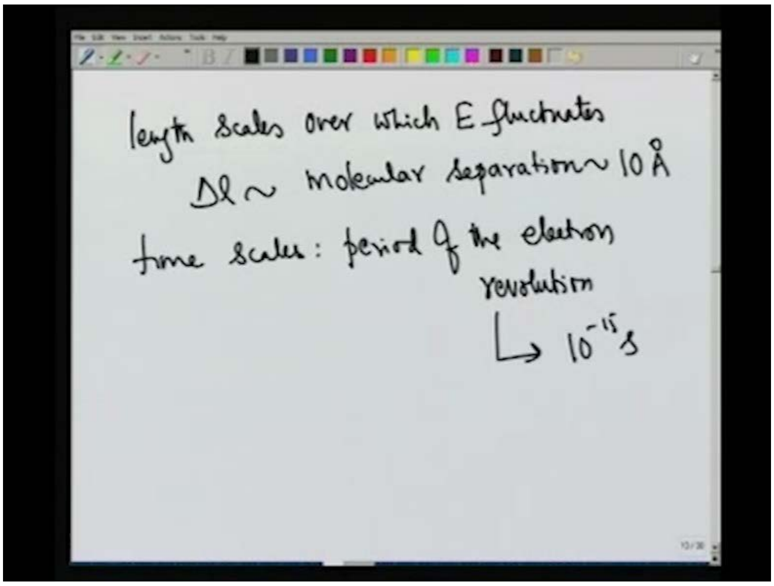

The length scale over which E fluctuates, the electric fields fluctuates, let me call it delta l, which of the order of molecular separation. If I look at the length scales, time scales then they are of the order of the period of revolution of the electrons electron revolution. So, these are of a few terms of these are about 10 to the power of minus 15 seconds or so, extraordinarily small numbers.

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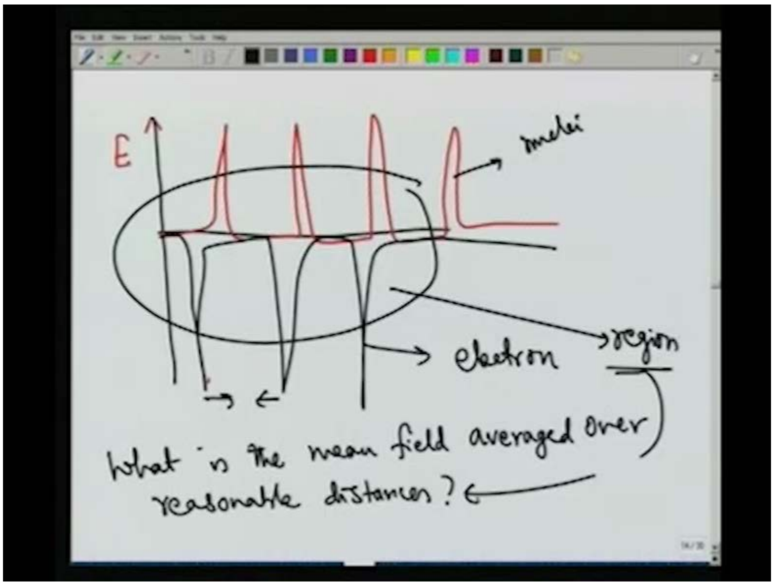

Now, that was only looking at the electron, however suppose, I were to draw the complete picture including the field produce by the nuclei also which are carrying positively charge. Now, what happens is something funny at any given point by electron field will behave like this these are very large fields, whereas, the field due to the positively charged particle will look like this, is that right. Is going to look like this these are at rest but these are moving therefore, the point is that if I am going to look at these atomic dimensions, I will be able to see this electric field I will be able to see this Electric field.

But, my electroscope is not sensitive to this, so this is my electric field that is what I have this is coming because of the nuclei, this is coming because of the electron. We ask ourselves, what is the mean field what is the mean field averaged over reasonable distances. Perhaps the tip of my electroscope is of the order of a few microns, then it is going to measure the average field over a spacial extent of a few microns and if this is of the order of a few amstorms tons of amstorms.

I am, obviously going to ask the mean field in this region, this is highly exaggerated I am asking what is the mean field in this region, and clearly the answer to that is the mean field be Equal to 0. So, what we have found is that this spacial average of my highly fluctuating very strong electro electric fields are going to average to 0, that I have to write formally.

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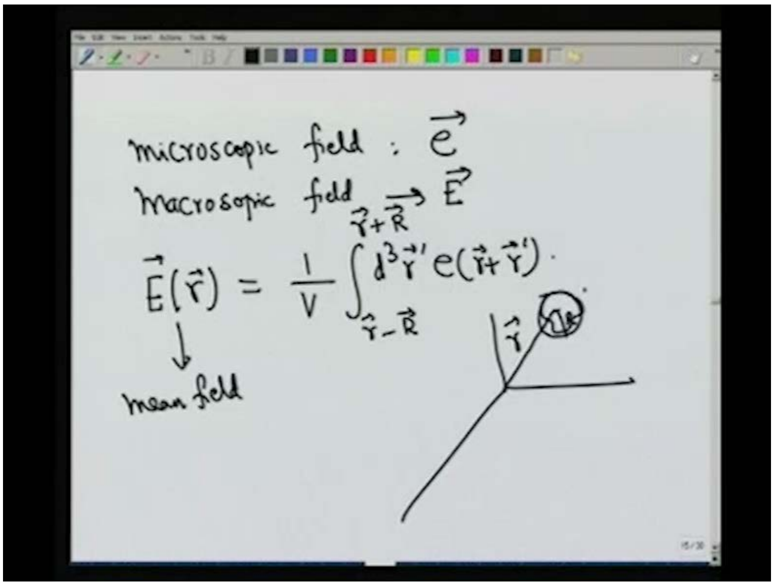

So, let me go back to my original question, I have to make a distinction between the microscopic field and the macroscopic field; microscopic fields let me denoted by the lower case. So, let me say microscopic field is denoted by e, the small e and the macroscopic fields are denoted by the capital E let me imagine that. So, how do I define my macroscopic field E given by the microscopic field e, I will write it to be the spacial average.

My E at (r) is the mean value is nothing but 1 over volume integral d cube r prime e of r plus r prime the radius into this where my r prime will go. Let us say over a reasonable volume r prime will go from r minus r to r plus r you can put a factor of two r’s also. So, what am I trying to indicate here, so this is my volume element, so let me imagine this to be as sphere.

What I do is to look at a radius r calculate the mean value and replace the microscopic field by the value of this, that is what we are saying. So, you integrate over a volume of radius r find the mean value and replace the microscopic value of at this point, next move to the next point mu point and so, on. And this is my mean field clearly my mean field does not show the wild fluctuations, that my electric field was showing. Now, the next thing that we have to know is that, suppose I want my electroscope to monitor the time dependence in the field. I cannot say that my electroscope has a sensitivity of 10 to the power of minus 15 seconds, may be it can measure over microseconds.

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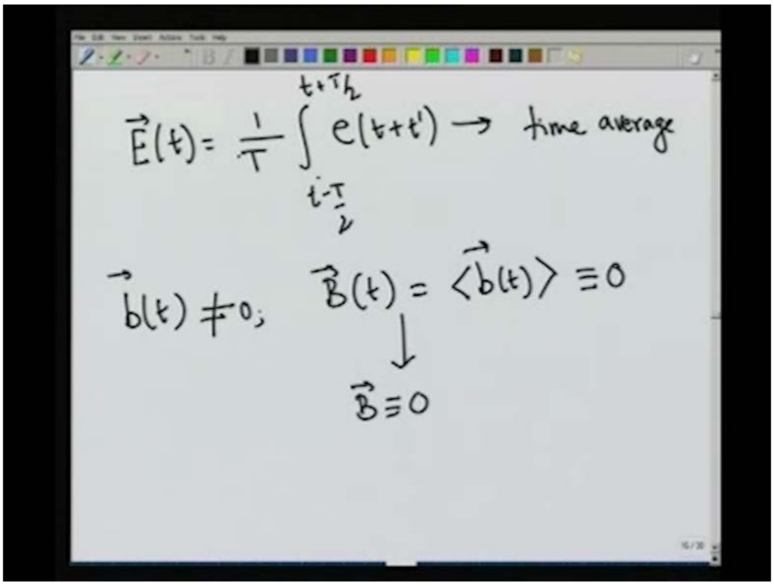

Therefore, the next thing that we have to do is to look at E of (t) which I will write it as the average over the time, I will write t minus T by 2 t plus T by 1 into e of (t plus t prime). I average over an interval t minus t by 2 to t plus T by 2, so this gives me time average.

My previous expression gave me the space average, this gives me the time average, so studying the bulk properties of the material trying to write down the Maxwell's Equation in the presence of the material that amounts to replace in the microscopic fields by the macroscopic field. Since, I am interested in electrostatics I have to make one more mandatory statement and that is the following, when I performed the is I get my microscopic field all right, what about the magnetic field.

We know although we may not know quantitatively but at least qualitatively we know that, moving charges produce a magnetic field. If I produce a magnetic field by a moving charge, if I average over several periods, then we know what happens to the electron. The electron half the time is moving in the upper circle half the time, it is moving in the lower circle, then there may be another electron close by which is moving anti clock wise if this is moving clock wise.

Therefore, what we are trying to say is that, if I look at the microscopic b of (t) which is not equal to 0, the time average B of t which comes from a similar definition. I shall employ the notation used by the probability of people, which comes from the time average of this fellow this will turn out to be 0.

Therefore, in studying the electrostatics of the microscopic fields, we may safely ignore the magnetic field produce by the moving electrons. If I consider a small physical volume, then roughly equal number of electrons will be moving in clockwise and anti clock wise direction. And therefore, the macroscopic field vanishes both in the time average and in the space average; therefore, we can forget all about this and say that b identically equal to 0; before I go on to continue my studies which will be postponed to the next lecture.

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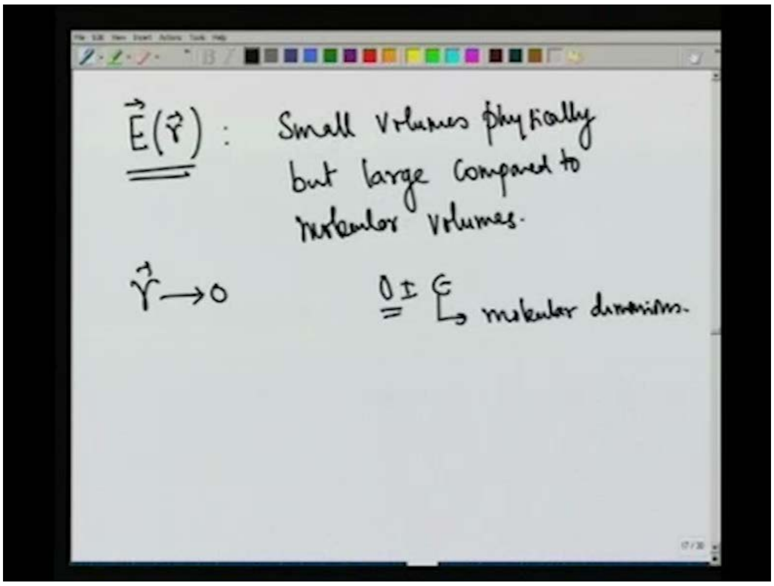

Let me summarize whatever I am trying to tell you, the study of the properties of matter electro dynamics in media, involves macroscopic fields E of r. So, if I want to use gauss's law or curl of E etcetera, etcetera, I am going to apply it to the macroscopic field and not the microscopic field.

Therefore, when we are using the macroscopic fields, we want small volumes physically, but large compared to molecular volume. So, for example, I tell you r going to 0, when I am taking the limit r going to 0, you should understand that I make no distinction between the mathematical 0 plus or minus epsilon, which correspond to molecular dimensions. So, we should learn to distinguish between an infinitesimal mathematical volume and an infinitesimal physical volume. If you remember this, then electrostatics is not a difficult thing to understand to reconcile with, whatever we know from the fundamental Maxwell equation and that we shall continue in the next lecture.