Introduction to Electromagnetism
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Lecture - 29
Electric Polarization and Bound Charges – I

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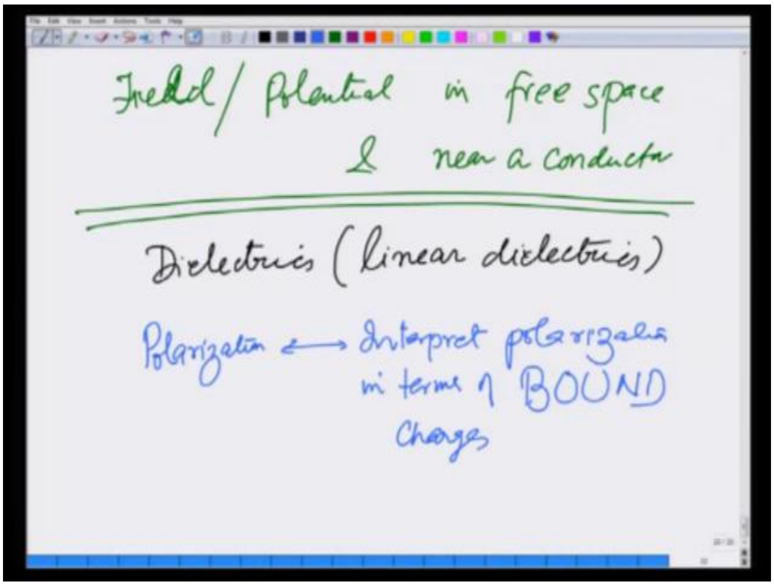

We have talked about different electrostatic situations. So, we have talked about fields, potential in free space and near a conductor. What we want to talk about now is, another kind of material and how they affect the fields, etcetera is Dielectrics. In particular, what we are talking about are linear dielectrics. To understand how dielectrics behave, we will first talk about a polarization, what does it mean, because dielectrics affect the field etcetera by getting polarize. So, polarization and how we can interpret polarization in terms of bound charges, after all electrostatics is all about fields being produced by charges.

So, we will translate polarization into bound charges, and then develop it in term of Mathematics of dealing with dielectrics or polarizable medium and try to see it physically also.

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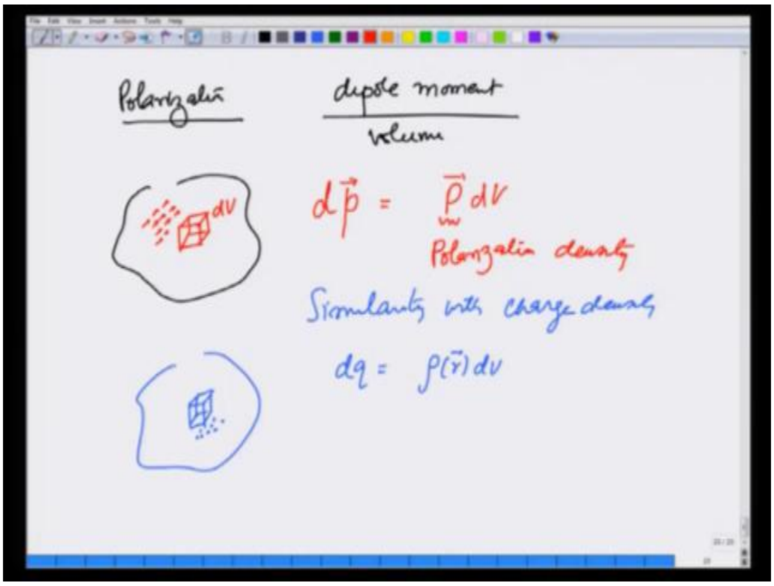

So, let us first understand, what does polarization mean. By polarization we mean, dipole moment per unit volume, let us understand that. So, if I have a material, this is which is a solid material and inside, if I take a small volume d v, then if the dipole moment of this small infinitesimal volume. So, let us call it infinitesimal dipole moment d P is equal to P d v and this is known as the polarization or polarization density.

See the similarity with charge density, in charge density, what did we have. If I have a small volume, then small infinitesimal charge in this volume was nothing but charge density times d v. So, in the same manner, I have polarization density P. So, just like charge density consisted of a small, small or the charge is distributed in space. Polarization density consists of let me remove this black lines; so that they do not disturb us, this consists of small point dipoles distributed in space, very close together.

And if I take macroscopically very small volume, this is like a continuous distribution, just like in charge density also in a very small volume, macroscopically small volume; it is a charge distribution continuous kind of distribution. However, if I go to microscopic scale, for example, if I go in charge density to very small scale, I see electrons, protons separately, then they are like not continuous. If I go to very small scale, they may not be continuous, but for the time being we will again like we treat charge density. We will consider polarization density to be continuous distribution.

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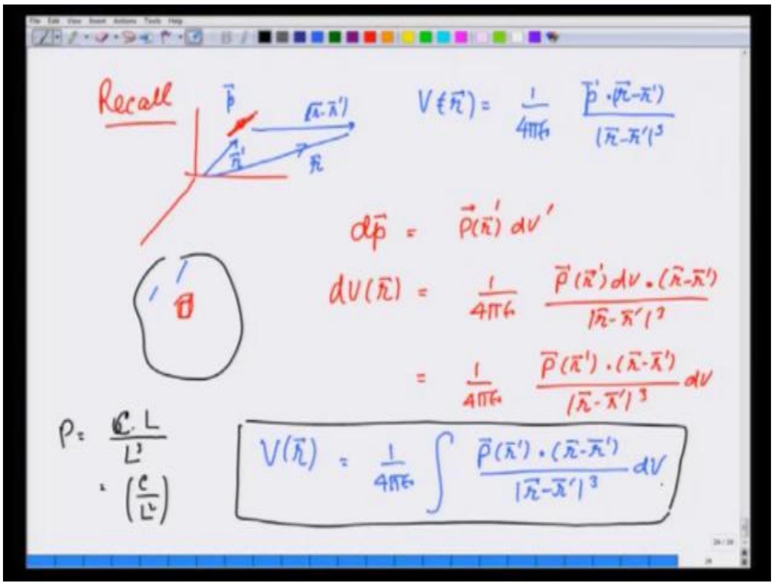

Now, we want to understand, how does this give raise to electric field and electrostatic potential. Recall that for a point dipole at r prime to the point dipole at r prime, the electrostatic potential at r. So, this vector becomes r minus r prime is given as V equals V at r is given as 1 over 4 pi Epsilon 0, P dot r minus r prime over r minus r prime cubed. This is one of the assignment problems I have given you earlier, we had calculated field in an electric field in a lecture, calculating potential due to a point dipole is much easier and that I have given as a assignment problem.

So, now if I have a distribution, I would let us take this small volume and I just said that, the dipole moment of this is going to be the polarization density P which is a vector quantity times d v at r prime d v prime. The potential infinitesimal potential due to this is going to be 1 over 4 pi Epsilon 0, P at r prime d v; that is a small dipole moment dot r minus r prime divided by r minus r prime cubed, which is equal to 1 over 4 pi Epsilon 0, polarization density p r prime dot r minus r prime divided by r minus r prime cubed d v.

And therefore, the net potential V at r due to this distribution all over the space is going to be equal to 1 over 4 pi Epsilon 0 integration of P, r prime dot r minus r prime over r minus r prime cubed d v. Just one note about the polarization density, what are the dimensions, polarization density is nothing but dipole moment which is charge Coulomb times distance L per unit volume. So, this is C over L square Coulomb per meter square; that is the polarization density.

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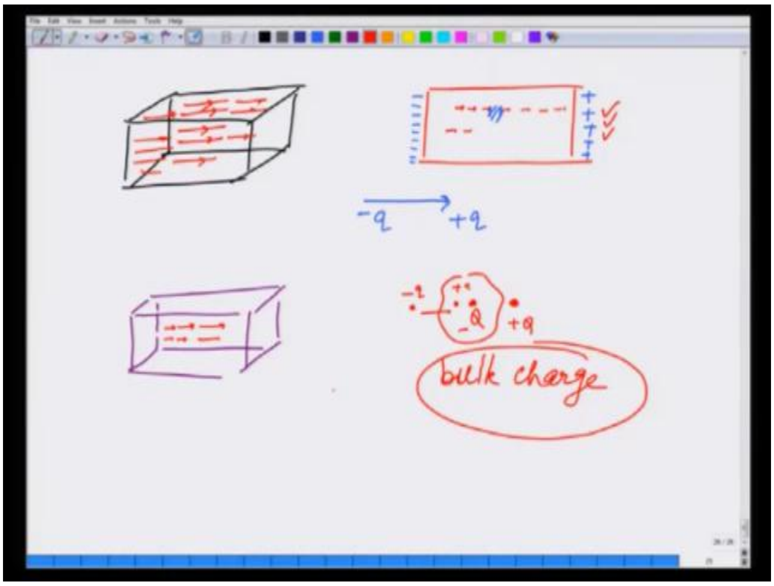

So, this is the potential that it gives raise to, but we want to interpret it further in terms of charges. Let us see, why do we want to do that, imagine a rectangular box, which has constant polarization density all over. Now, what we have seen is, that the polarization density arises from small point dipoles like this and if I look at one dipole, it has negative charge on the left and positive charge on the right.

Therefore, you can see that the charges inside are going to cancel and finally, going to be left with some positive charge on the right and negative charge on the left, if this is a constant polarization density. Let us also look at a situation, where the density varies. So, let us see that these maybe, arrows are getting bigger or arrows, so density varies or the charges are becoming bigger. So, let us say this is minus q plus q, for the same distance, next I have slightly larger charge minus q plus q. When I look at a microscope volume, you can see that these charges do not cancel. So, if polarization density changes from one place to the other, it also gives rise to a bulk charge. So, we have seen physically that polarization density is equivalent to a surface charge and a bulk charge, how they arise mathematically, we will see next.