Introduction to Electromagnetism
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Lecture - 01
Coulomb's Law

This is a course on Electromagnetic Theory and any courses starts with Coulomb's Law.

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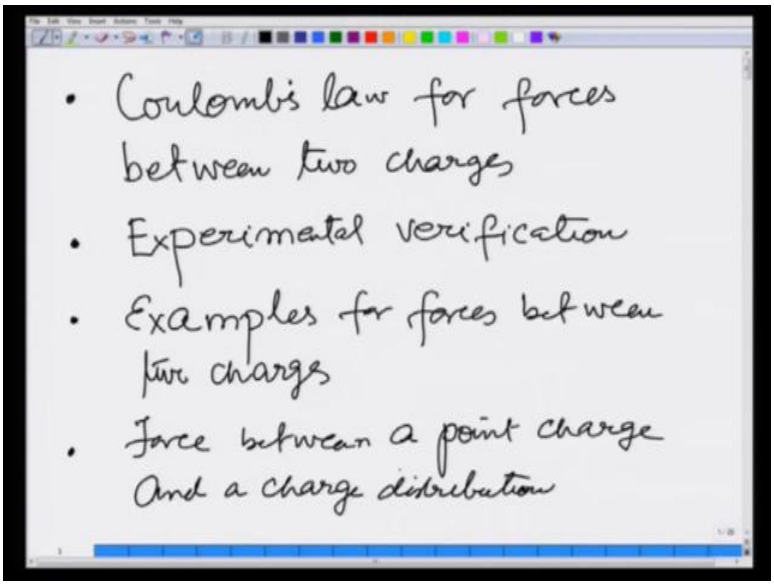

So, we start with in this lecture, we going to start with Coulomb's law for forces between two charges. Then, we are going to see how this can be confirmed that this is really true, experimental verification. Third, then we are going to solve some examples for forces between two charges. And finally, in this lecture we are going to talk about the force between a point charge and a charge distribution. This is the program for this lecture and based on what we cover today I am also going to give you an assignment, where you solve three or four problems employing these concepts.

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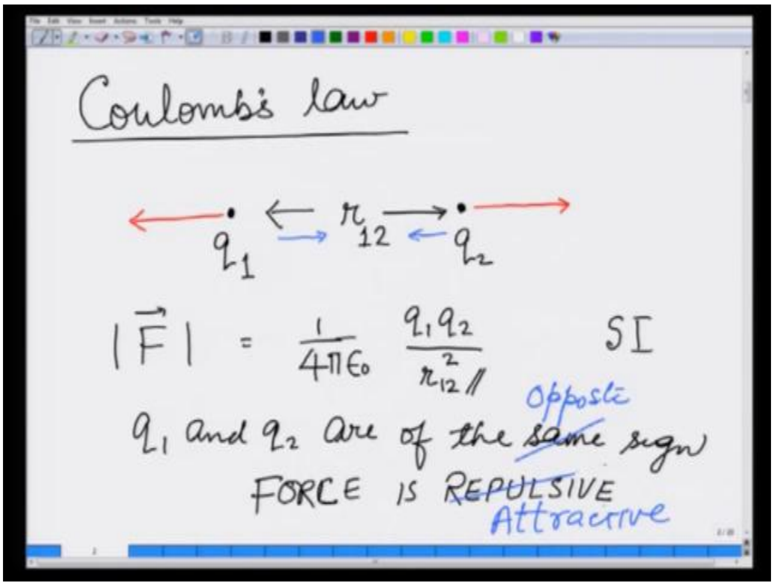

So, what Coulombs' law says is that if there are two charges points let us take the point charges right now. So, there is a charge q 1 and another charge q 2 separated by a distance r and for the future, because I am going to develop a notation also. Let us write this as r 1 2 that indicates, the distance between charge 1 and charge 2. Then, the force between them the magnitude force of course, you know from your Mechanics course that force is a vector quantity.

The force between them it is magnitude is going to be equal to and this depends on what units we are going to choose for q 1 and q 2 finally, it is the SI units that we work in. So, I am going to write this in terms of this SI units, it is going to be 4 pi Epsilon 0 where Epsilon 0 is known as the permittivity of vacuum q 1, q 2 over r 1 2 square. That means, if the distance between two charges doubled, because of this square out here.

If there is square out here, the force going to become less by a factor of force, but I just said forces not only quantity which is as magnitude, it also has direction what about the direction of the force. Now, you learnt in your previous classes that, if q 1 and q 2 are of the same sign, then the force is repulsive. What it means is that, the force is going to be along the same lines as the line joining the charges and they going to repel each other and the magnitude being the same.

On the other hand, if they are at opposite sign, so let me write opposite out here. If they are at opposite signs, then force is going to be attractive. What that means is, in that case the force is going to be in this direction towards each other. So, I hope this point is clear, but let me make it clear by drawing this picture again.

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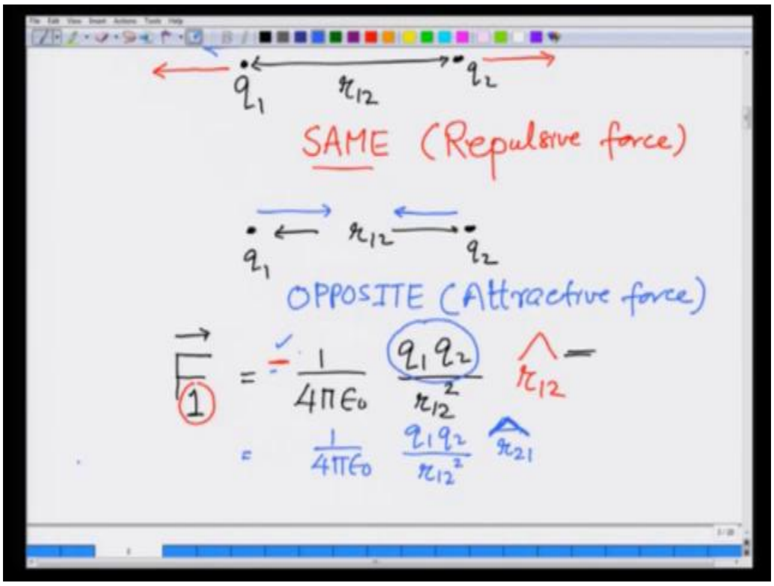

I am drawing two charges q 1 and q 2 separated by a distance r 1 2 and if the charges are the same, so it is for same I am going to use the color orange with the charges of the same, then the force is repulsive. On the other hand, if the charges are at opposite sign, then the force is going to be attractive. How can we write all these in vector notation? This is very simple way of writing it I am going to write force.

Now, I am write the whole thing, force of vector with the magnitude 1 over 4 pi Epsilon 0, q 1 q 2 over r 1 2 square. Now, if I am writing it in the vector notation I have to denote force on 1 or force on 2, let us write the force on 1 which I denote here by this subscript 1 here. It is going to be in the unit vector r 1 2 direction, this hat here denotes the unit vector. Now, you will see that just write r 1 2 vector from going from 1 to 2, so this is r from 1 to 2.

The unit vector is going to be in r 1 2 direction of magnitude unity, if I write like this then you notice that force on 1 is in the direction opposite of r 1 2. So, I have to put in minus sign out of here which I can equally well write as 1 over 4 pi Epsilon 0, q 1 q 2 over r 1 2 square r 2 1, where r 2 1 is a unit vector form 2 to 1, r 2 1 should be unit vector. You notice that this takes care of everything signs, direction and everything in one shot.

If the forces are, if the charges are the same, then the q 1 and q 2 this out here is going to be positive and therefore, the sign gives the right direction. On the other hand, if q 1 and q 2 are opposite the sign changes.

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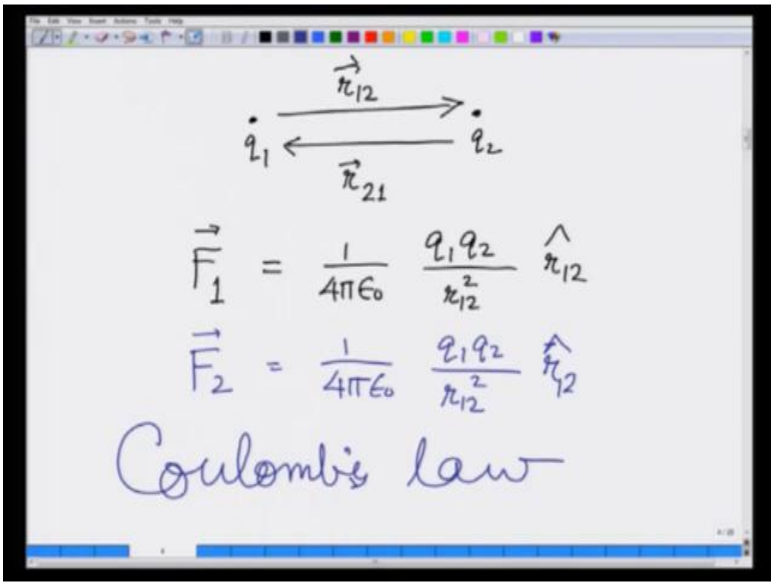

So, let us repeat this I am going to take two charges q 1 and q 2 and write everything in vector notation. So, let me write vector from 1 2 as r 1 2, vector from 2 to 1 as r 2 1, I follow this convention all throughout. Then, the force on 1 with proper direction can be written as 1 over 4 pi Epsilon 0 q 1 q 2 over r 1 2 square, r 1 2 square is the same as r 2 1 square times r 1 to 2 unit vector.

And similarly, force on 2 can be written as 1 over 4 pi Epsilon 0 q 1 q 2 over r 1 2 square which is same as a r 2 1 square or from 1 to 2 unit vector, this gives repulsion, attraction everything, because now we are taking care of the direction. So, these are this is the Coulomb's law, it gives the magnitude as well as the direction of the force. How do we check it experimentally? Did Coulomb's do experiment with point charges or their point charges available with which you could do experiment? The answer is no.

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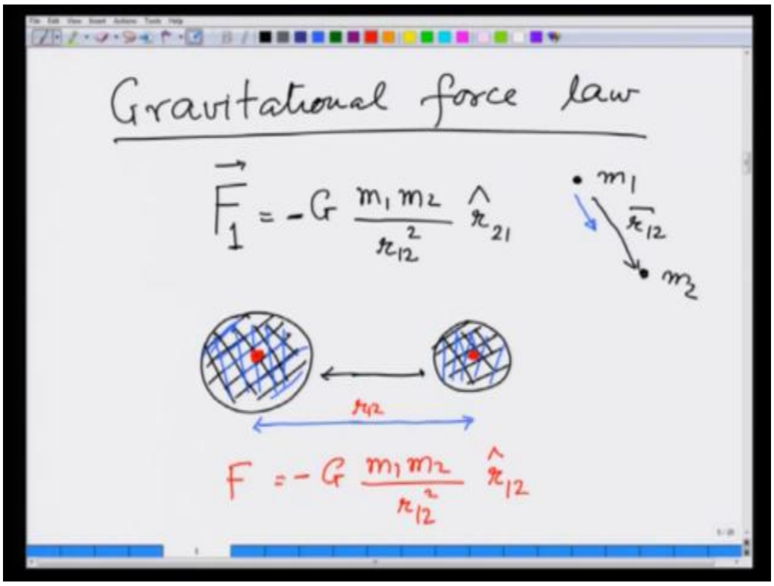

You recall that there is a similar law, one goes off and that is Gravitational law and what does that say, that says at the force between two masses F, let us say the masses are m 1 and m 2 and this is r 1 2 vector, then F on 1 is going to be equal to minus G m 1 m 2 over r 1 2 square r from 2 to 1 unit vector, this is always repulsive. In gravitation, we have mass does not have a sign, but the form of the law is the same, the way when could check this law by taking too large masses and find in the force of attraction between them.

So, the force is in this direction, this is always attractive. What one could do is that, one could take these masses, solid masses and measure the force between them. We will see later, that this force can be written as if the two masses are concentrated at their centers. So, the force between two perfectly spherical masses, the magnitude will be equal to G m 1 m 2 over r 1 2 square, where r 1 2 is the distance between their centers and of course, the directions is attractive, so this one. Can we do a similar thing to check Coulombs law? Let us see that.

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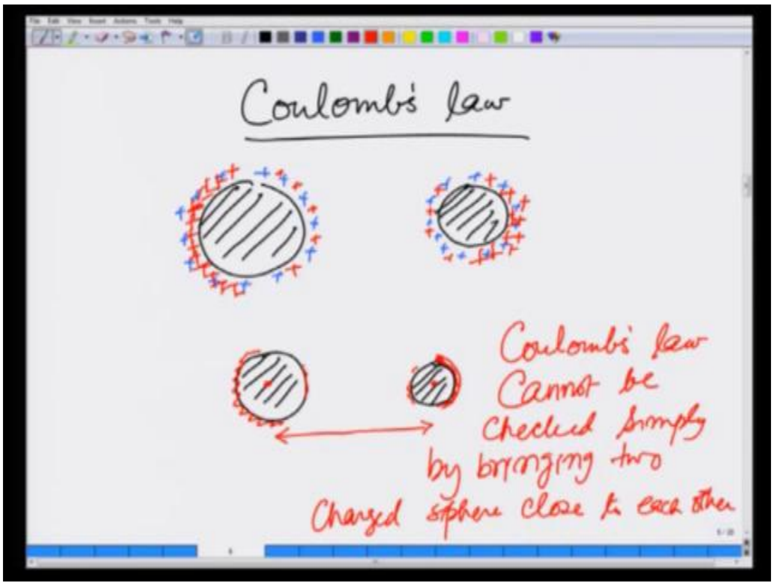

So, if I want to look at Coulomb's law I take too large masses and the easiest to charge r metallic spheres and put charge. Let us say I put positive charge here, since they are spheres in isolation these charges you are going to be all uniformly distributed, if these two sphere is far away, necessarily charge on them is movable. Because, there is some of the charge them, when you charge them charged moved on to them.

However, since these charges are mobile then the charges are closed whether this is not going to the situation, these charge is going move and they are going to have more and more charges, because they repel further away then there are nearer. So, here charges repel, so lot of them will go to the back side of the charges sphere and there will be a less charge in front, with the final picture that if I take this two charges, charge spheres that the charges are going to be more concentrated here and less out here more concentrated on the back side and less in front.

As a result I cannot really think of them being separated by distance which is the distance between the centers of this charge. And I do not know what the distribution is, if I do not know what this distribution is how do I figure out, how far are the charges. So, coulomb's law cannot be checked simply by bringing two charge spheres of closed to each other and then measuring force between them a way out is very interested, the way out of this is at what you can show is that.

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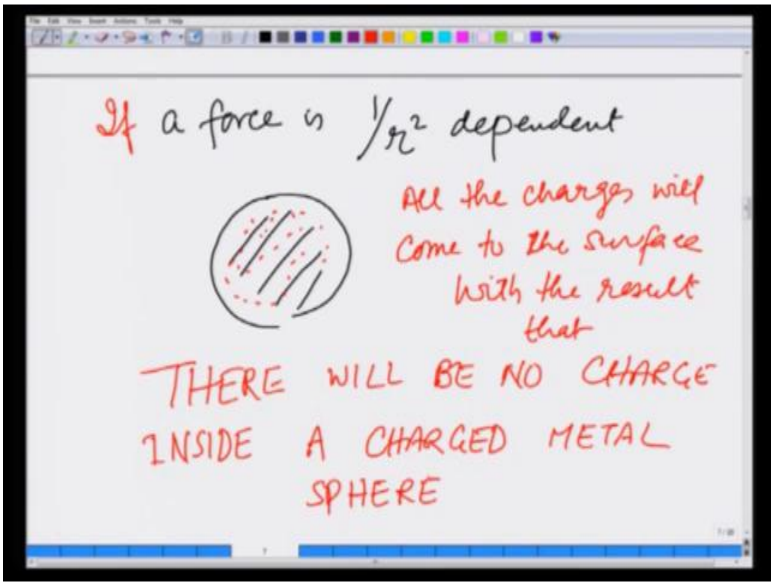

If of course, is 1 over r square dependent which we are assuming coulomb's law is then on a sphere, then if I take a sphere say metallic sphere and put charges on it all the charges will come to the surface with the result that there will be no charge inside charge a charged metal sphere. So, insisted again if a force is 1 over r square dependence or if this particular case of the electric force between charges is 1 r square dependent, all the charges that we put on a metallic sphere will come to the surface.

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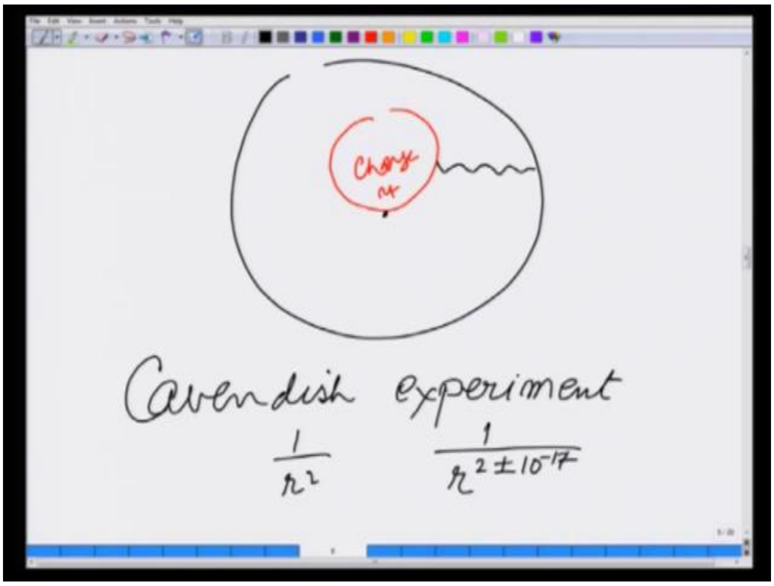

So, the experiment that is done to check this is precisely this you take a sphere charge it and then take a sphere outside and connect by wire, if the charge on this is sphere becomes is 0, I know the force field is 1 over r square. And that is how it is done and this is known as Cavendish experiment and this is confirm that it is 1 over r square is the degree that 1 over r square plus minus 10 rise to minus 17. So, we know very well that this coulomb's law is really 1 over r square.

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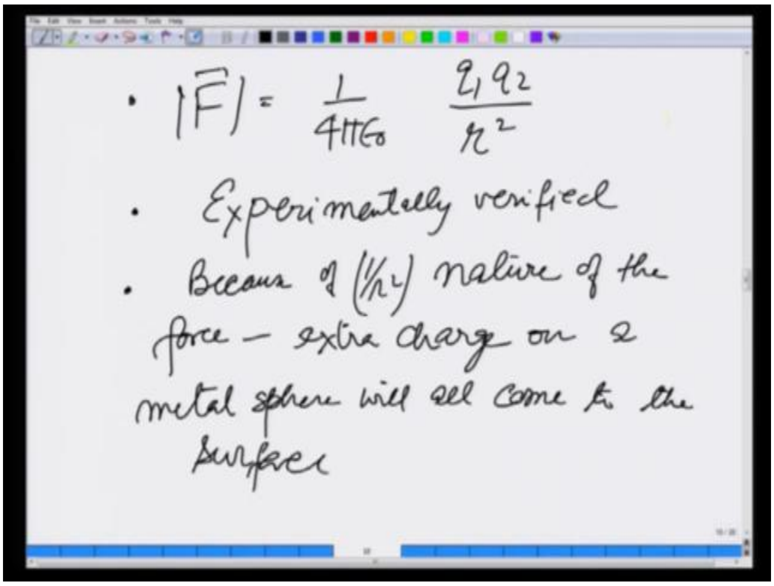

So, let us see what we established one force between two charges is 1 over 4 pi Epsilon 0 q 1 q 2 over r square, where r is the distance between them, number two experimentally verified here, because of 1 over r square nature of the force extra charge on a metal sphere with all come to the surface.