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8.02 Electricity and Magnetism, Spring 2002
Transcript – Lecture 5

So today no new concepts, no new ideas.

You can relax a little bit and I want to discuss with you the connection between electric potential and electric fields.

Imagine you have an electric field here in space and that I take a charge Q in my pocket.

I start at position A and I walk around and I return at that point A.

Since these forces are conservative forces, if the electric field is a static electric field, there are no moving charges, but that becomes more difficult, then the forces are conservative forces and so the work that I do when I march around and coming back at point A must be zero.

It's clear when you look at the equation number three that the potential difference between point A and point A is obviously zero.

I start at point A and I end at point A and that is the integral in going from A back to point A of E dot dL and that then has to be zero.

And we normally indicate such an integral with a circle which means you end up where you started.

This is a line now this is not a closed surface as we had in equation one.

This is a closed line.

And so whenever we deal with static electric fields we can add now another equation if we like that.

And that is if we have a closed line of E dot dL so we end up where we started that then has to become zero.

Later in the course we will see that there are special situations where we don't deal with static fields when we don't have conservative E fields, that that is not the case anymore.

But for now it is.

So if we know the electric field everywhere then we -- we can see equation number two then we know the potential everywhere.

And so if we turn it the other way around, if we knew the potential everywhere you want to know what the electric field is and that of course is possible.

If you look at equation two and three you see that the potential is the integral of the electric field.

So it is obvious that the field must be the derivative of the potential.

Now when you have fields being derivative of potentials you always have to worry about plus and minus signs, whether you have to pay MIT twenty-seven thousand dollars tuition to be here or whether MIT pays you twenty-seven thousand dollars tuition for coming here is only a difference of a minus sign but it's a big difference of course.

And so let's work this out in some detail.

I have here a charge plus Q.

And at a distance R at that location P we know what the electric field is, we've done that a zillion times.

This is the unit vector in the direction from Q to that point and we know that the electric field is pointing away from that charge and we know that the electric field E, we have seen that already the first lecture, is Q divided by four pi epsilon zero R squared in the direction of R roof.

And last lecture we derived what the electric potential is at that location.

The electric potential is Q divided by four pi epsilon zero R.

This is a vector.

This is a scalar.

So the potential is the integral of the electric field along a line and now I want to try whether the electric field can be written as the derivative of the potential.

So let us take dV, dR and let's see what we get.

If I take this dV, dR I get a minus Q divided by four pi epsilon zero R squared.

Of course if I want to know what the electric field is I need a vector so I will multiply both sides, which is completely legal, there's nothing illegal about that, with unit vector in the direction R so that turns them into vectors.

And now you see that I'm almost there, this is almost the same, except for a minus sign.

And so the derivative of the potential is minus E, not plus E.

And so I will write that down here, that E equals minus dV dR.

So they are closely related if you know what the -- oh I want -- I want this to be a vector so I put here R roof.

Vector on the left side, you must have a vector on the right side.

And so if you know the potential everywhere in space, then you can retrieve the electric field.

I mentioned last time that the electric field vectors -- electric field lines, are always perpendicular to the equipotential surfaces.

And that's obvious why that has to be the case.

Imagine that you are in an -- in space and that you move with a charge in your pocket perpendicular to electric field lines.

So you purposely move only perpendicular to electric field lines.

So that means that the force on you and the direction in which you move are always at ninety-degree angles.

So you'll only move perpendicular to the field lines.

These are the field lines, you move like this.

These are the field lines, you move like this.

So you never do any work.

Because the dot product between dL and E is zero and if you don't do any work the potential remains the same, that's the definition.

And so you can see that therefore equipotential surfaces must always be perpendicular to field lines and field lines must always be perpendicular to the equipotentials.

And I will show you again the -- the viewgraph, the overhead projection of the nice drawing by Maxwell.

With the plus four charge and the minus one charge.

The same one we saw last time.

Only to point out again this ninety-degree angle.

I discussed this in great detail last lecture so I will not do that.

The red lines are really surfaces.

This is three-dimensional, you have to rotate the whole thing about the vertical.

So these are surfaces.

And the red ones are positive potential surfaces and the blue ones are negative potential surfaces.

That is not important.

But the green lines are field lines.

And notice if I take for instance this field line, perpendicular here to the red, perpendicular there, perpendicular there, perpendicular there.

Perpendicular here.

Perpendicular here.

Coming in here, perpendicular, perpendicular, perpendicular.

Everywhere where you look on this graph you will see that the field lines are perpendicular to the equipotentials.

And that is something that we now fully understand.

The situation means then that if you release a charge at zero speed that it would always start to move perpendicular to an equipotential surface because it always starts to move in the direction of a field line.

A plus charge in the direction of the field line, minus charge in the opposite direction.

So if you're in space and you release a charge at zero speed it always takes off perpendicular to equipotentials.

You have something similar with gravity.

If you look at maps of mountaineers, contours of equal altitude, equal height.

If you started skiing and you started at that point, and you started with zero speed, you would always take off perpendicular to the equipotentials.

So this is the direction in which you start to move.

If you start off with zero speed.

I now want to give you some deeper feeling of the connection between potential and electric fields and I want you to follow me very closely.

Each step that I make I want you to follow me.

So imagine that I am somewhere in space at position P.

At that position P there is a potential, one unique potential, V of P.

That's a given.

And there is an electric field at that location where I am.

And now what I'm going to do, I'm going to make an extremely small step only in the X direction.

Not in Y, not in Z.

Only in the X direction.

If I measure no change in the potential over that little step it means that the component of the electric field in the direction X is zero.

If I do measure a difference in potential then the component, the X component of the electric field, the magnitude of that, would be that little sidestep that I have made, delta X, it would be the potential difference that I measure divided by that little sidestep.

And I keep Y and Z constant.

And these are magnitudes.

But that's why I put these vertical bars here.

Equally if I made a small sidestep in the Y direction and I measured a potential difference delta V keeping X and Z constant, that would then be the component of the electric field in the Y direction.

Earlier we wrote down for E as a unit new- newtons per coulombs.

From now on we almost always will write down for the unit of electric field volts per meter.

It is exactly the same thing as newtons over coulombs, there is no difference, but this gives you a little bit more insight.

You make a little sidestep in meters and you measure how much the potential changes, it's volts per meters.

It is a potential change over a distance.

So now I can write down the connection between electric field and potential in Cartesian coordinates.

It looks much more scary than the nice way that I could write it down up there.

When I had only a function of distance R.

And so in Cartesian coordinates we now get E equals minus, that minus sign we discussed at length, and now we get dV dX times X roof plus dV dY times Y roof plus dV dZ times Z roof.

And what you see here, this first term here, including of course the minus sign, that is E of X.

And this term including the minus sign, that is E of Y.

And so on.

And the fact that you see these curled Ds it means partial derivatives.

That means when you do this derivative you keep Z and Y constant.

When you do this derivative you do X and Z constant and so on.

And so this is the Cartesian notation for which in eighteen oh two you will learn or maybe you already have learned we would write this E equals minus the gradient of G.

This is a vector function.

This is a scalar function.

And this is just a different notation, just a matter of words, for this mathematical recipe.

And you'll get that with eighteen-- in eighteen oh two if you haven't seen that yet.

So I now want a straightforward example whereby we assume a certain dependence on X and I give you, it is a given that V, the potential, is ten to the fifth times X.

So that is a given.

And this holds between X equals zero and say ten to the minus two meters.

So it holds over a space of one centimeter.

So the potential changes linearly with distance.

What now is the electric field?

In that space?

Well, the electric field I go back to my description there.

There's only a component in the X direction.

So the first derivative becomes minus ten to the fifth times X roof and the others are zero.

So EY is zero and EZ is zero.

So you may say well yeah whoa nice mathematics but we don't see any physics.

This is more physical than you think.

Imagine that I have here a plate which is charged, it's positive charge.

And the plate is at location X and I have another plate here, it's say at location zero.

I call this plate A and I call this plate B and this plate is charged negatively.

So X goes into this direction.

So I can put the electric field inside here according to the recipe minus ten to the fifth and it is in the direction of minus X roof so X roof is in this direction.

The electric field is in the opposite direction, and it's the same everywhere and that is very physical.

We discussed that.

When we discussed the electric field near very large planes, that the electric field inside was a constant, remember, and the electric field inside was sigma divided by epsilon zero if sigma is the surface charge density on each of these plates.

And we argued that the electric field outside was about zero and that the electric field outside here was about zero.

So it's extremely physical.

This is exactly what you see here.

The electric field minus ten to the fifth times so the magnitude of this electric field here, the magnitude, is ten to the fifth, volts per meter.

What now is the potential difference?

Well, VA minus VB-- minus VB is the integral in going from A to B of E dot dL.

Well I go from here to here so I write down for dL I wrote down dX of course.

Because I called that the X direction now.

So I will write down here dot dX.

And so this is minus ten to the fifth times the integral in going from A to B of X roof dot dX.

It looks scary but it is trivial, the X roof is the unit vector in this direction.

And dX is a little vector dX in this direction.

So they're both in the same direction.

So the cosine, the angle between the two is one.

So I can forget about vectors, I can forget about the dot.

And so this becomes minus ten to the fifth times the integral in going from A to B of dX and that is trivial.

That is minus ten to the fifth times the location.

I have to do the integral between A and B.

So I get here X of B minus X of A.

And if this is ten to the minus two meters, to go from here to here is one centimeter, I must multiply this by ten to the minus two so I get that this is minus one thousand volts.

So A is a thousand volts lower than B.

That's what it means.

And that's something that's very physical.

Notice that if you go from left to right that the potential grows linearly.

This is lower than that.

And if you in your head use planes like this parallel to the other planes, each one of those planes would be equipotentials, they everywhere have the same potential.

And gradually when you move it up your potential increases, but notice the electric field goes from plus to minus in the opposite direction.

That's always the reason that's behind that -- that minus sign.

Well clearly I'm always free to choose where I choose my zero potential.

We discussed that last time.

You don't always have to choose infinitely far zero.

So I could choose this arbitrarily to be zero potential.

This would then be plus a thousand.

And so you then find that the potential V is then simply ten to the fifth times X, when X is zero you find the potential to be zero, and when X is one centimeter you find the potential to be a thousand volts and that then goes together with the electric field equals minus ten to the fifth in this direction.

And so this is extremely physical.

This is something that you would have whenever we deal with parallel plates.

As long as there's no charge moving, and we're dealing with solid conductors, so we have static electric fields, the charges are not heavily moving, then the field inside the conductor is always zero.

Not the case in a nonconductor.

It's only in a conductor because conductors have free electrons to move and if these free electrons see electric fields inside which they may they start to move until they experience no longer a force, thereby they kill the electric field inside.

So the charge in a conductor always rearranges itself so that the electric field becomes zero.

If the field is a static field, not rapidly changing.

And so now I want to evaluate with you the situation that I'm going to charge a solid conductor and ask myself the question, where does the charge go?

In honor of Valentine's Day, let's take a solid heart, steel heart, it's solid all the way throughout.

So this is a solid conductor and I bring on this conductor charge from the outside.

Plus or minus, let's just take plus for now.

And so the question that I'm asking you now, this is a conductor, this is not an insulator.

The story for insulators is totally different, this has free moving electrons inside.

I'm asking you now if I touch this conducting heart -- by the way, your heart is a very good conductor -- if you touch this conducting heart where would this charge end up?

Where would it go to?

And I leave you with three choices.

And we'll have a vote on that.

The first choice is that the plus charges would uniformly distribute for throughout.

A possibility.

The second possibility, less likely, I think, that all the charge will go to one place there.

I don't know which place that would be, but maybe.

And then the third possibility is that maybe the charge will uniformly distribute itself only on the outer surface and then the fourth possibility is none of the above.

All these suggestions I made were wrong.

Who think that the charge might uniformly distribute it throughout the conductor?

I see one or two hands.

That's good.

Don't feel ashamed of raising your hands, in the worst case you're wrong.

I've been so many times wrong when it comes to this.

Don't feel bad about that.

Who thinks that the charge will all go to one point in the heart?

You have the courage?

You think it will go to one point?

Charge repels each other, right, so that doesn't seem likely.

Who thinks that it will uniformly distribute itself on the outer surface?

Who thinks none of the above?

Very good.

Well, those who suggested that it might be uniform on the outside I would still give them a B but it's not uniform, as you will see.

But it will go exclusively to the outside.

And I will prove that now to you.

Let us first look for that ridiculous possibility that the charge would somehow end up in the conductor itself.

I take here a Gaussian surface which is a closed surface.

I know inside the conductor if we have electrostatic fields, not fastly moving charges, but it's a static field, I know that the E field everywhere must be zero on the surface, this is a closed surface, so the integral of E dot dA equation one is zero.

That means the charge inside my sphere is zero and so there cannot be any charge.

So Gauss's law immediately kills the possibility that there would be any charge inside this conductor.

So that's out of the question.

So that leaves you only with one choice, that is on the -- at the surface.

So the charge must be at the surface.

And later-- in a later lecture I will discuss with you the details why that charge is not uniformly distributed.

It would be uniformly distributed at the surface if this were a sphere.

But not if it has this funny shape.

But it will be at the surface.

Now I'm going to make this heart a very special heart, more like a real heart.

It's open here, But it is solid here.

so this is a conducting, the heart muscle, and here it's open, there's nothing here.

And again I'm going to charge it.

Bring charge on the outside.

So now it's obvious that we don't expect that there is any charge that will be inside the conductor.

That's clear.

The same argument holds with the Gauss's law argument.

But now is it perhaps possible that some of the positive charge will go on the inside of this surface and some on the outside?

Who thinks that maybe some will now go on the inside, because now the situation is different, right, there is now, it's now a hollow conductor.

Anyone in favor of some of that charge maybe going on the inside?

I see one hand, two hands, who says no it's not possible, it will not go to the inside?

It will still go to the outside.

Well, most of you are very careful now, you don't want to vote anymore.

It cannot go to the inside.

Why can it not go to the inside?

Let this be my Gauss surface.

Closed surface.

Think of this as three-dimensional.

Everywhere on that line the electric field is zero because you're inside the conductor.

So the surface integral is also zero.

So Gauss's law says there cannot be any charge inside that box.

And so again the charge has to go to the outer surface and nothing will go to the inner surface.

And so the conclusion then is that the electric field is zero in the conductor but the electric field is also zero in this opening.

There's never any charge there.

And so the whole heart including the cavity is an equipotential.

There is never any electric field anywhere.

The only electric fields outside the heart.

And there are field lines and these field lines everywhere are perpendicular to the surface of the heart because the heart is an equipotential.

So here you get very funny field lines that go like this.

They have to be perpendicular locally where they reach the heart wall.

Earlier in my lectures I showed that a uniformly solid sphere has electric field zero inside and I even showed to you that a hollow conducting sphere also has zero electric field inside.

Today I have demonstrated that it doesn't have to be a sphere.

You don't need spherical symmetry.

That any shape provided that it's a hollow conductor, it has to be a conductor, any shape will give you an electric field of zero inside.

And I first want to demonstrate that.

I have here something that is not a sphere.

It's a paint can.

It has some aluminum on top.

It has an opening there.

It's not perfect.

It's not really closed like this is.

So the electric field inside will not be exactly zero.

But it will be very close.

I must have an opening because I want to get in.

I want to get charge, see whether there is any charge on the inside.

So I must be able to get through.

So I'm going to charge this one and then I will take some charge off the outside and take some charge off the inside and use the electroscope and see whether we can demonstrate that indeed there is charge on the outside but there is nothing on the inside.

I will use the same method that I used last time when I challenged you to figure out how this works.

This is this crazy method which we call electrophorus, elec- electrophorus, it's difficult to pronounce.

Electrophorus.

We have here a glass plate.

I rub it with cat fur.

Think about it again.

It's a little problem inside the problem.

Metal plate.

I put it on top.

I touch it.

I get a shock.

I touch it here.

I touch it again.

I get again a shock.

And I charge this up.

I touch it again.

I get another shock.

And I touch it again.

Let's get a little bit more on it.

The charge on this plate is positive by the way.

That I create on the glass.

I touch it.

The charge on here is negative.

Not positive.

Put it on again.

Touch it.

OK.

So I should have negative charge on there now.

Here is little test sphere.

It's a conductor.

I'll take some charge off from this side.

Touch it.

Boy.

There's charge.

There's no question.

We agree, right?

There's charge.

OK.

Now I touch the inside, let's hope that no sparks fly over.

I touch it.

Nothing.

See that?

Absolutely nothing.

So there's no charge inside, the charge is on the outside.

Which is what I've just demonstrated.

You see it in front of your own eyes.

All the charge goes to the outside.

Not so intuitive but an immediate consequence of the fact that it's a conductor that the electrons will move freely so that the electric field in the conductor itself is zero and we have argued that no charge can ever go on the inside of the surface.

It all stays on the outside.

So when I touch the inside there was no charge.

So if you are inside that conductor, if your house is a conducting house, and someone in the outside world charges your house up when you're inside, you have no knowledge of that.

It's quite amazing, isn't it?

You are electrically shielded from the outside world.

Now I'm going to make the situation even more complicated.

I now take a conducting object, doesn't have to be a sphere.

And I bring that conducting object hollow in an external electric field.

So someone outside your house is turning on a VandeGraaff creating an electric field.

What now is going to happen?

Well, due to induction, you're going to get some charge polarization in the conductor.

One side may end up negative and the other side may end up positive.

But what happens on the inside?

Nothing.

The electric field in the conductor must stay everywhere zero if it is a static electric field.

And so no charge will -- can accumulate here and no charge can accumulate on the inside.

And so as you bring this electric field on the outside you may get negative and positive charge on the outside, maybe negative here and positive there, but inside nothing.

You are inside electrically shielded from the outside world in the same way that you were when someone was trying to put charge onto your house, now someone is trying to zap you with electric fields.

Nothing will happen inside.

You will never see an electric field inside.

I will show you a interesting drawing, interesting figure, which is a conducting box.

It's closed.

The cup that you see open is just to allow you to look inside but it is closed from all sides.

And there are some negative charges here and there are positive charges in the foreground which you don't see.

The red field lines come from positive charges, end up on the box, and the negative field lines go from the box to the negative charges.

There is clear polarization.

The box itself is neutral.

I started with a neutral box.

But because of this electric field I get polarization.

I end up with negative charge on the box here, only on the outside, positive charge on the box here, only on the outside.

Inside electric field is zero.

No charge anywhere inside.

Due to this crazy electric field the free moving charges in the conductor will rearrange themselves in such a way that the electric field is zero everywhere in the conductor, is zero inside the cavity, and that the closed loop integral of E dot dL is zero everywhere if these are static fields.

And it is clearly impossible for us to ever calculate how that charge configuration at the surface will have to be in order to meet all those conditions.

But nature can do this effortlessly.

And it can do it extremely fast, obeying all the laws of physics.

It puts very quickly plus charge here and minus charge there.

Make sure that there is no charge on the inside of the surface.

It makes sure that the electric field is everywhere zero inside and in the box and it also makes sure that the integral E dot dL is zero everywhere in space.

And therefore the box and everything inside becomes an equipotential so it also arranges matters so that the field lines wherever they intersect with the box are always perpendicular to the box.

And all of that is done in almost no time at all by nature.

It is an amazing thing that this happens and something that as I said would be impossible for us to calculate because the field configurations are extraordinarily difficult.

So if you were inside this metal box, no matter what happens on the outside, you would be electrically isolated from the outside world.

You would not notice that there is a strong electric field outside, nor would you notice that people are trying to charge up your house.

We call that electrostatic shielding and we give that a name, that house of yours would be called a Faraday cage.

It's called after the great physicist Faraday.

You will learn a lot more about him during this course.

Before I demonstrate this, I want to address an issue which is related to problem two-one.

Which is your next assignment.

And I want to urge you, I make myself no illusion, but I want to urge you to start working on that assignment this weekend, not next week.

These assignments are not just baby assignments.

These are MIT assignments and you got to put in a lot of work to do them, so please start this weekend-- not to do me a favor but to do yourself that favor.

But let's talk about problem two-one.

In other words I will help you with that problem two-one.

I said several times that it is not possible to get an electric field inside a hollow conductor.

Well, suppose I go inside the conductor.

I go inside there.

And I put sneakily a charge in my pocket.

And I sit inside there and you close it.

Then there is a charge inside, there's nothing you can do about it.

And if there is a charge inside, there is an electric field.

So now we have a situation and since it is post Valentine's Day my heart has evolved into a sphere again.

So now we take a spherical conductor, solid, this is solid material, and somehow I'm sitting inside here with a charge plus Q.

Can make it minus if you want to.

That's exactly the problem two-one is about.

Now clearly there is positive charge inside.

So clearly there has to be an electric field.

But the electric field inside the conductor, that means the electric field anywhere here, must be zero.

If it's not zero the electrons will keep moving until it is zero.

So the conducting material itself has no electric field.

What does that mean now with respect to any charge on the inside surface?

Now there must be charge on the inside surface.

Because now if I made this my Gaussian surface, which is now a spherical surface, a closed surface, Mr. Gauss says that the closed surface integral of E dot dA over this surface must be zero because the electric field is zero anywhere.

That's the same as all the charge inside divided by epsilon zero.

So this -- the charge inside must be zero.

Since there can be no charge in the conductor itself, negative charge must now accumulate on the inside of that surface.

So that the net charge inside this surface is zero.

So now we do get charge on the inside, and how much charge do you get on the inside?

Exactly minus Q.

So that the sum of the two is zero.

Now this conductor originally was neutral.

It had no net charge.

So therefore on the surface of the conductor we must now see charge plus Q.

Because the minus charge on the inside came from the induct- conductor itself, and so the sum must be zero.

So now you get a peculiar situation that the plus Q charge inside, which creates an E field inside, creates negative charge on the inside, the same in magnitude opposite in sign, and plus Q charge on the outside.

And the electric fields, they're very complicated.

The electric fields, let me try to put them in, I would imagine that if this charge Q is closer to this wall than to this wall that the negative charge here will be larger in density than there.

It's really an induction effect.

The negative charge wants to go to this plus.

That's really what's happening.

And so since this charge is closer to this wall than to that wall it will be able to attract more electrons and so it's clear that the density of charge here should be higher than there and so the field lines, always perpendicular to the equipotential so they must be always perpendicular to the wall, sort of like this.

So I put in a few field lines.

But here the field will be stronger than there.

So there is a field inside.

What now is the charge distribution on the outside?

That is the hardest of all.

And by no means so obvious.

It turns out that the charge on the outside on this sphere, because it is a sphere, will be uniformly distributed.

And it is not intuitive and it is not obvious.

Nature must obey all laws of physics.

The conductor must become an equipotential.

There can be no electric field inside the conductor.

Electric field lines have to be everywhere perpendicular to the surface.

The closed loop integral of E dot dL must be zero everywhere.

And the only way that nature can do that is by making the charge distribution on the surface uniform.

And that is amazing when you think of that.

It's independent of the position of that charge plus Q inside.

So if you start to move around with that charge plus Q inside, the outside world will not know.

The outside world only knows that there is a charge plus Q uniformly distributed on the outside because it is a sphere.

That would not be the case if it were a heart.

But the outside world has no way of knowing that you are moving that charge inside around.

So I'm sitting inside there and suppose I crawl inside there with a rubber rod and with a cat.

And I use the rubber rod on the cat, creating positive and negative charge, same amount.

The outside world will not know because I don't change the charge inside.

Only if there's plus Q in my pocket.

The fact that I create plus on the cat and maybe minus on myself, the outside world will never know because the sum of the charges is still Q.

They may hear the cat scream, that's all they can hear.

But they have no way of knowing that I'm fooling around there with charges.

And so the outside world has no way of knowing what happens on the inside.

And we call that electrostatic shielding.

That's the effect of a Faraday cage.

I want to demonstrate when I bring this can in the electric field.

It's a conducting hollow object.

I bring it in an electric field of the VandeGraaff, the thing is a conductor, I will show you that because of the induction you're going to get like you see on that figure.

You're going to get negative charge on one side, positive charge on the other side, and zero charge on the inside.

That's quite amazing, isn't it?

If this were positive, let's assume it is, then this side becomes negative, this side becomes positive, the whole thing is an equipotential, no charge inside.

Quite amazing.

So let's turn on this, the VandeGraaff.

So we create that electric field.

We turn on the electroscope.

Here is my little Ping Pong ball conducting and I'm going to touch first the can on your side, on your left side, there we go, and I bring this charge on the electroscope.

Boy, nice charge.

I now touch the other side, and I will approach the -- I heard a spark, sparks are always bad.

I approach that electroscope, and if the reading of the electroscope, if the deflection becomes less, as we discussed earlier, it means that the polarity that I have on here is different from the polarity on the electroscope and you clearly see that.

The deflection becomes less.

So the charge that I took off from this side has a different polarity than the charge that I took on from that side.

But yet, it's an equipotential.

All that strange polarization of charges takes place at the surface.

And now I will try to get inside.

To see whether I can get some charge from the inside, and there shouldn't be any.

Ooh, I have to take this charge off of course, and I touch this and you see no charge.

So you've seen three things, which is quite amazing.

That the charge on this side has a different polarity from the charge on that side, and that everything happens on the surface, nothing happens on the inside.

I could not get any charge from the inside.

Now we're going to experiment with more dangerous stuff and that is with the VandeGraaff.

Here you see a Faraday cage with hat -- has some openings.

It's not solid conductor, but it has small openings, which doesn't change the situation too much.

Maybe only a little.

And I'm going to go inside that cage, this would also be a nice Faraday cage but it's very hard for me to crawl in there.

And if I go in there with a radio, just like the radio in your car, then you may not be able to hear the radio, even though radio waves is a difficult story because the shielding that we discussed is only electrostatic shielding and radio waves are electromagnetic radiation which strongly changing fields.

So it may not be as perfect a shielding as you may think.

But we all know if someone breaks off the antenna of your car which happens in Cambridge all the time, you have no reception inside.

Because your car is a Faraday cage.

And so what I will do, I will go into the cage.

I will first show you that when we charge that cage, that we bring it up to a few hundred thousand volts, I'll just hold some tinsel in my hand, to convince you that yes indeed this cage will be charged by the VandeGraaff provided there is contact here.

And we'll see that, yes Marcos give me the full blast, let's just look at the tinsel, you see this tinsel clearly indicates like an electroscope that I'm being charged now.

So I'll jump off, if you can discharge.

Then I will go inside.

I will have the tinsel with me.

So I will show you that inside there when they charge that cage that the tinsels will not spread out, and I will bring with me this wonderful radio and -- Radio: Said a woman who opposes embalming is a suspect in the murders -- [laughter] Lewin: I didn't plan that, believe me.

Radio: self-proclaimed prophet, Catherine Padilla, grandmother of ten, denies the charges and tells a reporter she's not quote -- Lewin: I'll first go in without any charge.

But don't do anything.

Radio: And she's one that -- -- when she calls her own -- Lewin: Nothing.

I'm shielded.

However, there is a problem.

You can still hear me and I'm wearing a transmitter and the receiver is somewhere outside this box.

So why can you still hear me?

That means that the kind of radio waves that I am transmitting are very high frequency, it's not a static field, so somehow they can get through.

So the shielding is not perfect for fast changing electric fields.

But it's good enough for AM radios.

So now I'll go in and I'll try to be brave and he's going to try to zap me now, to electrocute me.

But since I've taken eight oh two, I'm not afraid.

I burned my hand, that's a different story.

OK.

Marcos.

Do the best you can.

Here are the tinsels.

Run it up a hundred thousand volts.

Two hundred thousand volts.

I feel as happy like a clam at high tide inside here.

Nothing is happening.

I'm not worried at all.

If lightning were to strike me who cares?

I'm in a Faraday cage.

Not going to spoil my weekend.

I can touch the inside.

There's no charge anywhere here.

My weekend won't be spoiled.

And I hope that the new assignment is not going to spoil yours either.

See you next Tuesday.