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8.02 Electricity and Magnetism, Spring 2002
Transcript – Lecture 2

Today I'm going to work with you on a new concept and that is the concept of what we call electric field.

We spend the whole lecture on electric fields.

If I have a -- a charge, I just choose Q, capital Q and plus at a particular location and at another location I have another charge little Q, I think of that as my test charge.

And there is a separation between the two which is R.

The unit vector from capital Q to li- little Q is this vector.

And so now I know that the two charges if they were positive -- let's suppose that little Q is positive, they would repel each other.

Little Q is negative they would attract each other.

And let this force be F and last time we introduced Coulomb's law that force equals little Q times capital Q times Coulomb's constant divided by R squared in the direction of R roof.

The two have the same sign.

It's in this direction.

If they have opposite sign it's in the other direction.

And now I introduce the idea of electric field for which we write the symbol capital E.

And capital E at that location P where I have my test charge little Q, at that location P is simply the force that a test charge experienced divided by that test charge.

So I eliminate the test charge.

So I get something that looks quite similar but it doesn't have the little Q in it anymore.

And it is also a vector.

And by convention, we choose the force such that if this is a positive test charge then we say the E field is away from Q if Q is positive, if Q is negative the force is in the other direction, and therefore E is in the other direction.

So we adopt the convention that the E field is always in the direction that the force is on a positive test charge.

What you have gained now is that you have taken out the little Q.

In other words, the force here depends on little Q.

Electric field does not.

The electric field is a representation for what happens around the charge plus Q.

This could be a very complicated charge configuration.

An electric field tells you something about that charge configuration.

The unit for electric field you can see is newtons divided by coulombs.

In SI units and normally we won't even indicate the-- the unit, we just leave that as it is.

Now we have graphical representations for the electric field.

Electric field is a vector.

So you expect arrows and I have here an example of a -- a charge plus three.

So by convention the arrows are pointing away from the charge in the same direction that a positive test charge would experience the force.

And you notice that very close to the charge the arrows are larger than farther away.

That it, that sort of represents- is trying to represent- the inverse R square relationship.

Of course it cannot be very qualitative.

But the basic idea is this is of course spherically symmetric, if this is a point charge.

The basic idea is here you see the field vectors and the direction of the arrow tells you in which direction the force would be, if it is a positive test charge.

And the length of the vector give you an idea of the magnitude.

And here I have another charge minus one.

Doesn't matter whether it is minus one coulomb or minus microcoulomb.

Just it's a relative representation.

And you see now that the E field vectors are reversed in direction.

They're pointing towards the minus charge by convention.

And when you go further out they are smaller and you have to go all the way to infinity of course for the field to become zero.

Because the one over R square field falls off and you have to be infinitely far away for you to not experience at least in principle any effect from the..

from the charge.

What do we do now when we have more than one charge?

Well, if we have several charges -- here we have Q one, and here we have Q two, and here we have Q three, and let's say here we have Q of i, we have i charges.

And now we want to know what is the electric field at point P.

So it's independent of the test charge that I put here.

You can think of it if you want to as the the force per unit charge.

You've divided out the charge.

So now I can say what is the E field due to Q one alone?

Well, that would be if Q one were positive then this might be a representation for E one.

If Q two were negative, this might be a representation for E two, pointing towards the negative charge.

And if this one were negative, then I would have here a contribution E three, and so on.

And now we use the superposition principle as we did last time with Coulomb's law, that the net electric field at point P as a vector is E one in reference of charge Q one, plus the vector E two, plus E three, and so on and if you have i charges, it is the sum of all i charges of the individual E vectors.

Is it obvious that the superposition principle works?

No.

Does it work?

Yes.

How do we know it works?

Because it's consistent with all our experimental results.

So we take the superposition principle for granted and that is acceptable.

But it's not obvious.

If you tell me what the electric field at this point is, which is the vectorial sum of the individual E field vectors, then I can always tell you what the force will be if I bring a charge at that location.

I take any charge that I always would carry in my pocket, I take it out of my pocket and I put it at that location.

And the charge that I have in my pocket is little Q.

Then the force on that charge is always Q times E.

Doesn't matter whether Q is positive, then it will be in the same direction as E.

If it is negative it will be in the opposite direction as E.

If Q is large the force will be large.

If Q is small the force will be small.

So once you know the E field it could be the result of very complicated charge configurations.

The real secret behind the concept of an E field is that you bring any charge at that location and you know what force acts at that point on that charge.

If we try to be a little bit more quantitative, suppose I had here a charge plus three and here I had a charge minus one.

Here's minus one.

And I want to know what the field configuration is as a result of these two charges.

So you can go to any particular point.

You get an E vector which is going away from the plus three, you get one that goes to minus one, and you have to vectorially add the two.

If you are very close to minus one, it's very clear because of the inverse R square relationship that the minus one is probably going to win.

Let's in our mind take a plus test charge now.

And we put a plus test charge very close to minus one, say put it here, even though plus three is trying to push it out, clearly minus one is most likely to win.

And so there will probably be a force on my test charge in this direction.

The net result of the effects of the two.

Suppose I take the same positive test charge and I put it here, very far away, much farther away than this separation.

What do you think now is the direction of the force on my plus charge?

Very far away.

Excuse me.

Why do you think it's to the left?

Do you think minus one wins?

A: [inaudible].

Do you really think the minus one is stronger than the plus three because the plus three will push it out and the minus one tries to lure it in, right, if the test charge is positive.

A: [inaudible] plus two.

So if you're far away from a configuration like this, even if you were here, or if you were there, or if you're way there, clearly the field is like a plus two charge.

And falls off as one over R squared.

So therefore, if you're far away the force is in this direction.

And now look, what is very interesting.

Here if you're close to the minus one, the force is in this direction.

Here when you're very far away, maybe I should be all the way here, it's in that direction.

So that means there must be somewhere here the point where the E field is zero.

Because if the force is here in this direction but ultimately turns over in that direction, there must be somewhere a point where E is zero.

And that is part of your assignment.

I want you to find that point for a particular charge configuration.

So let's now go to-- some graphical representations of a situation which is actually plus three minus one.

Try to improve on the light situation.

And let's see how these electric vectors, how they show up in the vicinity of these two charges.

So here you see the plus three and the minus one, relative units, and let's take a look at this in some detail.

First of all the length of the arrows again indicates the strength.

It gives you a feeling for the strength.

It's not very quantitative of course.

And so let's first look at the plus three, which is very powerful.

You see that these arrows all go away from the plus three and when you're closer to the plus three, they're stronger, which is a representation of the inverse R square field.

If you're very close to the minus one, ah the arrows are pointing in towards the minus one, because the one over R square, the minus one wins.

And so you see they're clearly going into the direction of the minus one.

Well, if you're in between the plus and the minus on this line, always the E field will be pointing from the plus to the minus.

Because the plus is pushing out and the minus is sucking in.

So the two support each other.

But now if you go very far away from this charge configuration, anywhere but very far away, much farther than the distance between the two charges, so somewhere here, or somewhere there, or somewhere there, or here, notice that always the arrows are pointing away.

And the reason is that plus three and minus one is as good as a plus two if you're very very far away.

But of course when you're very close in, then the field configuration can be very, very complicated.

But you see very clearly that these arrows are all pointing outwards.

None of them come back to the minus one.

None of them point to the minus one direction.

And that's because the plus three is more powerful and then there is here this point and only one point whereby the electric field is zero.

If you put a positive test charge here, the minus will attract it, the plus will repel it, and therefore there comes a point where the two cancel each other exactly.

Now there is another way of electric field representation which is more organized.

And we call these field lines.

So you see again the plus three and you see there the minus one.

If I release right here or I place here a positive test charge, all I know is that the force will be tangential to the field lines.

That is the meaning of these lines.

So if I'm here, the force will be in this direction.

If I put a positive test charge here, the force will be in this direction, and of course, if it's a negative charge the force flips over.

So the meaning of the field lines are that it always tells you in which direction a charge experiences a force.

A force a positive charge always in the direction of the arrows, tangentially to the field lines and a negative charge in the opposite direction.

How many field lines are there in space?

Well of course there are an infinite number.

Just like these little arrows that we had before, we only sprinkled in a few but of course in every single point there is an electric field and so you can put in an infinite number of field lines and that would make this a representation of course useless.

So we always limit ourselves to a certain number.

If you look very close to the minus one, notice that all the field lines come in on the minus one.

We understand that of course because a positive charge would want to go to the minus one.

If you're very close to the plus and they all go away from the plus because they're being repelled...

You can sort of think as these field lines if you want to imagine the configuration that the plus charges blow out air like a hairdryer, and that the minus suck in air like a vacuum cleaner, and then you get a feeling for there is on this left side here this hairdryer which wants to blow out stuff and then there is that little sucker that wants to suck something in and it succeeds to some degree, it's not as powerful as the plus three, though.

Have we lost all information about field strength?

We had earlier with these arrows, we had the length of the arrow, the magnitude of the field was represented.

Yeah, you have lost that, but there is still some information on field strength.

If the lines are closer together, if the density of the lines is high, the electric field is stronger than when the density becomes low.

So if you look for instance here, look how many lines there are per few millimeters, and when you go further out these lines spread out, that tells you the E field is going down, the strength of the E field is going down.

It's the one over R square field of course.

If you want to make these drawings what you could do to make them look good, you can make three times more field lines going out from the plus in this case than return to the minus one.

So the field lines are very powerful and we will often think in terms of electric fields and the line configurations and you will have several homework problems that deal with electric fields and with the electric field lines.

If an electric field line is straight, so I have electric fields, get some red chalk, say we have fields that are like this, straight E field lines, and I release a charge there, for instance a positive charge, then the positive charge would experience a force exactly in the same direction as the field lines, because the tangential now is in the direction of the field line, it would become accelerated in this direction and would always stay on the field lines.

If I release it with zero speed, start to accelerate and it would stay on the field lines.

In a similar way, if we think of the earth as having a gravitational field, with eight o one we may never have used that word, gravitational field, but in physics we think of the -- of gravity of also being a field.

If I have here a piece of chalk the-- the field lines, the gravitational field lines, here in twenty-six one hundred, nicely parallel and straight and if I release this piece of chalk at zero speed it will begin to move in the direction of the field lines, and it will stay on the field lines.

So now you can ask yourself the question if I release a charge would it always follow the field lines?

And the answer is no.

Only in this very special case.

But suppose now that the field lines are curved.

So here are field lines, as you have seen in those configurations.

It is very common.

If now I release a -- a charge in here, say I have a point charge here, it will experience a force in this direction.

So it will get an acceleration in this direction, so it will immediately abandon that field line.

And so if now you ask me what is the trajectory of that charge, well, it could become very complicated, I really don't know.

Maybe it's going like this, and by the time it reaches this point, what I do know that then the force will be tangential to this field line, so will be in this direction.

And so as it marches out and picks up speed, locally it will experience forces representative of those field lines and so the trajectory can be rather complicated.

So field lines are not trajectories, and not even when you release a charge with, uh, with zero speed.

Only in case that the field lines are straight lines.

Let's now look at a field configuration, which Maxwell himself, the great maestro, in some of his publications put there.

And it's a ratio one to four and whether it is plus four plus one or minus four minus one is not important because that's just a matter of the direction of the arrows.

But uh Maxwell didn't put arrows in.

So I leave it up to you.

If it's plus four and plus one you have to put arrows going outwards.

And what you see now here is this airblower effect.

Think of them as both being positive.

So there is the plus four trying to blow air out like a hairdryer and the plus one is trying to do its own thing and so you get a field configuration, field lines, which are sort of- not perhaps easy- but you can sort of imagine why it has this peculiar shape.

If you put a plus test charge in between the one and the four, then the four will repel it but the one will also repel it and so there's going to be a point somewhere, probably close to one, whereby the two forces exactly cancel out.

Therefore E will be zero there.

In a similar way between the moon and the earth, there is a point not too far away from the moon where the gravitational attraction from the earth and the gravitational attraction from the moon exactly cancel each other out.

That's not too dissimilar from this situation.

So when you have charges of the same polarity, you always find in between somewhere a point where the electric field is zero.

Let's now go to a very special case whereby I make the two charges equal in magnitude but opposite in sign and we have a name for that, we call that a dipole.

The plus charge is here and the minus charge is there.

Situation is extremely symmetric, as you would expect, because they have equal power.

There's one airblower upstairs and one vacuum cleaner downstairs.

If you're close to the plus charge, notice that all the field lines go away from the plus.

And if you're close to the minus, notice that all the field lines come in on the minus-- you expect that.

If you are far away from this dipole, now you have a problem.

Before we had a plus three and a minus one and when you're far away the plus three wins.

So it's like having a plus two charge.

If you're far away you always expect the electric field then to be pointing away from the equivalent charge of plus two.

But if you add up plus and minus and they have equal magnitude, let's say plus one and minus one, you get zero, so neither one wins if you're far away, and notice carefully if you're very far away, indeed you do not see arrows either pointing out nor pointing in.

Nature cannot decide.

There isn't one that is stronger than the other.

And that makes dipole fields very, very special.

In the case of the plus three and the minus one, if you're very far away, it's like having a plus two charge and the E field when you go further and further out will fall off as one over R squared.

With a dipole your intuition sort of tells you that it will probably fall off faster than one over R squared.

And that is part of a homework assignment that you have this week.

In fact I can already give you the answer.

You have to prove it.

If you're far away from an electric dipole the electric field falls off as one over R cubed.

It goes faster than one over R squared.

There is not a single point in space where the electric field is zero.

And you can think about that why that is the case.

So these field configurations can be rather complicated, and can be very interesting, and each one has its own applications.

Are dipoles rare in physics?

Not at all.

In fact, they're extremely common.

You cannot avoid them.

Remember last time, I told you if you have a spherical atom or we have a spherical molecule, and you bring that close to a charge -- let's now think of it you bring it in an electric field, it's another way of saying the same thing.

So we have a nice spherical atom or a nice spherical molecule and we bring it in an electric field.

The electrons want to go upstream the electric field vectors, they go against the direction of the electric field.

And the positive charge wants to go in the direction, wants to go downstream.

And so what are you going to do?

The electrons will spend a little bit more time on one side of the nucleus than they would in the absence of that electric field.

And therefore you are through induction turning that atom, turning that molecule, in becoming a dipole.

If you have a little bit more charge on this side, averaged over time, you have the same amount of extra charge plus on that side averaged over time.

So you make dipoles very often whether you like it or not.

And later in this course we will learn more about the polarization of atoms and molecules creating dipoles when- when we talk about dielectrics.

And you will see that it will have an en- can have an enormous impact on the properties of the material.

Could I make you a dipole here in class?

Oh yeah, that's very easy.

To make one of nonconductors is not so easy in class.

To make one of conductors is very easy.

And I'm going to do that with these two spheres that you have.

Look at these two metal spheres.

Conductors.

Free electrons.

It's very easy for them to move.

And I'm going to bring this rubber rod which I will rub and becomes I think negatively charged if I remember correctly, and I will bring that so close to these two, which are touching each other.

So here is this one metal sphere and here is the other metal sphere and here comes the rubber.

Negatively charged.

Ah! What's going to happen?

The electrons want to go away, so this becomes negatively charged, and therefore this remains a little bit positively charged.

For every one electron that has is excess here, when I start it's neutral, there will be a positive excess there because charge is conserved.

You can't create charge out of nothing.

And now what I do, while this rubber is still here, while that rubber rod is there, I separate them, so here the- they're in contact with each other first, they have to be in contact.

Wow, we get some visitors.

[clap-clap] Don't be late, that means you, pretty boy.

I'm impressed.

Thank you.

So what I do now is while this rubber rod is still in place, I take them apart, and when I take them apart this negative charge is trapped and this positive charge is trapped.

And so I have thereby created negative charge on this one, positive on this one and it's equal in magnitude, so I have a dipole.

What I want to demonstrate to you is that indeed I have positive charge here and negative here, that there is a difference in polarity between these two, and that's the way that I will do the experiment.

I will not show you that the amount of charge is exactly the same on each, which of course it has to be.

So let me give you some better light, or we have to get the view graph off, the overhead.

You see there for the first time an electroscope, we discussed it last time.

It is a piece of aluminum foil, very thin, with a metal rod next to it, and when I put charge on the rod it will also go into the aluminum foil, and they will repel each other, and so the -- the aluminum tinsel will go to the right.

And the more charge there is on it, the farther it goes to the right.

So let me first put these two together, make sure they are completely discharged, and now I'm going to bring these two into an electric field which is produced by this rubber rod, I have to rub with the cat fur, and I believe it was negative but if you -- you'd never have to remember whether it's negative or positive of course, that is not so important, what is in a name, after all.

But it did happen to be negative.

OK.

So now we go here.

I bring it here.

I hope that no sparks will fly over because that ruins the demonstration.

And now notice what I do.

While the -- while the rod is here I separate them.

So as I was holding it there, things were going on in there that you and I couldn't see but electrons, the rubber rod is negative, electrons were shifting in this direction and this is now positive and that is now negative.

If I take this one and I touch it with the electroscope, you clearly see that there is charge on this.

How can I show you now that there is charge of different polarity on the other one?

Well, the way I will do that is, I will approach this electroscope by bring this sphere very close to it.

And if this charge is different than the charge that is on it the electroscope will -- the reading will become smaller.

And why is that?

Why will the reading become smaller?

Well, here is the situation of the electroscope now.

And here, is that ball that you see on top, this is upside-down there.

If this is all negative, that's why it is apart, if now I approach this here with an object which is positively charged and I claim that this one now is positively charged, because this one was negatively charged, then electrons are afraid of the positive charge, so more will go -- excuse me, electrons love the positive charge, so the electrons want to come to the positive charge, so these electrons drift down again, and so if they come down, fewer will be here, and so you will see this.

If however, I put here a negative rod, then the electrons which are here want to go further away, they will stream up, and therefore the reading will become larger.

So you can always through induction test what the polarity is of your charge.

Let's hope that this one is still holding its charge while I was talking.

So I claim now that if this polarity is different, and if it's still there when I approach the electroscope, come very close, that the reading should become a little smaller without even touching it.

Let's see whether that works.

You see, it goes down.

You see, it goes down.

Goes down.

So through induction I have demonstrated that this has indeed a different polarity from this one.

If I approached it with this one, it would go further out, unless it already is at the maximum, let's try that, you see, it goes further out.

So not only have I demonstrated that I created a dipole, but you've also seen that by means of induction, that you can demonstrate that the -- there's a difference in polarity between the two spheres.

If I create a dipole and I put that dipole in a -- in an electric field, the dipole will start to rotate.

Let's first talk about it.

Why it rotates, and then I will try to demonstrate that by making a dipole, a big one, this big.

Right in front of you, almost as big as the one there.

So let's have a -- an electric field like so.

And I bring in this electric field a dipole, a biggie.

Here, this is the one I'm going to use for this demonstration.

Ping Pong balls on either side, they are conducting, and they are con- connected with a rod which is not conducting.

And so here is this dipole.

To this rod is not conducting.

And this is a conducting and this is a conductor.

And let's suppose this is positive and this is negative for now.

And I'll show you how we get the charge on it.

Well, the positive charge will experience a force in this direction, always in the direction of the electric field, and the negative charge will experience a force always upstream.

And now there is a torque on this-- and there is a torque on this dipole.

It will start to rotate clockwise.

And of course if it overshoots the field lines when it is in this direction, the torque will reverse.

It's very easy to see.

And so what you will see, it's going to oscillate and if there is enough damping, it will come to a halt more or less in the direction of the field lines.

And this is something that I can demonstrate.

First, I have to make a dipole of this kind and the way I will do that is the following.

This is a metal bar, it's this insulator, and here is this -- are these two Ping Pong balls, the one on this side has a yellow marker, the one on that side has an orange marker.

And I'm going to attach them holding them up against this metal bar.

In other words, here is this dipole, it's not a dipole yet, metal metal and here is a metal bar, this is a conductor which connects them.

I'm going to turn on the VandeGraaff here, and the VandeGraaff creates an electric field, so we have the VandeGraaff here.

And let's suppose that this VandeGraaff creates positive charge.

Sometimes a VandeGraaff creates positive charge on the dome, others can be designed to create negative charge on the dome.

And remember, for now I assume that's positive.

What will happen now?

Electrons want to go in this direction.

So this becomes negative.

Protons, positive charge, stays behind.

So that becomes through induction a dipole.

Because I have them connected.

I have them connected with this metal bar.

So these electrons can flow through this bar and end up here.

Now I remove the bar.

And so when I remove the bar I have created now a dipole.

I have here an insulating thread and I have a fishing rod and at the end of my fishing rod I have now a permanent dipole.

With that permanent dipole I'm now going to probe the electric field around this VandeGraaff.

I could have chosen the same VandeGraaff but there's a reason why I picked this one and as I walk around this VandeGraaff you will see that this fishing rod at the end is this dipole, that the dipole always wants to go radially inwards or outwards depending on how you look at it of this field, so I can probe this field and make you see for the first time that there is indeed somewhere here a strong radial field going in or out of the VandeGraaff.

And now comes something very interesting, which I found out this morning for the first time when I did this experiment.

If the other VandeGraaff there is also positive when I run it, how do you think this dipole is going to align then if I walk into it?

Will the negative ball be closer to the VandeGraaff or will the positive one go closer to the VandeGraaff?

So I give you thirty seconds to think about it.

So I make the dipole as it is here, let's assume this one is positive, this VandeGraaff.

So this side becomes minus, I call that A, and this side become positive, that's B.

I now walk with this dipole, I bring it in this field.

And let's assume that one is also positive.

We don't know that yet.

How will the dipole align now?

Will A go inwards or will A go outwards?

Who thinks A goes inwards?

Very good.

Who says A goes outwards?

OK.

A will go inwards.

If the two VandeGraaffs have the same polarity.

So if that doesn't happen tha- that doesn't mean that physics doesn't work, it means the two VandeGraaffs have different polarities.

And we'll see what happens.

So let me first then create a dipole.

So here is the -- the dipole.

It's shorted out now.

I turn on the -- this VandeGraaff.

So induction takes place.

Remember that the yellow is pointing towards the VandeGraaff and that the orange is away from the VandeGraaff.

OK.

So I induce a dipole.

Oh.

I really should redo that.

I don't know what happens when it -- I have to remove the field first.

OK.

The yellow was inside, right, was that the way it was?

OK.

Yellow inside.

There we go.

So now it's creating a dipole through this metal bar.

And I break contact and this should now be a dipole.

Now I turn on the field of the -- so if the polarity is the same, yellow will go in.

I will try to swing it a little.

Notice two things.

It's going to line up beautifully radially but the yellow is not in, the yellow is out.

So the two VandeGraaffs have different polarities.

But you will see they rotate nicely.

And they end up beautifully radial and when I go all the way around here, again, they may swing a little, they may oscillate a little, but through damping they will come to a halt and look, the field is indeed beautifully radial and the yellow is, so to speak on the wrong side.

The two VandeGraaffs have different polarities.

So you see how we can create a dipole and you've also seen how we often can make statements about the specific polarity.

I can probe an electric field using grass seeds in oil.

Grass seeds are elongated and when I put a grass seed in the electric field it will become polarized, there's nothing you can do about it.

Here is a grass seed and the electric field is like so.

And so the electrons want to go as far away in this direction as they can through induction.

And so this side remains positive, and so what is this grass seed going to do?

It's going to rotate.

It's going to line up with the electric field.

And this is the way that I'm going to show you now field configurations in the vicinity of a dipole.

And I will also show you then field configurations in a vicinity of two charges which have equal polarity.

You may have seen this in high school with magnetic fields, with iron files, that's kid stuff.

That's the easiest thing to do.

This is the real thing, this is the electric fields, I bet you you've never seen electric fields which are traced by these mysterious seeds.

So I'll give you some light that may optimize the demonstration.

These seeds first have to be oriented in a way so that it is chaos.

The first thing you see is I'm going to make this -- I believe it's going to be a dipole first.

Almost certain.

So I'm going to charge one positive and charge the other negative.

And then we'll see how these grass seeds will form each other.

Watch closely.

There you go.

My goodness.

That is a wonderful dipole field.

Of course we don't know which one is plus or minus because the grass seeds have no arrows on them.

But you clearly see these incredible lines radially inwards or outwards on each one of the charges and then you see these nice arcs in between.

Who could see it easily?

OK, you got something worth for your twenty thousand dollars tuition.

Put a little bit more charge on maybe.

Very clear.

And now which is perhaps more interesting, I'd like to show you the field surrounding two charges but now the charges are both the same polarity.

So we have to undo the -- the memory of the grass seeds.

OK, now we'll try to make them both the same polarity.

And then watch this hairblower effect that I told you about.

Maybe not make -- I'm not sure they made contact.

OK, we'll try it again.

Come on.

It's very funny, you know, it looks like there is some -- some charge hidden because it doesn't look as beautiful as we had earlier on the Maxwell view graph.

It seems like there is something here on the side which it prefers.

And therefore the electric field is being distorted.

Let me try to discharge it.

I'm a reasonable conductor, so I should be able to take any stray charges off.

Oh, wait a minute.

Ha! I had it upside-down.

[laughter] Oh my goodness.

Can happen to anyone.

All right.

So they were never really in good contact, we ready now?

Ah, look at that.

Great.

Now you really cle- clearly see these -- these field lines, and you see in between how the two airblowers are competing with each other.

Very impressive.

All right, so that's the way you see field lines now, electric field lines.

And some of you may have seen with iron files magnetic field lines.

If I have the VandeGraaff and I have the VandeGraaff here, and let's suppose the VandeGraaff is positive, I don't know whether it's positive or negative, let's suppose it's, I'm going to use the one over there, and I'm going to stand here, on the ground, Walter Lewin, what is going to happen with me?

Through induction, the electrons being sucked out of the earth and coming up because they want to go close to the positive charge.

So I will become negatively charged.

What will the field lines do?

Oh, they will be extremely complicated.

Very complicated.

But something like this maybe.

Maybe something like this.

Some may come out here.

Some may end up on my neck here.

Some may go here.

Like so.

Very complicated field configurations.

But I want to probe that field.

Somehow, a little.

Get a feeling for how that -- what that field is like.

And the way I'm going to do that is I'm going to put a charged balloon.

There you see the balloon.

It's a conductor.

I'm going to put a charged balloon and put it here say.

Well if it is a positively charged balloon it will take off in that direction.

Right?

The force is always tangential to the field lines.

It will abandon the field lines, it won't stay on the field lines, there's a lot of damping on the balloon, that's why I chose the balloon, so it will move relatively slowly, and it will ultimately maybe end up on my head, right here.

Once it ends up on my head there, so it comes in maybe like this, now it will get the negative charge from my head and so it will become immediately negatively charged and so the force now will reverse and will be in this direction, tangential to this field line, and so it will go back.

When it hits the VandeGraaff again it will get positive charge, reverse its polarity, and it will go back.

And so it will b- bounce back and forth between me and the VandeGraaff and it gives you some rough feeling of what this field configuration is about, although I want to remind you that the charge does not follow exactly field lines.

So I'm going to sit here and I will be part of this, so that's probably going to be positive, I will automatically become negative, there's nothing I have to do, all I turn is the VandeGraaff and we have to put a little bit of charge on that balloon.

It will probably do that by itself, but I can always give it a little kick so that it goes to the VandeGraaff, there it goes.

[laughter] Oh [inaudible] because my -- my glasses are a good insulator, so I better take my glasses off, so that every time it hits me.

[laughter] Changes polarity.

[laughter] So this is a way you can do physics and have fun at the same time.

See you Monday.