8.02 Electricity and Magnetism, Spring 2002
Transcript – Lecture 15

We've seen last time that using Biot and Savart's formula that if you have a current going straight into the blackboard perpendicular to the blackboard that we get a magnetic field at a distance R.

The magnetic field tangentially to the circle, B here, B here, and that the strength of that magnetic field equals mu 0 times I divided by 2 pi R.

If you walk around this circle, just walk around, and you carve up this circle in little elements dL, and you calculate the closed circle integral, so the closed circle of B dot dL, so everywhere locally you dot B with dL, the B and dL are in exactly the same direction everywhere, then you would find that this obviously is B times 2 pi R.

But B times 2 pi R equals also mu 0 times I.

This dL here has nothing to do with this dL here.

Don't confuse the two.

This dL is a small amount of length in the wire that goes into the blackboard which carries a current.

This dL is simply your dL when you walk around this current wire.

It doesn't matter at what distance you walk around.

You always get mu 0 times I.

You see it right in front of your eyes because B is inversely proportional to R.

And it was Ampere who first recognized that you don't have to walk around in a circle to get the answer mu 0 I, but that you could walk around in any crooked path as long as it is a closed path, something like this.

And now you have here the local B, which of course is perpendicular to this radius and here you have your local dL and if now you go around, closed circled any path, it doesn't have to be a circle, dot dL that now becomes mu 0 times I, which is known as Ampere's Law, and I then is often given an index enclosed.

It is the current which is enclosed by that path.

It is actually easy to prove this using Biot and Savart's formalism.

This is almost a third Maxwell's equation.

We already had two out of four.

This is almost number three, not quite.

We're going to amend it in the future.

What is ill-defined a little bit in this equation is what we mean by enclosed, and I'm going to define that now so uniquely that there is never any misunderstanding.

If I have a very strange looking closed path that I have chosen, that's the path I walk, I have to attach to that closed loop a surface, an open surface.

That's mandatory.

You can make it flat.

That's fine.

You're free to choose it.

You can also make it sort of a plastic bag so it's open here.

You can put your hands in here, and here, like a hat.

Any surface is fine, but you must attach to that loop a surface, so here I have some path that you could be walking, and this would be perfectly fine open- open surface.

Could be flat, but it could also be open, so it's like a hat.

And now I can define uniquely what it means by- what it means by this I enclosed, because if now I have a current that goes through this surface and pokes out here, then I have a current penetrating the surface and that is uniquely defined, and if I have another one coming in through the surface, call it I2, this is penetrating that surface.

By convention, if you go clockwise around, we follow the same notation that we had before, in the right-hand corkscrew notation, the connection between magnetic field and current.

If you go around clockwise seen from this side, so you go clockwise, then I1 as I have it here, in your equation would have to be larger than 0.

I2 is then smaller than 0.

But if you decide to go counterclockwise, which is perfectly fine, Ampere's law doesn't at all dictate in which direction you have to march around, then I1 would be negative and then I2 would be positive.

So we follow the right-hand corkscrew notation.

And so if you want to amend now Ampere's Law to do me a favor, but you don't do books a favor because all the books use the word enclosed.

I would like to see this replaced by penetration.

It is the penetration of the surface of the current, that is uniquely defined.

But a current enclosed by a loop is ill-defined.

Because where possible, when we apply Ampere's Law, we will try to find easy passes around circles sometimes, sometimes rectangles, and since you are free to choose the surface that you attach to the loop if you can get away with it you use a flat surface, but you cannot always get away with a flat surface.

So the recipe is as follows.

You choose your closed loop.

Any loop is allowed.

It may not help you very much if you choose the wrong loop.

Any loop is allowed.

You then attach an open surface to that loop.

And I penetrate is now the current that penetrates through that surface, according to this convention.

And the direction of rotation is free to you.

How you go around the path is your choice, but that defines then the sign of the penetrating of the curve, of the- of the current, according to the right-hand corkscrew.

So now we can, for the first time, calculate the magnetic field inside a wire that draws a current using Ampere's Law.

I have here a wire that has a radius capital R and a current is coming to me, I, and let's assume that the current is uniformly throughout the wire, so it has a uniform current density.

And I would like to know what the magnetic field is everywhere.

Cylindrical symmetry, I want to know outside the wire and I want to know inside the wire.

Let's first look at radius which is larger than R, and so here we have the cross-section of that wire, radius R.

The current I is going through this surface.

I now have to choose a closed path.

Since we have cylindrical symmetry it is clear that we would choose a circle, with radius little r, so we can be sure that the magnetic field strength is the same everywhere because of reasons of symmetry.

Since the current is coming towards me and I am free to choose in which direction I'm going to march, I know that the magnetic field is in this direction, so I might as well also march in this direction so that my dL's are all in this direction.

I don't have to do that.

I could march the other way around, but if I march counterclockwise then both terms left and right of Ampere's Law will be positive.

I now have to attach an open surface to my path.

Well, this will be, the blackboard will be, that open surface.

And so now I apply Ampere's Law, so I get B times 2 pi little r, because dL and B are in the same direction so it's a trivial integral.

That now equals mu 0 times I, which now penetrates my surface.

Uniquely determined, all these current from this wire that comes to me penetrates my surface, so times I, and so B equals mu 0 times I divided by 2 pi R, and that's the same result that we found last time, when we applied Biot and Savart.

So that's no surprise that you see this.

But now we have a way of finding the magnetic field also inside the wire, so here we have the wire again, the cross-section, current coming out of the blackboard, and now I want a radius which is smaller than capital R and of course my closed path again for reasons for symmetry is going to be a circle with radius R.

And my surface that I attach is a flat surface, and so here I go, B times 2 pi little r equals mu 0 times- ah, now I have to be careful, because now not the full current I is now penetrating my surface, but it is only a fraction that penetrates the surface, and the fraction that penetrates the surface is now little r squared divided by capital R squared times I.

You see, because the total current comes through the radius capital R, but I only have now a circle with radius little r.

And so I lose one r here and so we get a very different result.

You get now that the magnetic field equals mu 0 times I is now linear in little r divided by 2 pi capital R squared.

And this grows linearly with r, whereas this falls off as 1 over r.

And if you substitute in this equation r equals capital R, which then would be the magnetic field right at the surface of the wire, you find exactly the same result here.

Little r becomes a capital R.

If little r becomes a capital R, you lose one capital R, you get the same result.

And so if you make a plot of the magnetic field as a function of little r, then it looks like- like so, so this is little r, this is capital R, and this is the magnetic field strength because we know that it is tangentially to the circles.

It would be straight line and then here it falls off as 1 over r, and the maximum value here is the value that you find there if you substitute little r equals capital R.

I will now show you that we can, using Ampere's Law, also come very close to calculating the magnetic field inside what we call solenoids.

Solenoids is like a slinky current that goes around in a spiral, one loop after another.

I want to remind you that if we had a loop, a nice current loop coming out of the blackboard here, and the current going into the blackboard so there's a circular wire but I only show you the cross-section.

I want to remind you that the magnetic field as we discussed last time, would be clockwise here, would be counterclockwise here.

In the middle, remember, it was like this.

And then in-between it was like so.

That was sort of the magnetic field configuration in the vicinity of a loop through which we have a current going.

But now imagine that you put another loop here, current again coming out of the blackboard, going into the blackboard, and another one, and so on, several.

What do you think is going to happen with these magnetic field lines which now diverge?

They're going to be sucked in here.

This loop also wants the field lines to come through its circle, so to speak, and this one too, and so you're beginning to get a near-constant magnetic field and the more tightly these loops are wound, the more accurately will your magnetic field be approximately constant, and I have some transparencies which will show that in more detail.

Here we have a figure from your book.

You see five windings, a spiral.

If you look from the left, the current is going in clockwise direction, and so the magnetic field is going from this side to that direction.

And when you look here you see that the magnetic field is approximately constant inside, and outside these current loops, outside the solenoids -- we call them solenoids -- magnetic field is extremely low.

And if you start winding these loops very tightly, then you get a configuration looks like this.

You get an almost perfect constant magnetic field inside the solenoids and the magnetic field outside the solenoids is extremely weak.

And now I would like to calculate with you using Ampere's Law what that magnetic field inside such a solenoid would be.

And we have to make a few assumptions.

Let this be my solenoid, and the length of the solenoid is capital L.

A current I is going through like so.

I, and I assume that if I look from the left side that the windings are wound clockwise, so I know that the magnetic field is then in this direction.

I make the assumption that the magnetic field outside the solenoid is approximately 0.

I will show you later with a demonstration that that's a pretty good approximation.

And so the question now is, what is the magnetic field there.

And I assume I have N loops, N windings, capital N.

So now I have to choose a path.

I have to apply Ampere's Law.

I choose a path, and you may be surprised the path I'm going to take.

This is the path I choose.

It's a rectangle.

And the length of this side inside the solenoid is L.

And I think of this as four different passes.

Number one, number two, number three, and number four.

Let's first look at number two.

We have assumed that the magnetic field is practically 0, so clearly if you go the integrals, if you go around, then the contribution here must be 0.

If the magnetic field is 0, then the integral B dot dL is 0, so that's easy.

But if you look at one and three, there is no magnetic field, very small magnetic field outside.

The magnetic field inside is in this direction.

But dL is like this if I march like that, and B is like this so there 90 degree angles and so the dot product is 0.

And so the only path that contributes to my closed-loop integral of Ampere's Law is only path four, and that tells me then that B times little L -- because B is constant, I have assumed that it is constant, and I integrate it over a length little L.

Now I have to agree on my surface.

What surface am I going to choose to attach to that closed loop?

Well, why not using a flat surface just like the blackboard?

Now, I have to calculate the current that penetrates that surface.

The current that penetrates that surface, I have to know how many times this winding pokes through that surface.

If the length of my rectangle is little L and is if the length of the solenoid is capital L, and if there are N windings on capital L, this is the number of times that the current pokes through that surface, uniquely defined.

I have a surface now.

There is no such thing as I enclosed.

There is I penetrating, through that surface.

It's a soap film, and I poke straight through it, and I do it so many times that I poke through it, and then I have to multiply this by mu 0, and then I have my I, but each time that it pokes through I have current I.

And so what you see now is that B equals mu 0 times I times N divided by L, and so that is our prediction for approximating the constant magnetic field inside a solenoid, and this actually is a very good approximation as long as L, the length of the solenoid, is substantially larger than the radius of the solenoid.

The radius would be the radius of these loops.

I'll work out a numerical example which is aimed at a demonstration that comes shortly.

We have here a solenoid whereby N is about 2800 and L is about 60 centimeters, that is 0.6 meters, and I'm going to run through there a current which I really don't know yet but is going to be close to 4.5 amperes, we will see when we do the demonstration.

And so I can calculate now what the magnetic field is going to be.

So the magnetic field strength is going to be 4 pi times 10 to the -7, because that's what mu 0 is, and then I have to multiply it by 2800.

I have to multiply it, divide it by 0.6, and then I multiply it by the current, 4.5, and when I do that I find about 0.026 Tesla.

0.026 Tesla, that is about 260 Gauss.

And when we do the experiment, the current will be a little different but you will see that indeed the field will be very close to 260 Gauss.

Why is it that the magnetic field is not proportional to the number of loops, but proportional to the number of loops per unit length?

You may say well, if I have one loop I have a certain magnetic field, two loops I have twice that magnetic field, 10 loops I have 10 times that magnetic field.

Well, imagine that we start a solenoid in lobby 7.

And so here is lobby 7, and here is that solenoid.

There it goes, all the way, all the way, thousands and thousands and thousands and thousands of loops, and we end up here in 26-100.

Look at this loop.

Think of it at the first loop.

Creates a magnetic field.

What is the shape of that magnetic field?

Well, it is a current loop and as we discussed last time, the magnetic field that one loop produces is like a dipole field.

So do you really think that here in 26-100 we can sense the magnetic field that is produced by this one dinky toy loop?

Practically nothing! It falls off so rapidly, the magnetic field, that we don't notice it- notice it here.

So it's immediately obvious that the magnetic field is not proportional to how many loops you have.

If, however, you put all those loops on top of each other, then of course you can add the magnetic fields.

And so it is natural that you get how many windings you have per unit length.

So now I want to first show you the magnetic field configuration of a very loosely wound loop, seven windings, and I will do that by sprinkling magnetites, these iron file, in the vicinity.

We've done this before for other current configurations.

Now we'll do it for this solenoid with seven windings, and I'm going to run a few hundred amperes through there, have to first get this car battery.

All right.

And so we put some iron files on here and what I want you to see now is that the magnetic field inside, even though it's very loosely wound, begins to look nicely uniform and that there's almost no electric- er, magnetic field outside.

Look at this, isn't that wonderful?

Isn't that incredible?

You see how these iron files line themselves up very nicely horizontally inside the loops and when you look outside the loop here or there, where we assumed the magnetic field was about 0, you don't see the iron file being oriented in any preferred direction, which indicates that the magnetic field is very low.

Now, I want to show you what magnetic field we can get with this baby, which is exactly what I had here on the blackboard.

It has 2800 windings, and we're going to run a current which is something like 4.5 amperes, but I'm going to tell you what that current is, because I have a current meter there for you and I also have a- a meter which indicates the magnetic field.

The lower one is the current meter, and the maximum current that you see there at the three would be 6 amperes.

And the upper one is calibrated in such a way that if it is full scale, you would have 300 Gauss, so it's three, it's 300 Gauss.

And I can -- I have a probe, a magnetic probe -- we never discussed how that works.

We call it a Hall probe, and this Hall probe allows me to measure the magnetic field in the vicinity of this solenoid.

It's even sign-sensitive.

If the magnetic field is like this, it would go to the right.

If the magnetic field is like this, it would go to the left.

And so this allows us, then, to be actually quite quantitative and evaluate the magnetic field near the opening of the solenoid.

Then we can go in there and we can also probe the outside.

So I'm running now a current.

Let's look at it, that's the bottom meter.

So that is about 4.8 amperes.

I assumed it was 4.5.

It's a little higher.

And here comes this probe, and I'm now about a foot away from the entrance, and you see nothing.

And I come closer to the entrance and the magnetic field begins to show.

Nowhere nearly constant yet.

I'm now entering 100 Gauss.

I'm going in deeper.

200 Gauss.

Even deeper.

And deeper, and now I have about 240 Gauss and notice, as I go in farther, it doesn't increase.

It's more or less constant.

Amazing, that it's more or less constant.

And when I come out here, I move it back and forth about 20 centimeters.

If I came in from the other side, you would simply see a reversal in the sign, which is not so interesting, so you see 240 Gauss with the other direction because this probe is sign-sensitive.

I can now also show you that if I come on the outside of the solenoid, you see nothing.

So indeed, our assumption that the magnetic field is very low outside a tightly wound solenoid was a very good assumption.

Very well.

You've been asked, and the deadline is Friday 4 p.m., to explain the behavior of the Kelvin water dropper.

And I decided to give you a little bit of help on that.

Most of you may already have figured it out, but those who haven't probably won't figure it out between now and Friday anyhow, so I might as well tell you.

That water dropper, called the Kelvin water dropper, is an amazing battery.

We've seen it before.

We know what it's doing, but I will go over that again.

We have here buckets A and B.

Water comes down from above, water runs through.

You see the water there, it runs out.

And we collect these water drops here in bucket D, it's a conductor, and this water is collected in bucket C, is also a conductor, and the paint can A is connected to C.

That's crucial.

And the paint can B is connected with D.

And here there are two balls, which I can bring close together.

I run water, and after a while I see a spark here.

I can even see a spark when the distance is something like 6 millimeters, which would be about potential difference of about 20 kilovolts.

How does it work?

Well, water has a pH of 7.

And that means 1 in 10 to the 7 molecules is ionized.

So I have OH-, and I have H+.

And the- Those are going to be the current carriers.

The ions are doing the work here, are doing the job.

Let us make an enlargement here of can A.

And can A, let us assume that purely by chance, it has a little bit of positive charge on it.

It could be negative, but I'll just assume it's positive for now.

In either case it will work, you will see.

Just by chance, like you have a little bit of net charge.

You're not completely neutral.

And so this can has a little bit of positive extra charge.

Now here is the drop from the spout.

What's going to happen?

Through induction, through polarization, you get a little bit of excess-excess negative charge here and a little bit of excess positive there, because the positive repels each other and the negative is being attracted.

So the H+ goes a little bit up and the OH- comes a little bit down.

But now the drop breaks, and there goes the drop.

So it's a little bit negative.

So now a little bit of negative drops come down and so this becomes negative.

But this is connected with B, so B becomes negative.

But what do you think is going to happen now with the drops that fall through B?

They are going to become positive, because if B is negative then of course this will be reversed, the bottom will be positive, the top will be negative, and so those drops now that are going to fall through are going to be positive.

So C becomes positive.

But C is connected with A, so A becomes more positive, and so A can do even a better job now on these water drops, and polarize them even more, and so you get a runaway process.

And the whole system feeds on itself until the potential difference here becomes so high that you exceed the 3 million volts per meter, and there you get a breakdown and you see a spark.

Now, you can think of a continuous stream of water as a stream of individual drops, so it also works if you just have a regular stream of water going down.

Who is doing the work here?

Someone has to do the work.

You have a battery.

The battery's being charged, and then it is discharged to the spark.

Who is doing the work?

Any idea?

Have you thought about that?

Yeah?

Gravity.

Very good.

It's gravity that is doing the work.

We can see that very easily by identifying the current that is flowing and the electric field.

How is the current flowing?

If negative charge is going down, would we all agree that the current is going up?

If positive charge is going down, do we agree that the current is going down?

This side of the spout, here, will be slightly positive and this is slightly negative, because the H+ is more abundant here than there, and so we're going to get a current through the water, in this direction.

Current has a reasonable conductivity, because it's ionized one out of 10 to the 7 molecules, and so once in a while if you see a spark here, then you get a current there, but that's intermittent of course.

How about the electric fields?

Well, electric fields we know go from plus to minus, so that's easy.

We can put the electric fields just in like that.

Electric field must here be in this direction.

Electric field here goes from plus to minus.

C is to plus charge, B is minus charge, and so the electric field is in this direction.

Electric field is from plus to minus.

This is plus, this is minus, so the electric field is in this direction.

Electric field is from plus to minus.

The can A was positive, remember?

So the electric field is from plus to minus.

So that's the electric field configuration.

But now look what's happening.

Here, the E field and the current are in the same direction.

That's fine.

Here the E field and the current are also in the same direction.

That's great, but now look at these poor negative ions.

These negative ions don't want to go in the direction of E.

Negative charge wants to go against the direction of E.

But gravity says, "Sorry, you can't do it.

I force you down." And so these negative drops are forced by gravity to go down.

Look at this positive charge.

These poor water drops which are positively charged go against the electric field.

They don't want that.

Positive charges want to go with the electric field.

Gravity says, "Sorry, it's too bad.

I force you down." And so gravity is doing the work, so to speak, against the will of the charges.

And then the battery charges up and charges up until the potential difference becomes so high there that you see a spark, and you deal with potential differences of something like twenty kilovolts.

Remember last time, and you will see that again today, that as the water goes through and as the system charges up, that you begin to see that the water which starts running like so, begins to spread out.

It fans out.

You can hear it by changing the sound, but you can also see it, and I'll make you see it again today.

Why is that?

Well, that's immediately obvious.

If this can is positively charged but if the water is negatively charged, the negative charge wants to go to the positive can, and so it spreads out.

So it's clear that by the time that you reach almost a spark, that that water will spread out quite substantially and you will see that.

And then when there is a discharge, it will start running again narrow stream, and then slowly in time the water will spread.

And so now I will do a series of demonstrations which will support what we know and what we perhaps don't know.

Let's first give a little bit of light here, because we will need that, and then I'm going to make it completely dark, so that you get maximum pleasure for your money.

And I will first show you here the- the gap those two balls and this time we have a real treat, which we owe to Marcos, who is standing behind the instrument very modestly.

This time we have a gauge, a meter, which measures the electric field very close to can A, and the reason why that is nice is that as this system charges up, we just don't have to wait now just until we see the spark, but we can look at the galvanometer there and slowly see it being charged up and then we get a spark and then it discharges, so you get a lot more for your money.

So I propose that the first thing we do is what we did last time, that we simply let it run and see whether we get a spark.

Uh, there's always air bubbles in the system which I have to get out.

OK, I think I did that.

OK, let's just be patient.

Ah, it starts already.

Look at the- look at the E-field.

Bang! First spark.

Can you see the spark on the screen?

Look at it again.

There's a spark.

And at the same time you see how the electric field goes away, charges up, bang.

Charges up, bang.

So it cha- it starts the whole system charged because of a random positive or negative charge that would be present on one of the cans.

What I want to do now is I want to increase the gap between the two balls, and I'll make it so large that you will never achieve a magnetic- an electric field there of 3 million volts per meter.

But somewhere else on the unit, it has lots of sharp edges and sharp points, somewhere else the electric field will reach the breakdown voltage and so the system will go into dis- into discharge, into corona discharge.

You will never see sparks but it goes into discharge.

And you can see that because now, I will open the gap now.

If you now look at the electric field it will reach a maximum value and now it goes into discharge, you see.

It begins to sort of sputter a little bit back and forth, so now there is no longer the spark on the ball, so you don't see anything between the balls, but it is somewhere else.

I don't know where, where there is a continuous stream now of charging, leaving the system, and so it's discharging to corona discharge.

And so in this mode, you expect the water to be spread all the time.

And I will show that to you by switching now to the water.

Maybe Marcos, you can improve on the- on the, on the light.

I could turn this off, maybe then you'll see it better.

But you see that the water is spread and I will now bring the two balls closer together -- ah, you also want to see of course the electric field, to see the discharge.

I bring them closer together, stopping the corona discharge.

There's a spark.

And now watch the water.

See, the water is now just not interesting, and there it spreads.

I'll turn the light off.

You look at the water.

And slowly the system is charging up.

You see the water?

Bingo.

You can even tell by the water when it sparks.

There it goes.

Now I want to do something real mean.

What I want to do now is to raise the spout so high that A can not reach out all the way to the spout.

It's too far away, and can not polarize the water.

So the poor battery can not start.

That's a pretty mean thing to do to a battery.

But on the other hand, I'm not all bad.

What I can do is I can start the system, I can help the system.

I use my electrophorus disk and I'm going to hold my electrophorus disk very close to one spout, temporarily allowing it to polarize the water and once it starts, chances are that it will feed on itself and go into the runaway.

It's not very predictable, but I will make an attempt.

So the first thing that I will have to do is maybe you can zero the E field.

Yeah, thank you.

So the first thing I want to do is to make sure that if we start running water now, that the system doesn't start by itself, because then I can't make -- then I can't be nice to the system anymore.

So let's just run some water.

I hope that Marcos brought it high enough, and let's see -- and you can really tell by looking at the - oh, there's the air bubbles in the system.

I have to get rid of the air bubbles.

There we go.

OK.

So look at the electric field doing nothing.

The system can't start.

A is desperately reaching out to this water, but it's too far away.

It can't polarize it and the battery can't get going.

Ah, ay, ay, it does get going.

Oh, Marcos, we didn't bring it far enough! You have to bring it higher! Oh, by the way, this is interesting.

Let's see whether it actually -- oh, boy, this is incredible.

This is a distance of about fifty centimeters, and look at it! That is amazing! The little sucker, I had never expected that.

Let's give it a fair chance.

Let's give it a chance.

It's only reasonable.

Goes very slowly now.

You can see why it goes so slowly, because A very far away from the spout.

But boy, and- and you can see the water.

The water is still pretty normal.

Oh, man, it's almost cheating on me! Uh-oh, uh-oh, we'll have to raise it a little further, er, aft- but I- I want to give it a chance to, uh, to spark.

Yeah, the two balls are close enough, so I will probably get there.

Boy, this is almost torture for me.

Aw, look at that, look at that.

I begin to see the water already.

Look at the water, it's already spreading it -- ah, there it is.

Marcos, can you run it even higher and then we'll see whether we can actually stop it altogether, bring it a lot higher and then we will make an attempt to start it with some help from a friend.

You ready?

Oh, man, I can hardly -- OK.

Don't tell me that it going to- it can go to the other direction, of course, because it's a random choice that it has at the start.

Ah, ah, it's letting me down! Let me see whether I can help it a little.

My electr- electrophorus disk.

I'm going to hold it here.

You know why I held it there?

Because I was hoping it would reverse the direction.

It doesn't even want to do that.

It's really recalcitrant today, isn't it?

Hold it here, negative charge.

The reason why you see the sudden change in the electric field is because of the E-field probe, which senses the electrophorus disk when I held it near the spout above B.

It has decided, no matter what -- well, has it really?

Ah, ah, ah, ah.

Has it really made any decision?

Ah! It's thinking now what it's going to do.

Oh, man.

Yeah, it's going in the direction that I wanted it to go because I held negative charge close to B and I know that would force it into the direction that it's going now.

Oh, man.

Yeah.

Well, look, the distance is -- now, what is it, now, something like 80, 85 centimeters?

The system is desperate, but it's, it's, it's doing what it's supposed to do.

Physics works again.

And we will get a spark because -- is this close enough?

Ah, boy you got a lot for your money this time.

You really did, didn't you?

You saw for one thing that the system first started up going in one direction and later in the other because there was a random charge which changed polarity, which is something that we can not always control, but by holding this negatively charged disk close to the spout above B, I forced the polarization in the way that I wanted it, and that's what you're seeing now.

We've got to give it a fair chance, and then I'll give you light and then you have 4 more minutes left to fill out the evaluation.

But let's at least give this battery a charge now, to lay its egg.

The water, it still doesn't show much of a sign of spreading, but I expect that that will happen very shortly because we've seen this now before.

It's slowly increasing the charge on the cans, A and B.

It's creeping so slowly that if we wait you may never able to fill out your -- I'll give you a little light so that you can s- fill out the evaluation and then we can still let it run and see what happens.

So please leave the evaluations here as you leave, and I will keep that going for some of you who have the patience to see what will happen.