MIT OpenCourseWare
http://ocw.mit.edu

8.02 Electricity and Magnetism, Spring 2002
Transcript – Lecture 18

Today, I'm going to take a critical look at Ampere's Law.

I'm going to run a current through a wire, as we did before, but now I'm going to also put a capacitor in that line and so we are charging a capacitor.

Here is that capacitor.

And here is the wire.

We are running a current I.

And as we are running this current, clearly, we get a changing electric field inside the capacitor.

The electric field inside the capacitor, sigma free divided by kappa epsilon 0, which is also Q free divided by the area.

This is a circular plate capacitor.

Capital R, is the radius of this capacitor, so we get pi R squared kappa epsilon 0.

But since I run a current the Q free is building up all the time, and so the current per definition is dQ/dT, and so I now have ex- a changing electric field inside, dE/dt, which is the current I divided by pi R squared, kappa epsilon 0, because I simply take the derivative of this equation, I get dQ/dT, and dQ/dT is I.

And only if the current is 0 is there no changing electric field inside.

So how does this affect the magnetic field?

Well, if I take here a point P1 at a distance little r from the wire, if you're far away from this capacitor it's hard to believe that Ampere's Law would not give the right answer.

And we will apply that very shortly, Ampere's Law.

It's on the blackboard there.

Suppose you are at the same distance from this line here at point P2.

Well, yeah, you've got to admit there's an interruption of current now.

There is no current going through this space and so you expect that the magnetic field here would be a little lower perhaps than it is here.

But not very much.

So the question is, how can we now calculate the magnetic field here and there, now that we have this opening in the wire.

Well, Biot-Savart could handle it but I wouldn't know how to do it because if there's a current flowing like this there's also a current going up on these plates, and one like so, and I wouldn't know how to apply Biot-Savart.

In principle, yeah, but in practice, no.

How about Ampere's Law?

Well, let's give Ampere's Law a shot.

This is a cylindrical symmetric problem, so I choose a closed loop, which of course itself is a circle with radius R, and I apply -- I attach to this closed loop an open surface.

That's mandatory.

And I give myself an easy time, I make it a flat surface.

So now I apply Ampere's Law.

You see it there on the blackboard.

Anywhere on that closed loop, the magnetic field will have the same strength, for reasons of symmetry, and so we get B times 2 pi r equals mu 0 times I pen, and pen means the current that penetrates my open surface.

Well, that's I.

I goes right through that surface.

And so the magnetic field at that point, P1, mu 0 times I divided by 2 pi r.

We've seen this several times before.

Now I wonder about P2.

Can I apply Ampere's Law for point P2?

Well, yeah, you can try.

So now I attach a closed loop to this point.

Circle again, radius little r, and I use this flat surface and I apply Ampere's Law.

Well, I'm in for a shock, because B times 2 pi r is not changing but there is no current that penetrates that surface.

And so I is 0, and so I have to conclude that the magnetic field at point P2 is 0 which is absurd.

Couldn't be.

I can make the situation even worse.

I'm going to revisit point P1, and here is my capacitor, and here is my point P1.

My current is flowing like so.

Here's my closed loop.

According to Ampere's Law, int- closed loop integral B dot dL.

Why should I choose a flat surface?

I'm entitled to any surface! I like surfaces like this.

They are attached to a closed loop, so I will choose that kind of a surface.

The surface now goes like so.

[whistle] Right through the capacitor plates, and I apply Ampere's Law, it's open here.

B times 2 pi r, the radius is little r.

Mu 0 times I, but there is no I going through that surface.

Nowhere through this surface is a current poking, because there is no current going between the capacitor plates, so now I have to conclude that the magnetic field at P1, which we first concluded was this, is now also 0.

So something stinks.

So Ampere's Law is inadequate.

And so of course, Faraday and Ampere were both perfectly aware of this.

But yet it was Maxwell who zeroed in on this and he argued that any open surface that you attach to a closed loop should give you exactly the same result, same answer.

And so he suggested that we amend Ampere's Law, and so he asked himself the question, what is so special about in-between the capacitor plates?

Well, what is special there is in-between the capacitor plates there is a changing electric field.

And Maxwell reasoned, gee, Faraday's Law tells me that a changing magnetic flux gives rise to an electric field, so he says maybe a changing electric flux gives rise to a magnetic field.

And I want to remind you what an electric flux is.

Phi of E is the integral.

In this case it would an open surface of E dot dA.

That is an electric flux.

With Gauss's Law that you see on the blackboard there, we had a closed surface.

I'm talking now about an open surface.

That is an open surface.

This is an open surface, and this is an open surface.

And so Maxwell suggested that we have to add a term which contains the derivative of the electric flux.

And that's what I'm going to do there now, walking over to Ampere's Law.

I'm going to amend it in a way that Maxwell suggested.

He adds a term here, epsilon 0 kappa, d/dT, of the integral over an open surface attached to that closed loop of E dot dA.

This current, which is the one that penetrates, remember, through the surface is really a real current.

This term here, Maxwell called "displacement current.

I want to make sure that I have no slip of the pen, because I hate slips of the pen.

That is correct.

I have everything in place.

You may think now that we can start a party because all four Maxwell's equations are now in place.

Not quite.

We're going to make one small adjustment after spring break, and that adjustment is going to be made in this one, and then we'll have our party.

So now, I would like to use the new law and see whether we can clean up that mess.

So I'm going to revisit my point P1 and I'm going to apply the new law by first having a flat surface, that surface that we have here, and then trying this surface.

And I want to get the same answer.

If I use that surface, do we agree that there is a current going through that surface but there is no electric flux going through that surface?

So that second term, that displacement current term, is 0 for that flat surface.

So this answer is completely valid.

But now, I want to pursue this case.

And so I'll make a new drawing.

We have here this point, P1.

This is my radius little r.

This is my surface going right through here.

Here's the current I, and here is my changing electric field.

And so I get B times 2 pi r, mu 0.

I pen is 0.

There is no current penetrating through this bag.

This is open here.

So the first part is 0.

So I only deal with the second part, which is epsilon 0 K, kappa, displacement current.

And now I have to put in there d phi E/dt.

Phi E is very easy to calculate because E and dA right here- think of this part being flat.

Wherever you were inside the capacitor, if we assume that there are no fringe fields, then there is an electric field only where you're inside the capacitor, and so the electric flux is simply E times the surface area, E and dA are in the same direction, so it is the electric field times this pi capital R squared.

And therefore, if I want to know what the derivative is, then I get this pi R squared which is that surface area and now I need there dE/dt.

And the dE/dt, we have, that is I divided by pi R square kappa epsilon 0.

I divide it by pi R squared kappa epsilon 0.

So this is the area A, and this is dE/dt, and this is the area of the part inside the capacitor that has a flux going through it, cause outside here there is no flux going through there, so there's no contribution.

There's no contribution here, either.

There's no contribution here, either.

The electric field is only existent there.

That's my assumption.

And so the whole thing here is now d phi E/dt.

Well, let's look at our results.

I lose a pi, I lose my R squared, I lose my kappa and epsilon 0, and look what I get.

I get mu 0 times I.

That is truly amazing, so I find now that B equals mu 0 times I divided by 2 pi little r, which is exactly what we had before.

Hooray for Mr. Maxwell, because now it doesn't matter anymore whether you take the flat surface or whether you take the bag surface.

You now get the same answer.

In one case, there is no contribution from the displacement current term, and in the other case there is no contribution from the first term, the real current.

Let me make sure whether I'm happy with my results.

Yup, I think that's fine.

We can now also go one step further, and we can calculate anywhere in between the capacitor what the magnetic field is.

I'll make another drawing of the capacitor.

It's right here.

I have this E field.

I will not repeat that every time.

And here I have my point P2 now, which is inside the capacitor at a radius little r from the center.

And this is capital R, circular plates.

I have here my closed loop.

It's a circle, radius little r.

I apply now the new law, B times 2 pi r.

And there we go.

We have a mu 0, we have an epsilon 0, we have a kappa.

There's no current going through here, so it's non-negotiable.

I pen is 0, right?

That's not even an issue.

So we get mu 0, epsilon 0.

I get kappa.

But now, the surface area right here is not pi capital R squared, where there isn't changing electric field, but it is only pi little r squared.

I take a flat surface now.

And so now we multiply this by pi little r squared, and then of course dE/dt is the same, so we get our current I divided by pi capital R squared, divided by kappa epsilon 0.

And now you're again losing a lot.

You lose your epsilon 0, you lose your kappa.

I lose a pi.

And look, I have a little r here and I have a l- little r square there.

So now we're going to get a result which is something that you may actually have anticipated, namely that you get a- a field inside the capacitor that is growing with r, because if I make up my balance I get upstairs mu 0 times I but I get one little r upstairs.

You see, you have r squared here and you have r here.

And downstairs I get 2 pi and then I get a capital R squared, and I believe that's correct.

Let me check my notes.

And yes, I'm happy with that.

And this is proportional with little r, whereas here falling off 1/R.

And so I can now make a plot of the magnetic field as a function of little r when I'm inside the capacitor plates.

Little r, these are the magnetic fields, and this is the radius of the capacitor plate.

It's going to be a straight line up to that point, and then it will fall off as 1 / little r and you can do your own work on that, that it's very trivial to calculate, to demonstrate that when you go beyond the edge of the capacitor that then it falls off as 1/r, just in the same way that point P1 is doing.

So now we have a tool to calculate the magnetic field even inside capacitors while we were charging, which we didn't have before.

The strength here, the maximum magnetic field here, you'll find by substituting in there for little r capital R.

And when you do that, if this becomes capital R, this becomes 1/capital R.

If you had substituted in here for little r capital R, you would've found the same result.

This part is not kosher.

It cannot be correct, and I cannot make it right for you.

And the reason why that part can not be kosher is because we have made the assumption, which is wrong, that there is no fringe field.

And so we have assumed in our calculations that the electric field is only here and there, but it's 0 here so that there is nothing, no dE/dt here, no changing magnetic, uh, electric flux.

And that's not true.

So clearly, when you get close to the edge, this is not correct.

And there's no way I can correct for that, because the fringe fields will be different from capacitor to capacitor and those calculations of course are not even very easy to make.

But Maxwell had introduced his displacement current term.

He was a very smart man.

He predicted that as a consequence of that term that radio waves should exist.

There was a time that we didn't know that radio waves existed.

He predicted their existence, but not only did he predict their existence, he even was able to calculate what their speed was going to be.

We call that the speed of light.

And we will do that in a few weeks ourselves in 8.02.

In 1879, which was the year that Maxwell died, the German physicist Helmholtz asked once of his students, Hertz- he was 22 years at the time, he was a junior- to try to demonstrate that radio waves indeed exist.

Hertz declined, because he argued that the equipment that was available at the time was not good enough.

But 7 years later when new equipment had been developed, he accepted the challenge and it took him 2 years, but then he indeed was able to demonstrate that radio waves do exist.

Imagine what a victory that was! Someone like Maxwell, who predicts out of nothing that radio waves should exist, and here comes someone who actually shows that they do exist.

Hertz died 5 years after his great experiments.

He was 37 years old.

He was very young.

Had he lived 10 more years, there is no doubt in my mind that he would've been awarded with the Nobel Prize for physics, but the first Nobel prize was only given in 1901, so he died just a little bit too early.

Maxwell also died very young, age 48.

Why did Maxwell call that strange term displacement current?

In the presence of a dielectric, if you put a dielectric in there, the changing electric field will indeed cause a current in between the plates, because the polarization will change all the time.

You get a re-eras- re-arrangement of these induced charges, so there is indeed a current, but in vacuum there shouldn't be any current.

Any electric field changing or not changing will not cause a current in vacuum.

But Maxwell believed that vacuum in a way behaves like any other dielectric, just a special dielectric, happens to be a dielectric with kappa equals 1.

And so he really believed that there was an actual current going between the plates, even though we now know of course that that is not the case.

So the name displacement current was perhaps not a very lucky one, but the term is a must, and it completes the theory of electricity and magnetism.

The name is obviously of no consequence.

After all, Shakespeare said it himself, in Romeo and Juliet, what's in a name?

Remember, what's in a name?

That which we call a rose by any other name would smell as sweet.

Those were the words by Shakespeare.

I will abandon for now the displacement current, but we will revisit it later when we will deal with radio waves and with the propagation of electromagnetic radiation, and I will return now to good old Faraday, and I will return to electric generators that run our economy.

We've discussed this at length, and I want to revisit that to you- with you.

Remember that if you rotate conducting loops in magnetic fields.

that you create induced EMFs, currents, and that keeps our economy going.

Here is again one of those loops.

Conducting wire, and I don't care about the direction of the magnetic field.

If you want it this way, that's fine.

What matters is that we're going to rotate it about this axis, and as we rotate it about this axis we're going to get an induced EMF.

And that induced EMF, which we derived I think it was last lecture, as a function of time, will be a sinusoidal or a cosinusoidal curve, and therefore, will look something like this.

I call this loop number one, and so this is the EMF produced by loop number one.

But now I'm going to add two more loops which are not electrically connected, physically separate.

If you look from this direction you will see the following.

This would be your loop number one, because you're looking in this direction and you would only see the conducting wire like so.

I have now a second one which is rotated 120 degrees, and so in this picture you will see it like so.

Look number two, and this is 120 degrees.

Physically 120 degree rotated.

And then I have a third one which is again 120 degrees rotated.

It is like so.

And so this angle here is also 120 degrees and so this angle is 120 degrees.

And this is my look number three.

And so each one of those will give an EMF that has this shape but they are offset now in phase by 120 degrees.

And so they're all rotating in exactly the same way, like so, and so the second one will give me an EMF if I try to estimate that roughly, something like this, so this is loop number two.

It comes a little later in time and number three will again be offset, will look like this.

Number three.

And what we- we call this a three phase current.

And a three phase current can produce a rotating magnetic field.

We will make one for you but I'll first explain to you how that works.

So if the period of number one is 60 Hertz, then the period of number two is also 60 Hertz, and number three is also 60 Hertz, but they're just offset in terms of the phase angle.

Suppose you're looking down onto a horizontal table, so this is a horizontal table.

And I have here a solenoid.

This is one and the same solenoid.

When the current runs clockwise here it will also run s- run clockwise there.

But it's open here.

Going to put something in there.

We call this number one.

Then I have another one which is rotated, physically rotated 120 degrees.

It's here.

Also coils.

And I'm going to feed current number two through those coals later, through those coils.

This is number two.

And I have a third one and I'm going to run current number three through those.

So here are coils, here are coils, this is number three.

And so one sees current number one, two sees current number two, and three sees current number three.

At the moment that the current through number one reaches a maximum, the currents in two and three are down by a factor of two.

You can check that [break in tape].

During my lecture I went a little bit too fast over the part that is coming up now, so I'm going to redo it a little slower to make it more clear.

When the current through loop one reaches a maximum, let's say then that the magnetic field due to loop one is in this direction.

The current through this one and the current through this loop are two times smaller.

You may want to check that.

But it just so happens that the vectorial sum of the magnetic field produced by loop number two and by loop number three also happen to be in this direction, so the net magnetic field is in this direction.

Let's now look one third of a period later in time.

Now, the current in loop number two reaches a maximum, so its magnetic field is now in this direction, and you guessed it of course, that it just so happens that the vectorial sum of the magnetic field produced by the other two loops is now also in this direction.

And if we now look again one third of a period later, when the current through loop number three reaches a maximum, then the magnetic fields will be in this direction and the vectorial sum of the magnetic field of the other two loops will also be in this direction.

And look now what has happened.

In one complete period, the magnetic field started out like this.

One third of a period later it was like this, and one third of a period later it was like this.

So what we have created is now a rotating magnetic field, and it rotates in one period all the way around, 360 degrees.

OK, let's now go back to my original lecture.

[break in tape] rotates once around in the period of your alternating current.

If that is a 60 Hertz current, then it will rotate around with 60 Hertz, 60 times per second.

And so if we put a, a magnet in here, then this magnet will want to go around -- wants to follow this rotating magnetic field.

And we call that a synchronous motor.

So the rotor of such a synchronous motor itself would be a magnet and it would rotate around with the frequency of your alternating current.

But you need a three-phase current for that so that the magnetic field rotates.

I can also place in here -- this is again a horizontal surface, you have it here, you're going to do it right here.

Here is that -- here are those crazy loops with the three-phase current.

We can also put in here um conducting sphere, or in my case I will use a conducting egg.

And when the magnetic field rotates around, there's a continuous magnetic flux change through the surface of that conducting sphere or egg, and so it's going to run cur- eddy currents.

Now, if you have an eddy current going around, and you have a magnetic field, then the magnetic field in the area current will cause a torque on the current.

In a similar way, when we discussed earlier the idea of a motor that you were going to build, there was a magnetic field and there was a current and that caused a torque, in the same way you get a torque on the eddy current and so it starts to torque up this conducting sphere.

And all the time there will be eddy current because the magnetic field keep going around, and so you're going to get a torque which will always be in the same direction and this conducting object will now start to rotate and we call that an induction motor.

Induction motors have no brushes.

How fast the induction motor will go depends on the conducting object.

If it is a sphere, it will probably come very close to 60 Hertz because a sphere has many possibilities for eddy currents to run around, whereas if you take a ring, and we will try that, if you try to spin a ring in a rotating magnetic field then of course the various paths that are available for eddy currents are very limited and only go around in the ring.

Many of the stationary tools that you find in people's workshops and in the basements are induction motors.

A table saw and drill presses, also electric grass mowers are induction motors.

I want to demonstrate now to you what three-phase currents can do, and the first thing I'm going to do is show you that unit that we have here which is the- which are the coils that I described, through which we are going to run the three-phase current.

Must get my lights right.

There you see it.

Coils are wound in a very strange way.

After class, you can come a little closer, and so in here you would have a rotating magnetic field.

We use 60 Hertz, which rotates around 60 times per second.

And the first thing I'm going to do is something wild, a little bit in style, I suppose.

I will put on top there a cardboard cover with little magnets.

They're randomly oriented.

There's no way that they can ever rotate.

They th- thee- are these little magnets, flat, a lot of friction.

If I expose them to a rotating magnetic field, then they will go nuts.

I told you, they were going nuts.

You're not supposed to show this to students, but OK.

Now here I have a conducting egg.

And this now has ample possibilities for eddy currents to flow, and so now if I give these coils the right current, a three-phase current, it spun up, the magnetic fields acts on the eddy currents, and it starts to spin and I have actually tried to measure the rotation rate.

It's only a little bit under 3600 RPM.

3600 RPM would be 60 Hertz.

It's very close to that.

If I spin this object in the direction in which the magnetic field is not rotating, then it says sorry, no way.

It just reverses, because the magnetic field is going to slave it in the direction that it wants it to go.

So we're looking there at an induction motor.

I have here a ring.

Now a ring doesn't have as many possibilities for eddy currents to run.

Could only go around like this, or like this, right?

But I can still make it spin probably if I do the right thing.

First of all, I have to rotate it in the right direction, which would be this one, I think.

There it goes.

It doesn't go anywhere nearly as fast as the egg because of the restrictive paths of the eddy currents.

But it rotates.

It's trying to follow that magnetic field to the best it can, but its abilities are very limited.

And needless to say, if I try to spin it in the wrong direction, that of course it will stop and it has no way like the egg to reverse its direction because of its peculiar geometry.

I owe you an explanation to the secret top.

If you haven't found one yourself yet.

Let me first come to a simple conclusion, and all of you must have come to that conclusion.

That top, when I showed it to you during my exam review was spinning for more than an hour.

In fact, it was spinning the next day.

Energy has to come from somewhere, and so the only conclusion that you could've drawn that the energy came from inside the box, there must be something inside the box.

Clearly there must be a battery in that box, and there is.

But that doesn't tell you how it works yet.

And I can assure you, I can admit that it took me quite a while before I fully understand how it works.

And I want to explain that to you, and then I will demonstrate it to you again.

Remember what it looks like.

In the top itself is a magnet.

So here is the top.

Let's say this is north and this is south and this is that top.

We're rotating it.

We're spinning it.

Inside the box, right at the center of the box, is a solenoid, a switch and a 9-volt battery.

Inside this solenoid is also a little bit of iron.

We have not discussed that in our course.

It's not important for the explanation.

You'll later understand why there is also some iron in here.

It makes the magnetic field so it's a little stronger.

This is right at the center of the- of the little platform on which I was running this.

It is a concave platform, and here is a little plastic node so when the top hits it it bounces off.

Imagine for now that it's rotating in such a way that the North Pole is approaching that solenoid, coming in from above.

What's going to happen now, in this solenoid, in this coil, you are changing the magnetic flux through the surface of this coil and so you're introducing an induced EMF, an induced current.

And this current is sensed by a transistor which I have not put in here, and the transistor throws this switch and now sucks energy out of the battery and runs current, very high current through this coil, such that the top becomes the south pole.

Remember if you have a coil, and you run current through here, that you get a magnetic field like so.

In this case, this would be north pole and this would be south pole.

If you reverse the current, then this is south and this is north.

That magnetic field that comes out there is fanning out in all direction three dimensionally.

It's going like this and it's fanning out like this.

So when it approaches this coil, there is a change in magnetic flux.

And this becomes a south pole.

The north pole is being attracted by the south pole.

I make you look at this from above now.

Here is the top seen from above, so it's spinning in this direction.

And let's say here is this coil.

This is the north pole and this is the south pole.

And I just discussed with you that the current that's going to flow from the battery will make this a south pole.

The current can only flow in that coil in one direction.

That's just the way it's designed.

So whenever the current goes it's always this becomes a south pole.

The north pole is being attracted by the south pole.

So notice it's going to be torqued up.

So far, so good.

A little later in time, looking from above, the north pole will be here and the south pole will be there, it has rotated a little bit further, and the coil is here.

So now the north pole is leaving.

It's receding.

It's not approaching, it's receding.

If this were to remain a south pole, that would be disastrous because south poles and north poles would attract each other.

You don't want that.

Well, the transistor senses that the EMF in the coil reverses direction.

It has to reverse direction, because if the north pole comes in, the EMF is in one direction but when the north pole leaves the EMF of course goes in the other direction.

You've got a reversal.

And so what the transistor does, it opens the switch, and so there is no north pole here and there is no south pole here, and so the thing starts to go around further.

What happens now when the south pole approaches that solenoid?

OK, here is the situation that the south pole is now approaching.

It's rotating in this direction.

And here is the coil.

South pole is coming in.

From Faraday's point of view, there is no difference between the north pole receding or the south pole approaching.

You should be able to reason that for yourself.

That's exactly the same thing, and so the transistor knows that indeed the current is still in the wrong direction.

It keeps the switch open.

It does nothing, so as the south pole approaches no current through this coil.

Because remember, the current can only go in one direction, can only make this a south pole.

It could have been designed in such a way that the current could go in both directions.

It would have made it more expensive.

Just a matter of economy.

So nothing will happen here.

But now, there comes a time that the south pole is leaving, is receding, and so let us have here our coil.

A south pole receding is exactly the same for Mr. Faraday as a north pole approaching.

And so now the EMF is in the same direction in the coil as it was here.

And so now the transistor says yippee, that's fine.

I close the switch and I'm going to run a current and so this becomes the south pole.

South pole and south pole repel each other, so now the thing gets a kick again.

So when the north pole approaches, it pulls on the north pole, and when the south pole recedes, it pushes on the south pole.

And so it is an induction motor which is only powered half per full rotation, but a very, very clever design.

And I'm going to demonstrate it to you again.

I want you to see that as this top approaches the center that actually, you can see it starting spinning up.

It really gets its energy when it gets close to this coil.

It also works, doesn't matter in which direction you spin it.

That's also great.

You can spin it clockwise or counter-clockwise.

Makes no difference.

And so, you're going to see that top here, I think.

There it is.

And this is probably the best way for you to see it.

We have here this box in which there is this very simple circuit, very simple, and here is the top.

Has little bar magnet in it.

I will try to spin it just a little bit, to make you see that it actually spins up.

It may not be so easy for you to see, but I can s- ah, you see it's really spinning up now.

And then it loses to friction, rotation rate.

It always comes back to the center because the surface is concave, and then it gets to the center there and gets its kicks again, gets spun up.

And this can go on for as long as your battery lasts, which is about a few days.

I can also rotate it counterclockwise.

It's not so easy, it's funny.

Have you ever tried to rotate a top counter-clockwise?

It's very hard! I don't know why that is, because maybe because I'm right-handed.

I'll try.

You see, I failed.

Ah, this is a nice one.

I gave it a teeny-wee little spin.

It doesn't like it.

It stays near the center.

Oh, doesn't like that.

It has to be a little bit away from the center.

Ah, I think, I think I've got it now.

Oh, no.

Oh, no.

Too optimistic.

Isn't it strange that it's hard for a person to rotate something counterclockwise?

OK, I did it.

Slowly coming in, to friction now.

And when it gets close to the center, there it gets its kicks.

Now it's spinning up.

Ah, you can really see it now.

It's being spun up.

You see that?

Really spun up.

I have another fantastic toy for you, which is also an induction motor.

And that one you're going to see there, first want to explain to you how that one works.

That's a real beauty.

It is an induction motor that runs on a two-phase current.

Here we have solenoid.

It's this, this baby here, big one.

And we're going to run 60 Hertz AC current through there, and here we have one, also going to run 60 Hertz AC through there.

Here's the coil.

This one is easy to show.

The other one, very heavy.

These two currents are 90 degrees out of phase.

Not 120, but 90.

So it's a two-phase current.

So when the current is maximum through this one, it is 0 through this one.

When it is maximum through this one, it's 0 through this one.

Let's look at the moment that the current is maximum through this one.

And let's say the magnetic field is in this direction, which is created by this coil.

Then there is no current here.

But one quarter of a period later, this one has no current but this one does.

Let's assume that now the magnetic field from this one is in this direction.

And so what you're going to see now is that again, you have a rotating magnetic field which goes like so.

And if I put in here a can, a paint can, we use a coffee can, it's right here, and at the surface of that can, so I will draw the can here, but it's really there.

At the surface of that can, you're going to have eddy currents, because you have change of magnetic flux all the time and these eddy currents with the magnetic field will cause a torque on this can.

And the torque will always be in the same direction and the thing is going to rotate.

So it's another example of an induction motor.

It's a very cute one.

And I want to show it to you and for that you're going to see it there.

Needless to say that the can is a very special can, Maxwell House coffee.

Of course.

And you see that?

Maxwell House.

All right, so let's see whether we can get this to run.

There it goes.

Nice example of an induction motor, and now I'm going to test you.

I'm going to ask you what happens if I take this coil here, which I can do, and flip over from here to here.

Who thinks that nothing will happen?

And you're all afraid of me now, right?

Who thinks that it will come to a grinding halt?

Grinding halt.

Who thinks that the direction of the motor will reverse?

Good for you.

It's clear that when I flip this one over, you can easily go through that for yourself, that this magnetic field is then not rotating this way, but is rotating that way, and so clearly the motor will reverse direction.

I'm going to do that now.

Watch it.

So it's torquing now in the opposite direction.

It's coming to a grinding halt.

You were right.

The other people were also right, because now it's reversing direction.

And you see there it goes.

Another striking example of an induction motor.

Next lecture, Friday, I'm going to elevate a woman.