Magnetic Induction

March 23, 2020

We will be using a simulation produced by the PhET program at the University of Colorado for a "hands-on" lesson in magnetic induction.

We use the term "electromotive force" (EMF) to refer to an electric potential gradient in a closed loop or circuit that can produce an electric current. One type of EMF is a DC power supply or battery like the ones we used during our DC circuit unit in January.

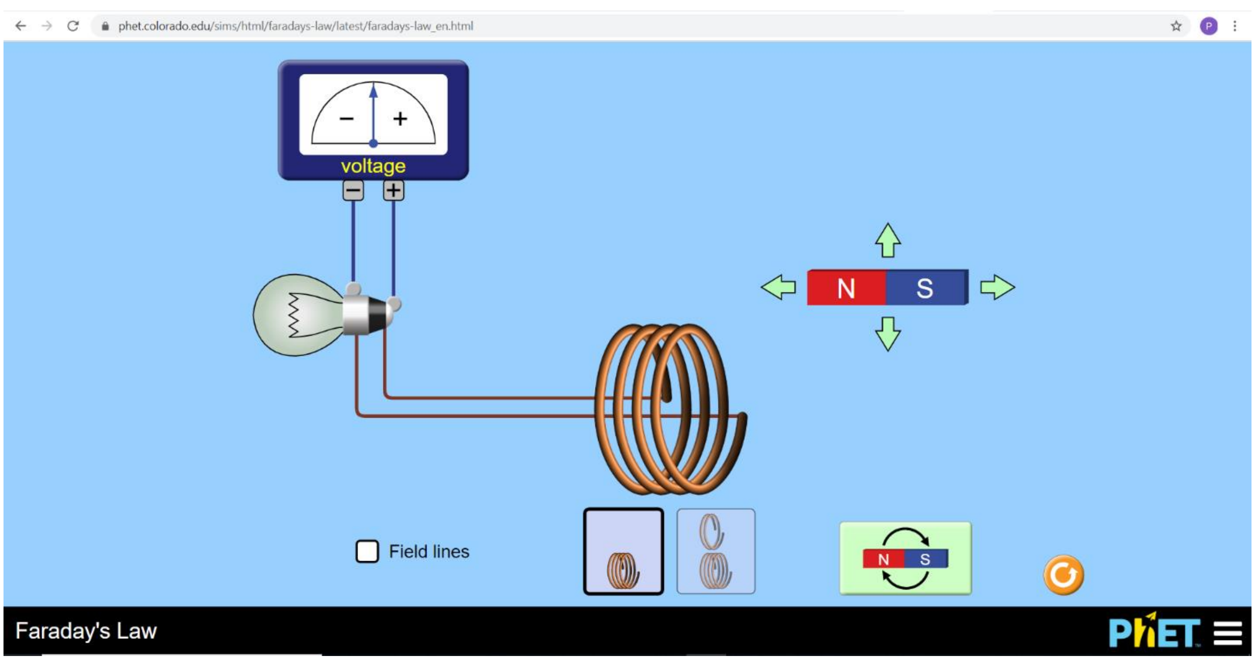
Magnetic induction is a way of producing an EMF in a loop or circuit without a battery. Instead, the EMF is produced by changing the magnetic flux through the loop or circuit. You can learn about magnetic flux either by watching the Khan Academy tutorial included in this week's module or by reading about it in your textbook.

We will be using the PhET Faraday's Law simulation here:

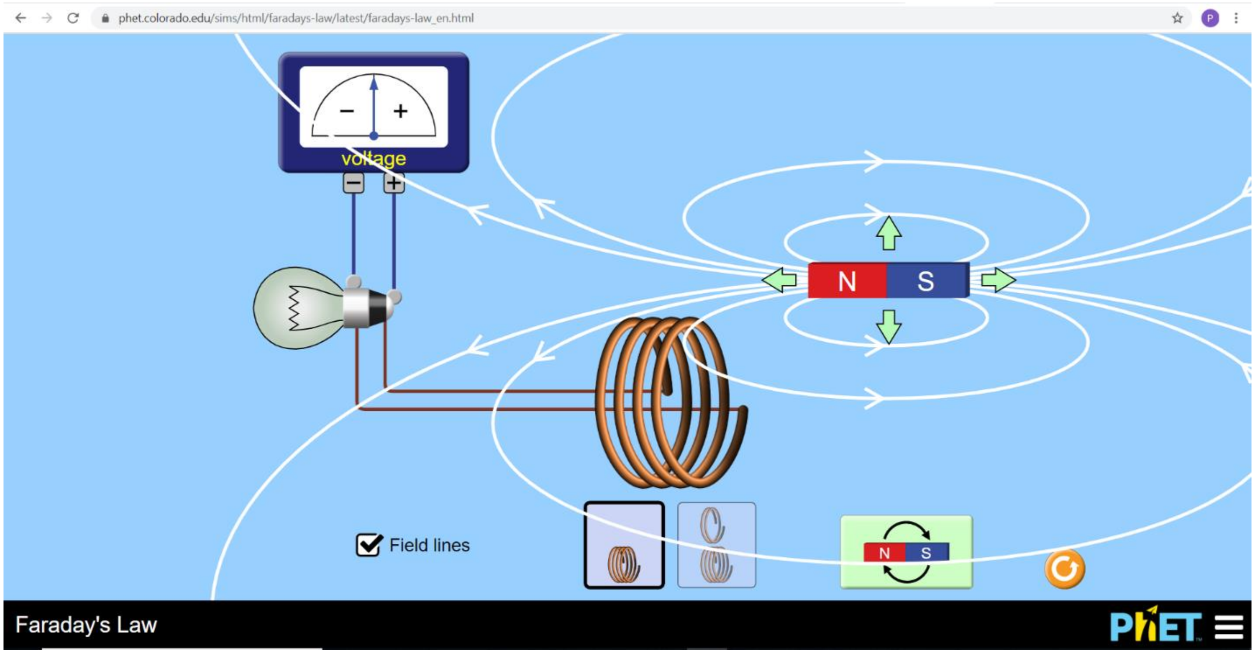
https://phet.colorado.edu/sims/html/faradays-law/latest/faradays-law_en.html

Faraday's Law is the name of the scientific principle that specifies how the change in magnetic flux produces an EMF.

When you first go to the url above, you should see this:



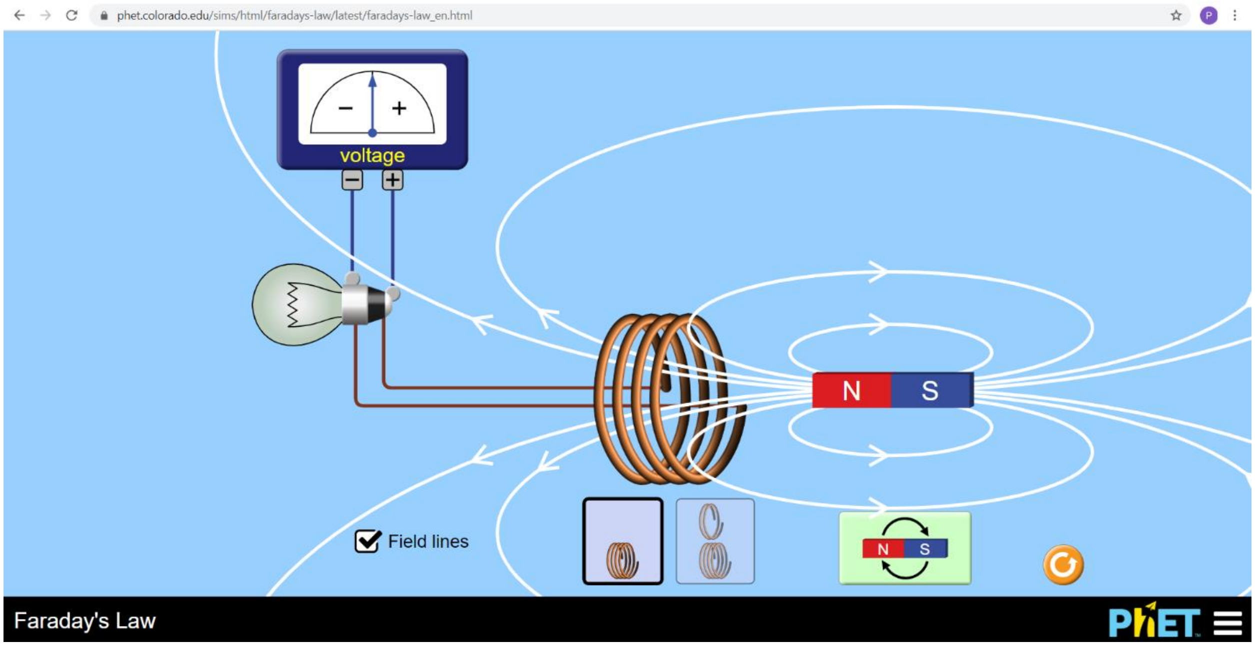
Click on the "Field lines" box so that you see this:



The voltage meter at the top of the screen will be your EMF measure, while the light bulb will tell you when there is current flowing through the circuit. You will see the magnetic field lines going through the coil near the center of the screen, and that will give you a qualitative measure of the magnetic flux.

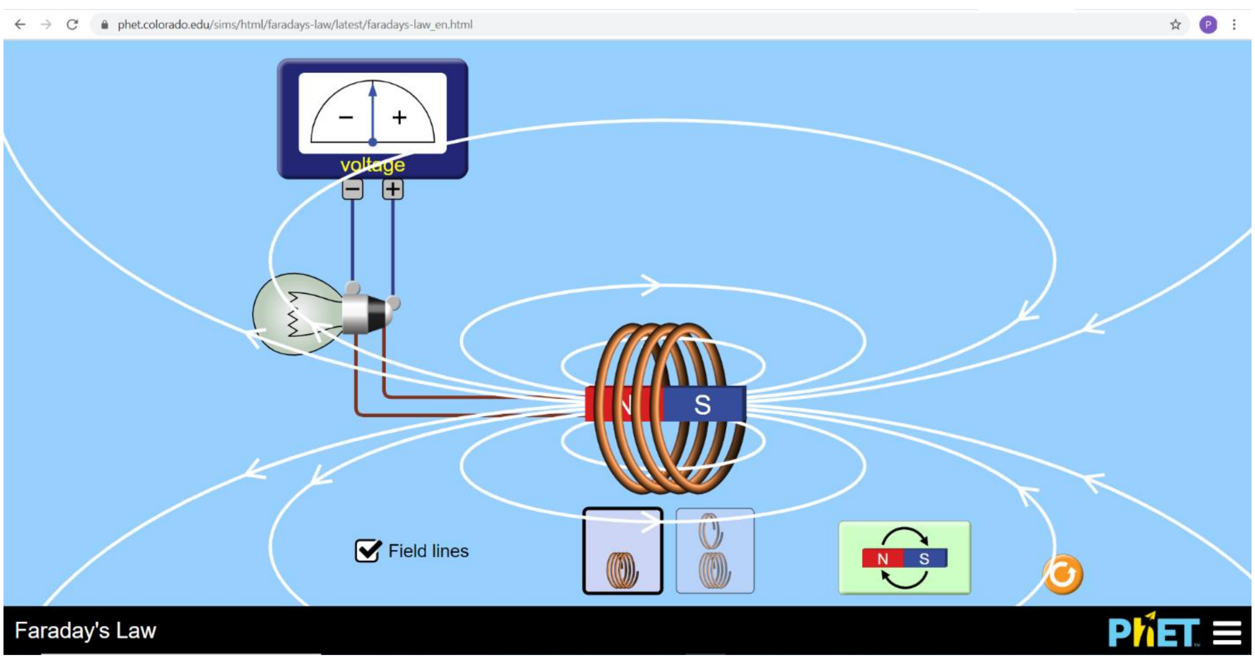
First of all, you will see that as long as you leave the bar magnet motionless at the location where it comes up when you first turn on the simulation, there is no EMF and no current.

Now move the bar magnet down so that it is level with the coil. Once the bar magnet is motionless at this new location closer to the coil, is there any voltage? Any current? Is the magnetic flux through the coil larger, smaller or the same when the bar magnet is in this new location closer to the coil?



Did you notice anything on the voltage meter when you moved the bar magnet? If so, keep that in mind as we go forward.

Now move the bar magnet into the center of the coil. What happened to the voltage meter and light bulb while the bar magnet was moving? What happened when the motion stopped and the bar magnet was just sitting in the middle of the coil? When was the magnetic flux changing? Did you have an EMF while the magnetic flux was changing?



Now pull the bar magnet back out to the right – what happens to the voltage meter and light bulb when you do so?

When you push the bar magnet into the coil, does the voltage meter read positive or negative? How about when you pull the bar magnet back out to the right? Does the voltage meter read positive or negative?

The voltage reading on the meter tells you the direction of the voltage gradient in the coil – sort of like whether you put a battery in the coil in one direction or the other.

When you put the bar magnet into the coil, you are increasing the magnetic flux. When you pull it back out to the right you are decreasing the flux. Faraday's Law (which is on this week's equation sheet among other places) says that the magnitude of the EMF depends on the rate of change (the time derivative) of the magnetic flux through the coil. But Lenz's Law says that the sign of the time derivative matters. So when flux increases the EMF is in one direction, and when the flux decreases the EMF is in the opposite direction.

Now use the button near the bottom of the screen to switch the direction of the bar magnet so that the north pole is pointed to the right instead of to the left as it was previously. And then push the bar magnet into the center coil and observe the sign of the voltage. Is the sign of the voltage the same or different as it was when you pushed the bar magnet into the coil when the north pole was pointed to the left? Then remove the bar magnet to the right again – and once again compare the sign of the voltage to what you saw before.

The definition of magnetic flux requires that you pick a positive and negative direction. If you define the magnetic flux in the coil to be positive when the field lines point to the left, the when field lines in the coil point to the right the flux is negative. And therefore, changing the orientation of the bar magnet (and thus the direction of the field lines) changes the sign of the derivative of the magnetic flux and the direction of the induced EMF.

Does the speed with which you push the bar magnet into the coil or pull it out change the magnitude of the induced voltage? Faraday's Law says that the induced EMF is proportional to the time derivative of the flux – which means that the faster the flux changes, the larger the magnitude of the induced voltage.