Magnetic flux

Magnetic flux is a measure of the number of magnetic field lines passing through something, such as a loop. If we define the area of the loop as a vector, with its direction perpendicular to the plane of the loop, the magnetic flux is given by:

$$\Phi_B = BA\cos\theta$$

where θ is the angle between the magnetic field and the area vector.

The unit of magnetic flux is the weber. 1 Wb = 1 T m^2 .

Magnetic flux

$$\Phi_B = BA\cos\theta$$

The more field lines pass through an area, the larger the flux.



Let's make a few observations, using a magnet near a coil connected to a galvanometer (a sensitive current meter). The magnet's north pole points at the coil.

Situation	Predict what the galvanometer needle does.	What the needle actually does.
The magnet is moved toward the coil.	No basis for prediction.	
The magnet is moved away from the coil.		
The magnet is moved toward the coil again, but more slowly.		
The magnet is held at rest near the coil.		
The magnet is held at rest and the coil is moved toward the magnet.		

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Situation	Predict what the galvanometer needle does.	What the needle actually does.
The magnet is moved toward the coil.	No basis for prediction.	Needle deflects to the left.
The magnet is moved away from the coil.	Opposite to the above.	Needle deflects to the right.
The magnet is moved toward the coil again, but more slowly.	Same as the first case, but needle deflects less.	Needle deflects a little bit to the left.
The magnet is held at rest near the coil.	??	Nothing!
The magnet is held at rest and the coil is moved toward the magnet.	Same as the first case.	Needle deflects to the left.

Let's make a few more observations.

Situation	Predict what the galvanometer needle does.	What the needle actually does.
The magnet is reversed, so the south pole points at the coil. The magnet is moved toward the coil.		
The magnet is moved away from the coil.		
The magnet is taken to the other end of the coil, and the north pole is closer to the coil. The magnet is moved toward the coil.		
The magnet is moved away from the coil.		
The magnet is rotated back and forth near the end of the coil		

Let's make a few more observations.

Situation	Predict what the galvanometer needle does.	What the needle actually does.
The magnet is reversed, so the south pole points at the coil. The magnet is moved toward the coil.	Opposite to when the north pole was pointed at the coil.	The needle deflects to the right.
The magnet is moved away from the coil.	Opposite to the above.	The needle goes left.
The magnet is taken to the other end of the coil, and the north pole is closer to the coil. The magnet is moved toward the coil.	Same as the south pole at the other end?	The needle deflects to the right.
The magnet is moved away from the coil.	Opposite to the previous.	The needle goes left.
The magnet is rotated back and forth near the end of the coil	The needle goes back and forth, too.	What we said.

Faraday's Law

Faraday's Law ties all of our observations into one neat package. It says that the voltage induced in a coil of *N* turns is given by the rate of change of the magnetic flux in the coil:

Faraday's Law:
$$\varepsilon = -N \frac{\Delta \Phi}{\Delta t}$$

This has an incredible number of practical applications, particularly in the generation and distribution of electricity.

We call the voltage induced by a changing magnetic flux an induced emf. This is because changing magnetic flux acts like a battery in a coil or loop, which is why there is a current when there's a complete circuit.

Graphs of flux and induced emf

In this situation, a bar magnet is moved at constant speed *v* toward a coil until the left end of the magnet is at the center of the coil. The magnet is held stationary for 3 seconds, and then moved to the right away from the coil with a speed *v*.

What does the graph of magnetic flux as a function of time look like? Assume positive flux corresponds to field lines passing through the coil to the left.

What does the graph of induced emf as a function of time look like?

Lenz's Law

Exposing a coil or loop to a changing magnetic flux will generate a current if the circuit is complete. The direction of the current is given by Lenz's Law:

Lenz's Law: A changing magnetic flux induces an emf that produces a current which sets up a magnetic field that *tends to oppose whatever produced the change*.

Coils and loops don't like to change, and they will try to counteract any changes in magnetic flux imposed on them. They are not successful - the change can be made, but the coil or loop tries to oppose the change while the change is taking place. This tendency to oppose is why there is a minus sign in Faraday's Law.

An easy way to approach Lenz's Law situations, to figure out the direction of an induced current, it to draw a set of three pictures.

First, some review. In which direction is the magnetic field inside a loop if the loop has a counter-clockwise current? What if the current is clockwise?

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First, some review. In which direction is the magnetic field inside a loop if the loop has a counter-clockwise current? What if the current is clockwise?



Example: A wire loop in the plane of the page is in a uniform magnetic field directed into the page. Over some time interval, the field is doubled. What direction is the induced current in the loop while the field is changing?

Step 1: Draw a "Before" picture, showing the field passing through the loop before the change takes place.

- Step 2: Draw an "After" picture, showing the field passing through the loop after the change.
- Step 3: Draw a "To Oppose" picture, showing the direction of the field the loop creates to oppose the change.
- Step 4: Use the right-hand rule to determine which way the induced current goes in the loop to create that field.

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One field line is enough for the To Oppose picture - that's enough to determine the direction of the induced current.







Graphs of flux and induced current

A square conducting loop moves at a constant velocity of 1 m/s to the right. At t = 0, its right side is at x = -6 m. A region of uniform magnetic field directed into the page is located between x = -4 m and x = 0. A second region of uniform magnetic field directed out of the page is located between x = 0 and x = 4 m. The field in the two regions has the same magnitude and the field is zero everywhere else. Assume the velocity of the loop is constant throughout its motion. Simulation



Graphs of flux and induced current

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The flux graph

Remember that flux is a measure of the number of field lines passing through the loop, with positive for, in this case, field lines into the page.



The graph of induced current

What is the connection between the graphs?



The graph of induced current

What is the connection between the graphs? The current graph is proportional to the negative slope of the flux graph.

