



IIIT-H

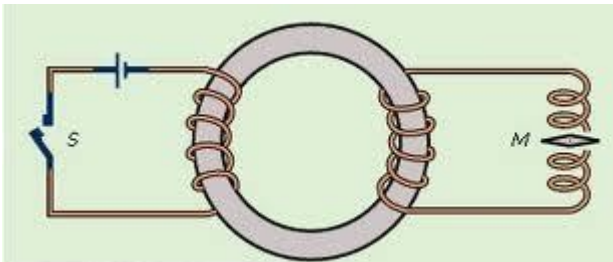
VIRTUAL LABS

Manual for Application of Faraday's Laws

Introduction:

Till now we have seen static magnetic fields. We found that various current distributions (moving charge) produces magnetic fields. It was of great interest to the scientists to find out if magnetic field would produce current. Joseph Henry and Michael Faraday independently worked on this and Henry was the first to find that it is possible. But Faraday published his results earlier than Henry hence the Faraday's law.

Faraday's experimental setup looked like the one shown below.



He expected to see deflection in the galvanometer when switch is closed as he anticipated that the magnetic flux created by the first coil induces current in the later one but he did not observe any deflection. Accidentally (Most of the discoveries are accidental !!!) he observed that the closing and opening of the switch caused deflection in the galvanometer.

Here we see how magnetic field can be used to generate electric field and its applications.

Objectives:

The main objectives of this experiment are the following:

1. Estimate EMF when a bar magnet moves through a stationary loop
2. Estimate EMF when a loop rotates in constant magnetic flux.
3. To relate the EMF applied and the speed of loop placed in a magnetic field.

Theory:

Faraday concluded from his experiment that the changing magnetic field induces current. He formulated the experimental result as follows:

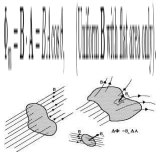
The induced electromotive force (EMF) in any closed circuit is equal to the time rate of change of the magnetic flux through the circuit.

The above law is known as Faraday's law of induction.

Let us first see what magnetic flux means:

Magnetic flux (most often denoted as ϕ_m), is a measure of the amount of

magnetic field passing through a given surface. The magnetic flux through a given surface is proportional to the number of (imaginary) magnetic field lines that pass through the surface. The magnetic flux for a uniform B (magnetic field) at any angle to a surface is defined by a dot product of the magnetic field and the area element vector.



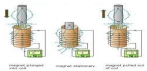
Magnetic flux equation in integral form:

$$\Phi_m = \iint_S \mathbf{B} \cdot d\mathbf{S},$$

Coming back to Faraday's law which states that the EMF generated in a circuit is proportional to the rate of change of the magnetic flux through the circuit.

$$\mathcal{E} = - \frac{d\Phi_B}{dt}$$

The figure depicts that a moving magnet through a electric coil induces current.



If the circuit contains closely wrapped coils as shown above such that same amount of magnetic flux passes through all of the coils then, if the number of turns of the coil are N , EMF induced would be given by:

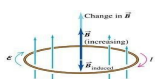
$$E_{emf} = -N \frac{d\Phi}{dt}$$

From the above formula we can conclude that the more EMF could be generated by:

1. Increasing the number of turns of the coil
2. increasing the rate of change of flux which can be done by either increasing the rate of change of magnetic field and increasing the magnetic field or increasing the rate of change of area and increasing the area exposed to the magnetic field.

In this context it is important to know about the Lenz law. It states that

" the induced current is always in such a direction as to oppose the motion or change causing it ".



This law determines the direction of induced EMF and hence we have a negative sign in the equations.

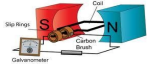
Generator

Electrical generator converts mechanical energy into electrical energy. It

works on Faraday's law of induction.



Hand Moving Generator



Suppose a conducting loop as shown above is made to rotate in a magnetic field B with angular velocity ω and assuming that the loop has an area A then from the Faraday's law of induction we have

$$\mathcal{E} = -\frac{d\Phi_B}{dt} = -\frac{d}{dt} \left(\vec{B} \cdot \vec{A} \right) = -\frac{d}{dt} (BA \cos \theta)$$

Since ω is proportional to rate of change of θ we have:

$$\mathcal{E} = -BA \left(\frac{d}{dt} (\cos \omega t) \right) = BA \omega \sin \omega t$$

If the coil has N turns then:

$$\begin{aligned} \mathcal{E} &= NBA \omega \sin \omega t \\ &= \mathcal{E}_0 \sin \omega t. \end{aligned}$$

The loop cuts the static magnetic flux created by the magnetic poles as it rotates, hence there is change in the flux through the coil and hence EMF is produced.

Motor

It has been observed that magnetic field exerts force on moving charges and it is given by:

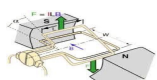
$$\vec{F} = q\vec{v} \times \vec{B}.$$

Similarly magnetic field also exerts force on a current carrying conductor (find out how?) and is given by

$$\vec{F} = I\vec{\ell} \times \vec{B}$$



Motor works as follows:



When a dc current carrying loop is placed in a magnetic field the sides of loop which are perpendicular to the magnetic field experience forces which are equal and opposite in direction. As we know this produces a torque on the loop which is given by

$$\tau = ILB\sin\theta * w = IBAsin\theta.$$

This torque results in rotational moment of the loop.

If the direction of flow of current would remain the same till the loop reaches vertical position(from the angle shown in figure) and moves beyond the forces would act in reverse direction and the loop would reverse the direction. To avoid this dc motor employs commutator and brushes.

Back EMF

One might assume that the loop would continue to move with infinite angular speed (if you did not assume refresh the concepts of torque). There is something called back EMF which comes into play.

Again Faraday's law helps us here. As the loop is moving in the magnetic field an EMF would be induced to oppose the cause. Thus it is opposite in direction to the applied EMF(Lenz's law). This is called BACK EMF. As the angular speed of the loop increases back emf also increases proportionally. The speed of the motor is restricted by this. Back EMF is both a boon and bane.

Now as part of your exercise find out how.

Procedure:

This experiment consists of three stages and each stage will teach you a new concept.

The experiment was designed in a way, so that you can quickly change the parameters and observe the results. This makes you to have a more clear picture of the concepts.

Start the experiment by pressing *start* button

• **STAGE 1:**

Want to learn more other than static magnetic fields !!! We show you the interesting (and most basic) concept of Faraday's laws.

1. Observe a magnetic bar(moving) which is at the center of a rectangular coil. Set the frequency and the magnetic flux of magnetic bar.
2. You can observe the amplitude (i.e., maximum value) of voltage (a sinusoidal wave) on the voltmeter.
3. By changing the parameters, see the graph (run time graph) on the rightside of window. Write a report of your observations.

- **STAGE 2:**

1. Now, we generate the voltage by rotating the rectangular plate. (B is constant) You can increase or decrease the rate of rotation of rectangular coil.
2. So, as the area (intersected with B) changes, voltage is produced. The amplitude of voltage is displayed in the voltmeter.
3. See the exact nature of voltage (sinusoidal) on the graph(run time graph) provided at the rightside of window.

- **STAGE 3:**

1. Let us do the opposite of what we have done in the above. So, we see the functioning of motor in this stage. That means, we rotate the rectangular coil, by giving voltage as input.
2. Measure how voltage is related to frequency of rotation of rectangular coil. Plot a graph and compare with given graph.