Week 6

Physics 1409/1430 – Physics 2

Hello and Welcome to the weekly resources for PHY 1409/1430 – Physics 2!

This week is Week 6 of classes, and typically in this week of the semester, your professors are covering these topics below. If you do not see the topics your particular section of class is learning this week, please take a look at other weekly resources listed on our website for additional topics throughout the semester.

We also invite you to take a look at the group tutoring chart on our website to see if this course has a group tutoring session offered this semester.

If you have any questions about these study guides, group tutoring sessions, private 30-minute tutoring appointments, the Baylor Tutoring YouTube channel or any tutoring services we offer, please visit our website www.baylor.edu/tutoring or call our drop in center during open business hours, M-Th 9am-8pm on class days, at 254-710-4135.

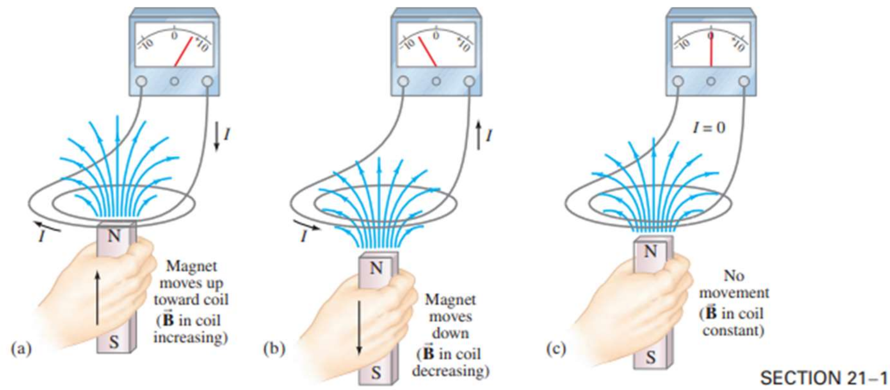
Keywords: Electromagnetic Induction, Lenz's law, Induced EMF

Topic of the Week: Electromagnetic Induction

Highlight 1: Induced EMF

Now that you have learned about electricity and magnetism, you will learn about how they relate to each other. This involves the work of one of my all-time favorite scientists, Michael Faraday. He discovered that a changing magnetic field produces an electric current, which is called the induce current. Hence, changing magnetic fields induce an EMF. This phenomenon is called electromagnetic induction.

What is extremely important to remember for this phenomenon is the rules that apply to the direction of the induced current. The induced current moves in a direction such that the magnetic field it produces, opposes the change in the magnetic field. So, if the magnetic field passing through decreases, the current goes in the direction in which it will produce a magnetic field in the direction of the initial magnetic field. The diagram below best demonstrates this idea. As an exercise, use the right-hand rule for magnetic field in a current carrying wire to see why the current indicated in the diagram is true. These principles will make more sense once we look at magnetic flux.

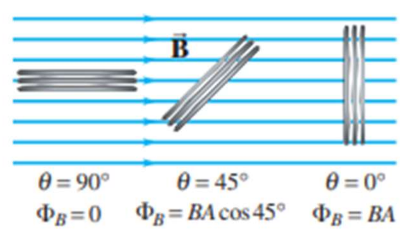


SECTION 21–1

Highlight 2: <u>**Magnetic Flux (Lenz's Law)**</u>

Magnetic flux is the magnitude of the magnetic field that is passing through a given area. The magnetic field considered must be perpendicular to the direction of the face of the surface. The magnetic flux for a uniform field can be calculated using:

$$\Phi_B = B_\perp A = BA\cos\theta.$$



The flux is proportional to the number of magnetic field lines passing through area enclosed by the given surface, as shown in the diagram here. The SI unit for flux is weber (Wb).

Mathematically, the induced emf is equal to the rate of change of the flux over time. What is important to note her is change of flux. If there is no change in the flux, there is no induced emf. The induced emf is also affected by the number loops through which the changing magnetic field passes. So, the induced emf can be calculated using:

$$\mathscr{E} = -N\frac{\Delta\Phi_B}{\Delta t}$$

Lenz's law states that *"a current produced by an induced emf moves in a direction so that the magnetic field created by the current opposes the original change in flux."* This the principle demonstrated in the first figure in this document. Another thing to note is that the flux is affected by relative motion, so the loop, or the source of conductor can be the moving component for the change.

Example:

A circular loop in the plane of the paper lies in a 0.65-T magnetic field pointing into the paper. The loop's diameter changes from 20.0 cm to 6.0 cm in 0.50 s. What is (a) the direction of the induced current, (b) the magnitude of the average induced emf, and (c) the average induced current if the coil resistance is 2.5 Ω.

Solution

(a) Consider what the change in area does to the flux. If you decrease the diameter of the loop, you decrease the area enclosed by the loop. If the area of the loop is decrease, less of the magnetic field lines can go through the loop. This decreases the flux through the loop. Now consider the Lenz's law. To oppose the decrease in flux, the induced current will try to compensate for decrease in magnetic field passing through the loop. So, the produced magnetic field will be in the direction of the initial magnetic field. Using the right-hand rule, we can see that the current is going clockwise.

(b)
$$\begin{aligned}\xi &= \Delta \text{Flux} / \Delta \\ &= B\Delta A / \Delta t \\ &= 0.65\,(\pi R1^2 - \pi R2^2) / (0.5) \\ &= 0.65(\pi(0.1)^2 - \pi(0.03)^2) / 0.5 \\ &= 0.0371 \text{ V}\end{aligned}$$

(c)
$$\begin{aligned}V &= I\,R \\ I &= V / R \\ &= 0.0371 / 2.5 \\ &= 0.015 \text{ A}\end{aligned}$$

The essential part of these problems is understanding

(a) how to see the changes in flux and

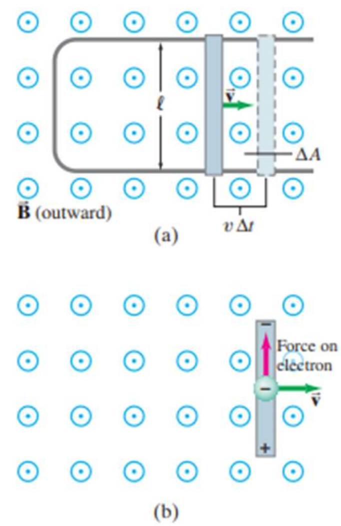
(b) how to use the right-hand rule to see the direction of the induced current.

Change in flux can be cause by the movement of a conductor. If you move a conductor in an electric field, the area for the flux will change. So, we can mess with formula for the induced emf to apply to this sort of problem.

$$\mathscr{E} = \frac{\Delta\Phi_B}{\Delta t} = \frac{B\,\Delta A}{\Delta t} = \frac{B\ell v\,\Delta t}{\Delta t} = B\ell v.$$

The emf induced due to the movement of a conductor in a magnetic field is called motional emf.

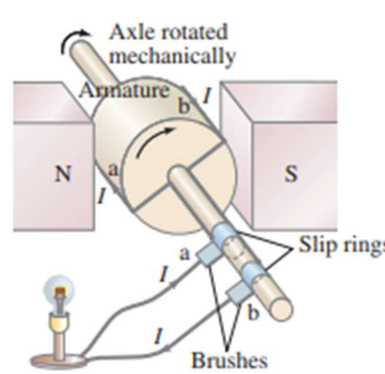
Highlight 3: **<u>Magnetic Flux and Electric Field</u>**



We see above that change in flux causes an induced emf. This implies that a changing magnetic field induces an electric field that pushes the electrons to produce a current. So, the electric field produced can be calculated using:

$$E = vB$$

Something interesting about this principle is that we can use a changing magnetic field to produce electricity. This is the principle on which electrical generators work. In an electric generator, there is a metallic rod placed between two opposite poles of a magnet. The pole is connected to a circuit. When the axle is rotated in the presence of the magnetic field, it produces an induced current. this is how generators make electricity and it is the principle of a major part of the energy production process. This is prominent in dams. The water in the dam is allowed to flow to turn a turbine attached to the rod in the electric generator. As the turbine spins, energy is produced. The principles of electromagnetic induction have had an enormous impact on technological advancement for our species and continues to help us every day!



All images are from Physics: Principles with Applications (7th Edition) by Douglas C. Giancoli

CHECK YOUR LEARNING

1. A wire loop moves at a constant velocity with the area of the loop perpendicular to the magnetic field. What is the direction of the induced current? What would be the direction of the induced current if the area and magnetic field were parallel?
   A) Clockwise
   B) Counter-Clockwise
   C) No Current
2. A 10 cm diameter loop of wire is initially orientated perpendicular to a 3 T magnetic field. The loop is rotated so that its plane is parallel to the field direction in 0.1 s. What is the average induced emf in the loop?
3. A 200 turn solenoid, 10 cm long, has a diameter of 2 cm. A 20-turn coil is wound tightly around the center of the solenoid (hint: must have same area as solenoid rings!). If the current in the solenoid increases uniformly from 0 to 1 A in 0.2 s, what will be the induced emf in the short coil?

THINGS YOU MAY STRUGGLE WITH

1. Determining the direction of the induced current and whether an induced current is produced. This is a difficult concept to get a grasp of so do not despair. Remember, induced current is produced to OPPOSE the CHANGE in magnetic field. So, there are a few things to consider when looking at the system. First, there must be a change in the magnetic field, an increase, or a decrease. If there is a decrease in the magnetic field, the induced current will flow in the direction to produce a magnetic field that was in the SAME direction as the magnetic field that decreased. If the magnetic field increased, the induced current will flow in the direction that produces a magnetic field in the OPPOSITE direction of the magnetic field that changed.

2. The way that induced current is produced is not only due to the change in the strength of the magnetic field but also the amount of magnetic field passing through an area. So, the change in magnetic field can also be brought about by changing the magnetic flux for the conductor in the magnetic field. This is how Lenz's law is derived. So, remember the two ways to produced induced current.

Thanks for checking out these weekly resources! Don't forget to check out our website for group tutoring times, video tutorials and lots of other resource: www.baylor.edu/tutoring ! Answers to check you learning questions are below!

Answers: 1) (c), (c) 2. 0.24V, 3. 7.9 x 10^{-5} V

All images are from Physics: Principles with Applications (7th Edition) by Douglas C. Giancoli