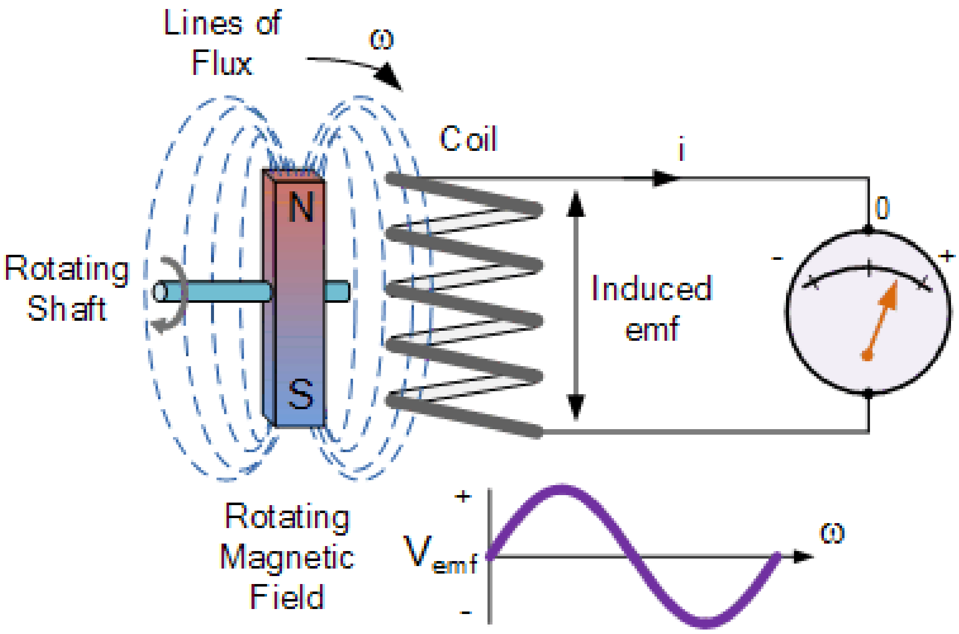
Gen Phys 2 12 Q4 M1 Magnetic-Induction Ver4

Senior High School

General Physics 2

Quarter 4 - Module 1

Magnetic Induction



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Quarter 4 - Module 1: Magnetic Induction
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This instructional material was collaboratively developed and reviewed by educators from public and private schools, colleges, and or/universities. We encourage teachers and other education stakeholders to email their feedback, comments, and recommendations to the Department of Education at action@ deped.gov.ph.

We value your feedback and recommendations.

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What This Module is About

You learned that stationary electric charges produce electric field, and moving electric charges (that is, electric current) produce magnetic field., you will find out that the reverse is also true: changing magnetic flux produces electric field or induces electric current.

After Oersted discovered that electric current creates a magnetic field around it in 1820, a lot of scientists began to duplicate his results as well as to reverse the process. One of the successful scientists that dwelled on the relationship of electricity and magnetism was Michael Faraday. He did experiments regarding the reverse relationship between magnetism and electricity, that is, the creation of an electric current using a magnetic field. So, what exactly is Magnetic Induction?

In this module you will learn many things on magnetic induction, Faraday's Law, Lenz's Law and applications of Magnetic Induction. This module explores how induction produces and changes alternating currents. This brilliant idea of Faraday led to the development of the electric motor, electric generator, and the transformer, which we often encounter every day. Because of these we can live comfortably even if our sources (or destination) of energy and information are from afar we exchange information wirelessly even with other people living in another island. This module will help you understand how these concepts relating to magnetic induction can be very important in our daily lives.

This module includes these lessons:

- **Lesson 1 – Faraday's Magnetic Induction**
- **Lesson 2 – Lenz's Law and Application of Magnetic Induction**

What I Need to Know

At the end of this module, you should be able to:

1. Identify the factors that affect the magnitude of the induced emf and the magnitude and direction of the induced current (Faraday's law) **STEM_GP12EMIVa-1**
2. Compare and contrast electrostatic electric field and non-electrostatic/induced electric field. **STEM_GP12EMIVa-3**
3. Calculate the induced emf in a closed loop due to a time-varying magnetic flux using Faraday's law. **STEM_GP12EMIVa-4**
4. Describe the direction of the induced electric field, magnetic field, and current on a conducting/nonconducting loop using Lenz's Law. **STEM_GP12EMIVa-5.**
5. Compare and contrast alternating current (AC) and direct current (DC). **STEM_GP12EMIVb-**

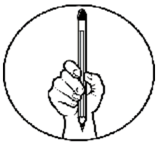
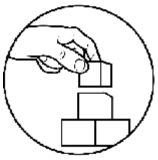
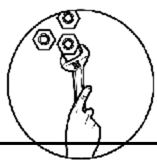
How to Learn from This Module

Below are guide steps for you to attain the learning competencies in going about the module:

- Read the lessons and follow the instructions carefully.
- Take the pretest to determine how much you know about the content. A multiple-choice test was provided for you. Be honest.
- Perform all the activities diligently to help you understand the topic.
- Take the assessment test (post-test) at the end of the module.

Icons of this Module

Here are the Icons used as your guide in every part of the lesson:

	What I Need to Know	This part contains learning objectives that are set for you to learn as you go along the module.
	What I know	This is an assessment as to your level of knowledge to the subject matter at hand, meant specifically to gauge prior related knowledge
	What's In	This part connects previous lesson with that of the current one.
	What's New	An introduction of the new lesson through various activities, before it will be presented to you
	What is It	These are discussions of the activities as a way to deepen your discovery and under-standing of the concept.
	What's More	These are follow-up activities that are in-tended for you to practice further in order to master the competencies.
	What I Have Learned	Activities designed to process what you have learned from the lesson
	What I can do	These are tasks that are designed to show-case your skills and knowledge gained, and applied into real-life concerns and situations.

What I Know

Multiple Choice. Carefully read each item. Choose the letter that matches to the best answer. Write your best answer on a separate sheet of paper.

1. The phenomenon of inducing a voltage by changing the magnetic field around a conductor is called __________.
   A. electromagnetic induction C. generated voltage
   B. Faraday's induction D. transformer induction
2. By accelerating the magnet inside the coil, the current in it
   A. increases B. decreases C. remains constant D. reverses.
3. What is the SI unit for EMF?
   A. Farad B. Ohm C. EMF D. Volt
4. EMF can be induced in a circuit by
   A. changing magnetic flux density.
   B. changing the area of the circuit.
   C. changing the angle.
   D. all of the above.
5. Total number of magnetic field lines passing through a given area is called
   A. magnetic flux density C. emf
   B. magnetic flux D. voltage
6. As per Faraday's laws of electromagnetic induction, an emf is induced in a conductor whenever it,
   A. lies perpendicular to the magnetic flux.
   B. lies in a magnetic field.
   C. cuts magnetic flux.
   D. moves parallel to the direction of the magnetic field.
7. A strong permanent magnet is plunged into a coil and left in the coil. What is the effect produced on the coil after a short time?
   A. The coil winding becomes hot.
   B. The insulation of the coil burns out.
   C. A high voltage is induced.
   D. There is no effect.
8. A loop of wire sits in an unchanging magnetic field. Which of the following is a NOT a way to induce a current through the loop?
   A. Rotate the loop about its diameter C. Stretch the loop
   B. Spin the loop about its center D. Squeeze the loop
9. Which of the following will generate a current in a conducting loop? **Select two answers:**
   A. A bar magnet moving towards the loop.
   B. A bar magnet remaining stationary within the loop.
   C. The loop rotating on an axis perpendicular to the bar magnet.
   D. A magnet and the loop moving to the right with the same velocity.
10. When current runs through a wire, a magnetic field is created. However, computer cables create little to no magnetic field external to their insulation. How is this possible?
    (Hint: computer cables contain multiple wires inside)
    A. The cables are insulated with plastic.
    B. The supply and return cables run anti parallel and their magnetic fields essentially cancel out.
    C. The supply and return cables run parallel and their magnetic fields essentially cancel out.
    D. The currents are too small to create a significant magnetic field.

Lesson 1

Faraday's Magnetic Induction

What I Need to Know

Our society's development depends largely on the development of energy resources and its generation. This is because of the bold discoveries made by numerous scientists headed by Michael Faraday in the early 19th century. Energy, in fact has becomes one of the main driving forces of a country's economy, because it powers industries, commercial establishments and residential areas. This lesson explores how induction produces and changes alternating currents.

In this lesson, you are to identify the factors that affect the magnitude of the induced emf and the magnitude and direction of the induced current, compare and contrast electrostatic electric field and non-electrostatic/induced electric field, and calculate the induced emf in a closed loop due to a time-varying magnetic flux using Faraday's law.

What's In

Is it possible to produce an electric current using only wires and no battery? So far, all electric circuits that you have studied have used a battery or an electrical power supply to create a potential within a circuit. In both cases, an emf increases the electrical potential energy of charges in the circuit, causing them to move through the circuit and create a current.

It is also possible to induce current in a circuit without the use of a battery or an electrical power supply. Just as a magnetic field can be formed by a current in a circuit, a current can be formed by moving a portion of a closed electric circuit through an external magnetic field as indicated in the figure.

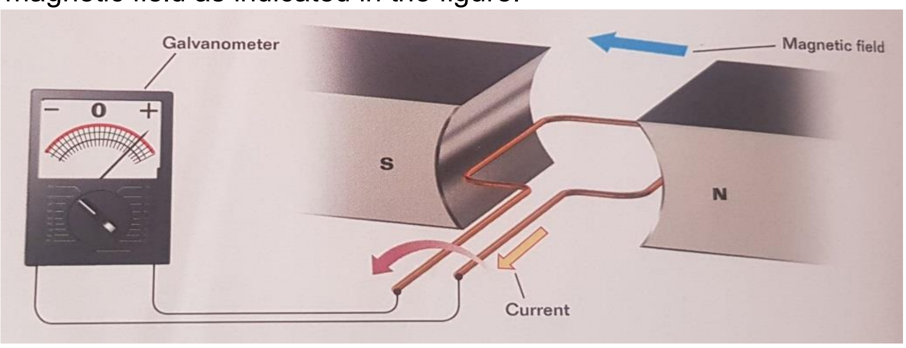


Figure 1.1: When the circuit loop crosses the lines of the magnetic field, a current is induced in the circuit, as indicated by the movement of the galvanometer.

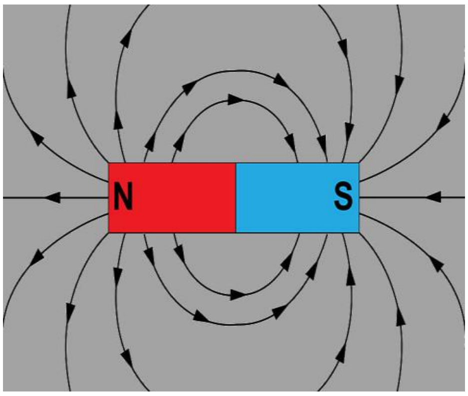
The process of inducing a current in a circuit with a changing magnetic field is called Electromagnetic Induction or Magnetic Induction.

What's New

Activity 1.1: Arrange the jumbled letters to form the word(s) to the given picture.

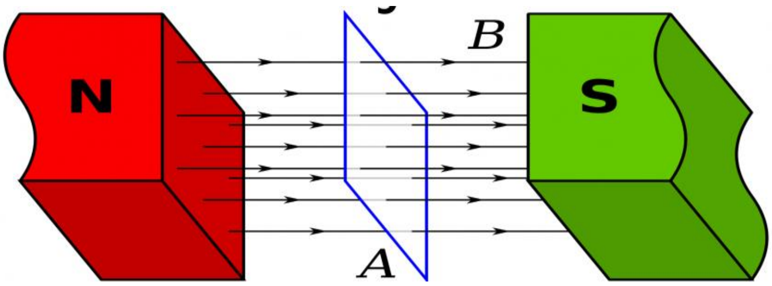
1. NDIESOOL ________________

3. GTASENM ________________



2. FILEDGENAMICT ______________

4. AAEEGLOMNRTV ____________



5. XUTNMLIGFECA (hint: enclosed in the blue line)

____

What Is It?

Key Terms

- **electromotive force**: (EMF)—The voltage generated by a battery or by the magnetic force according to Faraday's Law. It is measured in units of volts, not newtons, and thus, is not actually a force.
- **solenoid**: A coil of wire that acts as a magnet when an electric current flows through it.
- **flux**: The rate of transfer of energy (or another physical quantity) through a given surface, specifically electric flux or magnetic flux.

What Is Induction?

We have seen how Ørsted was able to demonstrate that electric currents can produce magnetic fields. The English physicist Michael Faraday, a brilliant experimentalist, was the first to demonstrate the converse effect: *magnetic fields can be used to produce voltage and in a closed circuit, induced electric currents*. This is now called the principle of **magnetic induction**. It is interesting to note that Faraday had little formal schooling, so mathematics was by no means his strength. Nevertheless, he was one of the most influential scientists not just of his time, but his contributions continue to find applications to this day.

Before we tackle the actual form of the principle of magnetic induction, we first need to define a quantity which is crucial to understand it quantitatively: the concept of *magnetic flux*.

Generalizing Flux

Let us discuss first the idea of *flux* in general using a familiar example: rain falling on the windshield of a car. Let us suppose that we want to quantitatively determine the amount of rain that hits the windshield of the car. For simplicity, let us first assume that the rain is falling vertically down, and that the shape of the windshield is a rectangle. Let us further simplify by assuming you are in a parked car, i.e. it is not moving. If we want to find how much rain hits the windshield, we need to consider chiefly these three variables:

- The amount of rain
- The size of the windshield
- The orientation of the windshield relative to the rain

Let's discuss each in turn. If it is raining hard, there will be a lot more raindrops hitting the windshield than if it is raining lightly. Likewise, If the size of the windshield is large, more raindrops will hit it than if it were small. The orientation between the rain and the windshield will also determine how much rain hits the windshield; if the windshield were arranged vertically, there would be no rain hitting the windshield (in the idealization that the windshield is infinitely thin). Conversely, the most amount of rain will hit if it's arranged perpendicular to the rain, or horizontally (like the sunroof on top of the car).

Magnetic Flux

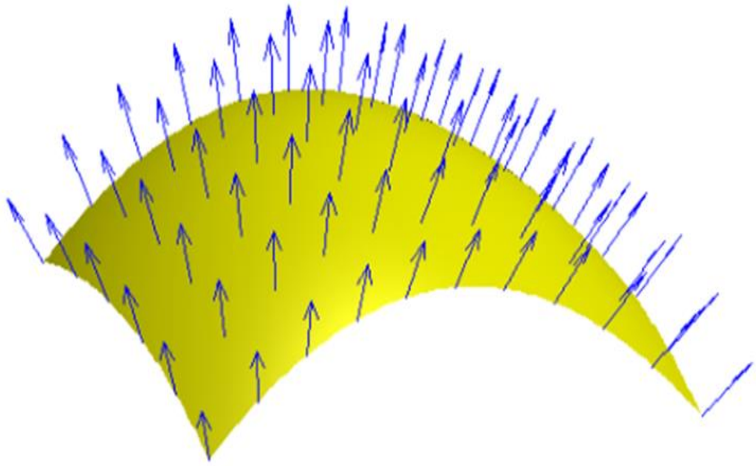
The magnetic flux (often denoted Φ or ΦB) through a surface is the component of the magnetic field passing through that surface. The magnetic flux through some surface is proportional to the number of field lines passing through that surface. The magnetic flux passing through a surface of vector area A is

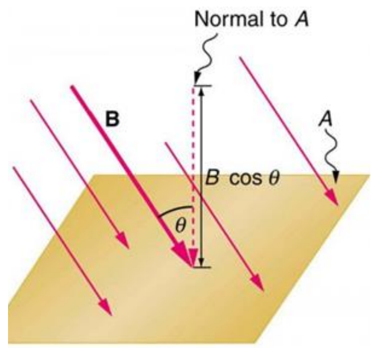
$$\Phi_B = \mathbf{B} \cdot \mathbf{A} = BA\cos\theta,$$

where Φ_B is the magnetic flux(having the unit Weber ,Wb), B is the magnitude of the magnetic field (having the unit of Tesla, T (Newton/Ampere-meter (N/Am)) but when calculating induced emf we use 1 T = 1 volt-sec/meter^2 (Vs/m^2), A is the area of the surface(m^2), and θ is the angle between the magnetic field lines and the normal (**perpendicular) to A**.

To summarize, the variables of interest when calculating the magnetic flux through an area will be:

- The magnitude of the B field
- The size of the area under study.
- The angle between the B field vector and the vector normal to the area.

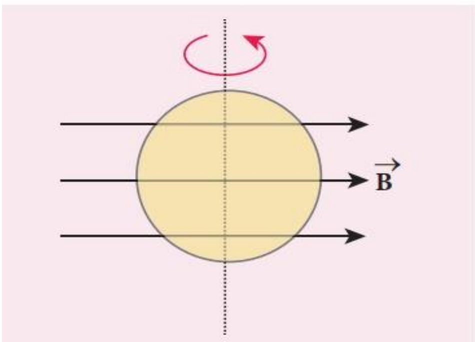




$\Phi = BA\cos\theta = B_{\perp}A$

Varying Magnetic Field: Each point on a surface is associated with a direction, called the surface normal; the magnetic flux through a point is then the component of the magnetic field along this normal direction.

Example 1:
A circular loop of area 5 x 10^{-2} m^2 rotates in a uniform magnetic field of 0.2 T. If the loop rotates about its diameter which is perpendicular to the magnetic field as shown in figure. Find the magnetic flux linked with the loop when its plane is (a) normal to the field (b) inclined 60^o to the field and (c) parallel to the field.



Given:

A = 5 x 10^{-2} m^2; B = 0.2 T

Solution:

i.) θ = 0°

$$\Phi_B = BA\cos\theta = 0.2\times 5\times 10^{-2}\times\cos 0^\circ$$

$$\Phi_B = 1\times 10^{-2}\,Wb$$

(ii) $\theta = 90^\circ - 60^\circ = 30^\circ$;

$$\Phi_B = BA\cos\theta = 0.2\times 5\times 10^{-2}\times\cos 30^\circ$$

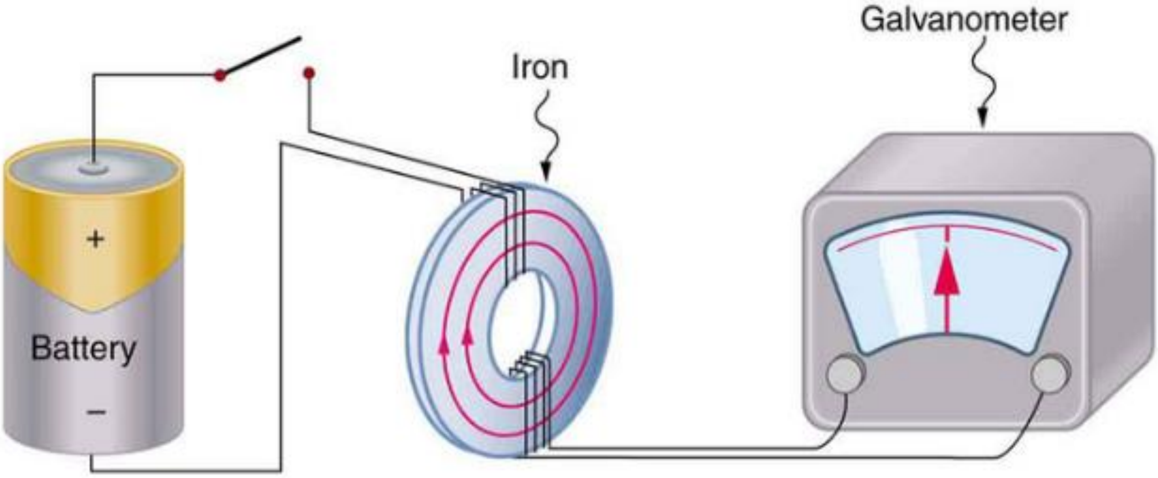
$$\Phi_B = 1\times 10^{-2}\times\frac{\sqrt{3}}{2} = 8.66\times 10^{-3}\,Wb$$

(iii) $\theta = 90^\circ$;

$$\Phi_B = BA\cos 90^\circ = 0$$

Induced EMF

The apparatus used by Faraday to demonstrate that magnetic fields can create currents is illustrated in the following figure. When the switch is closed, a magnetic field is produced in the coil on the top part of the iron ring and transmitted (or guided) to the coil on the bottom part of the ring. The galvanometer is used to detect any current induced in a separate coil on the bottom.



Faraday's Apparatus: This is Faraday's apparatus for demonstrating that a magnetic filed can produce a current. A change in the field produced by the top coil induces an EMF and, hence, a current in the bottom coil. When the switch is opened and closed, the galvanometer registers currents in opposite directions. No current flows through the galvanometer when the switch remains closed or open.

It was found that each time the switch is closed, the galvanometer detects a current in one direction in the coil on the bottom. Each time the switch is opened, the galvanometer detects a current in the opposite direction. Interestingly, if the switch remains closed or open for any length of time, there is no current through the galvanometer. Closing and opening the switch induces the current. It is the change in magnetic field that creates the current. More basic than the current that flows is the electromotive force (EMF) that causes it. The current is a result of an EMF induced by a changing magnetic field, whether or not there is a path for current to flow.

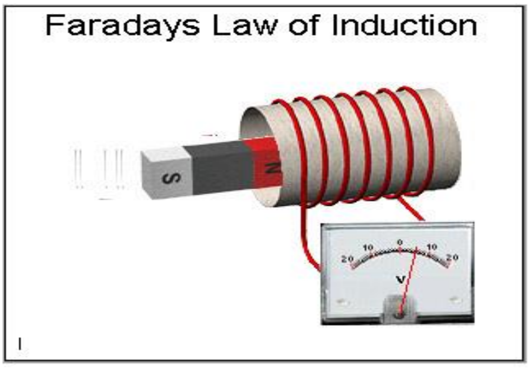
Faraday's Law of Induction

Michael Faraday concluded ***that when a wire is moved through a magnetic field, a current is generated in the wire***. This process of generating current by the relative motion between a wire and magnetic field is called ***electromagnetic induction.***

Faraday's law of induction is a basic law of electromagnetism that predicts how a magnetic field will interact with an electric circuit to produce an electromotive force (EMF). It is the fundamental operating principle of transformers, inductors, and many types of electrical motors, generators, and solenoids.

Considering the magnetic flux through a wire loop, Faraday asked what happened if you placed a magnet close to the loop and let it sit there. Would a current appear in the presence of the magnet? He carried out the experiment and found that there was no current in the loop. However, if you move the magnet away, then for a brief instant a current appears. If you move it back, then a current appears.

Whenever a conductor is rotated in magnetic field emf is induced which are induced emf.



Faraday's Law Animation

For simulation, watch:

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

Faraday's experiments showed that the emf induced by a change in magnetic flux depends on only a few factors. First, emf is directly proportional to the change in flux Δ. Second, emf is greatest when the change in time, Δt, is smallest—that is, emf is inversely proportional to Δt. Finally, if a coil has N turns, an emf that will be produced is N times greater than for a single coil, so that emf is directly proportional to N.

What Faraday found is there is an induced current (and therefore induced voltage) *only when the magnetic flux changes over time*. We say that the current is "induced" because it's not created by a battery, or some connected voltage source like we've seen before. The current is induced in the wire by the magnetic field. He called the induced voltage the induced "**electro-motive force**", or induced emf for short, denoted by Ɛ. We therefore refer to his findings as *Faraday's Law of Magnetic Induction*. Specifically, what he found was that:

- The induced voltage Ɛ is proportional to the rate of change of the flux with time, ΔΦ/Δt.
- If you add loops to the wire coil, each loop will contribute equally to Ɛ; if you have N coils, the induced voltage will be N times as strong.

We now summarize these findings in the equation that embodies Faraday's Law:

$$\mathcal{E} = -N(\Delta\Phi_B/\Delta t) \quad \text{or} \quad \mathcal{E} = -N(AB\cos\theta/\Delta t)$$

wherein N is the no. of loops, ΔΦ is the rate of change of the magnetic flux and Δt is the change of time. The unit for emf is volt. What this means is that you need to have a changing magnetic flux to produce an induced voltage. If the magnetic flux does not change with time, then there will be no current. Only if the magnetic flux changes with time will we observe a current.

Furthermore, the *faster* the flux changes, the *larger* the induced voltage. You can picture this last statement in the following way. If you are inducing current by moving a magnet close to a wire, the current will be larger if you move the magnet quickly than if you move it slowly. The magnitude of the rate of change is proportional to the voltage: the faster the magnetic field changes, the greater the induced current and induced voltage.

In sum, the induced emf can be increased by:

- 1. Increasing the number of turns(N) of wire in the coil – By increasing the amount of individual conductors cutting through the magnetic field, the amount of induced emf produced will be the sum of all the individual loops of the coil, so if there are 20 turns in the coil there will be 20 times more induced emf than in one piece of wire.

- 2. Increasing the speed of the relative motion between the coil and the magnet – If the same coil of wire passed through the same magnetic field but its speed or velocity is increased, the wire will cut the lines of flux at a faster rate so more induced emf would be produced.

- 3. Increasing the strength of the magnetic field (B) – If the same coil of wire is moved at the same speed through a stronger magnetic field, there will be more emf produced because there are more lines of force to cut.

Note also that Faraday's law focuses only on the effect of a changing magnetic field on a wire. For simplicity, we discussed using a permanent magnet as the source of our field. However, we could also use the magnetic field produced by current in *another* wire. In fact, this is how Faraday studied induced current and induced voltages.

Example 2:

A square loop of wire with 10 turns and a side length of 1 m is placed in a changing magnetic field. If the magnetic field changes from 2 T to 4 T within 8 seconds, what is the average induced emf?

Given:

N = 10 (no. of turns); Length of side = 1 m so that Area of the square is LxW : 1mx1m = $1m^2$

$\Delta\Phi_B$ = 4T - 2T = 2 T (change in magnetic field) and t = 8 sec

Note: 1 T = $1V.s/m^2$

Solution:

Using the magnitude of induced emf formula:

$$\mathcal{E} = -N(\Delta\Phi_B/\Delta t) = -N(AB\cos\theta/\Delta t)$$

(we use Faraday's law of induction as stated but without the minus sign)

Put the value into the formula:

$$\mathcal{E} = 10(1m^2)(2V.s/m^2)(\cos 0^0)/8s$$

Hence, the average induced emf is 2.5 V.

Example 3:

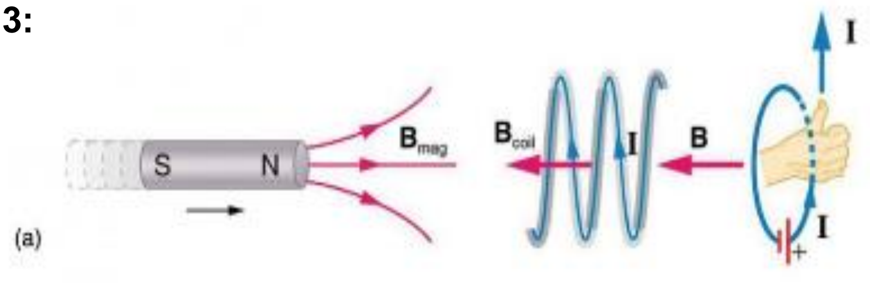


Figure 1.2(a)

Calculate the magnitude of the induced emf when the magnet in Figure 1.2(a) is thrust into the coil, given the following information: the single loop coil has a radius of 6.00 cm and the average value of *B* cos *θ* (this is given, since the bar magnet's field is complex) increases from 0.0500 T to 0.250 T in 0.100 s.

Strategy:

To find the *magnitude* of emf, we use Faraday's law of induction equation but without the minus sign:

$$\mathcal{E} = N(\Delta\Phi_B/\Delta t) = N(AB\cos\theta/\Delta t)$$

Solution:

We are given that $N = 1$ and $\Delta t = 0.100$ s, but we must determine the change in flux $\Delta\Phi$ before we can find emf. Since the area of the loop is fixed, we see that

$$\Delta\Phi = \Delta(BA\cos\theta) = A\Delta(B\cos\theta).$$

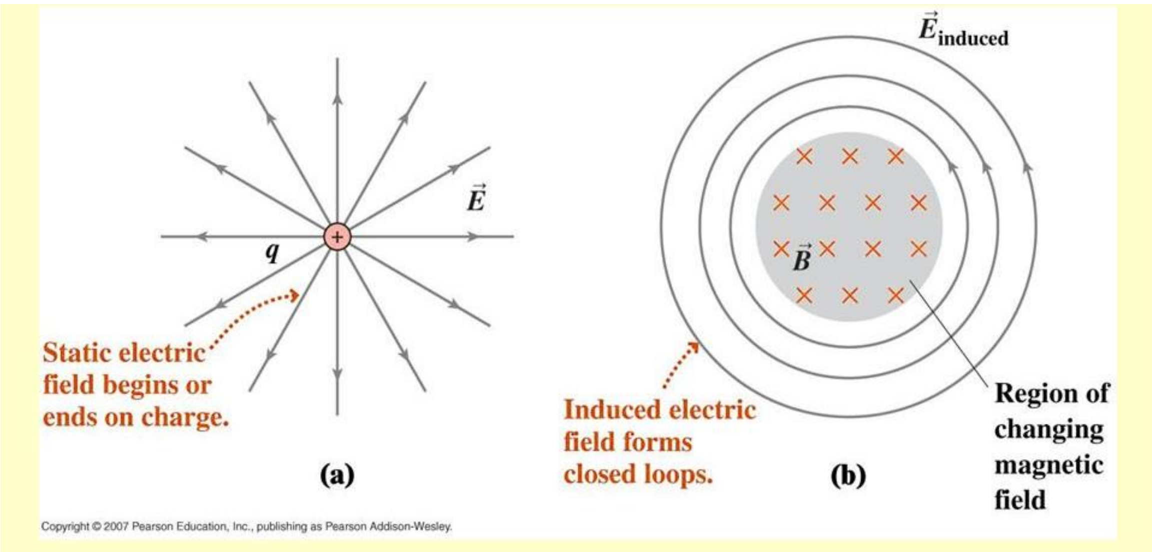
Now $\Delta(B\cos\theta) = 0.200$ T, since it was given that $B\cos\theta$ changes from 0.0500 to 0.250 T. The area of the loop is $A = \pi r^2 = \pi(0.060\text{ m})^2 = 1.13 \times 10^{-2}\text{ m}^2$. Thus,

$$\Delta\Phi = (1.13\times10^{-2}\text{ m}^2)(0.200\text{ T}).$$

Entering the determined values into the expression for emf gives

$$\mathcal{E} = N(\Delta\Phi/\Delta t) = 1(1.13\times10^{-2}\text{ m}^2)(0.200\text{ V.s/m}^2)/0.100\text{ s} = 0.0226\text{V or } 2.26 \times 10^{-2}\text{ V}$$

Two types of electric field:



The separation of static electric charges generates an electrostatic field.

Faraday's law tells us that a time-varying magnetic flux induces an electric field. Magnetic flux can best be thought of as the intensity of the magnetic field in an area or the "amount of magnetism" and can be visualized as the concentration of magnetic field lines through some surface area.

Intuitively, static (unmoving) charges make a static (unchanging) electric field and changing magnetic fields cause magnetic induction (induced electric field).

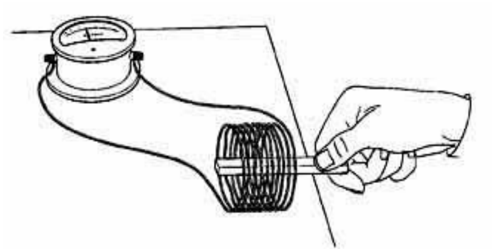
What's More

Activity 1.2: Magnet and Coil

- Permanent bar magnet
- Copper wire, insulated with bare ends, 200 cm
- Galvanometer, sensitive to e.g. 3.5–0–3.5 mA., 10 ohm resistance (see note below)

Please note: Strictly speaking, we generate emf but frequently measure the current through the load resistor (i.e. the wire) using a galvanometer (not an ammeter).

Procedure:



1. Wind a coil of 10 to 20 turns with long leads (say 50 cm). The coils should be formed in a manner that a permanent bar magnet can pass freely through it.
2. Connect the long leads to the galvanometer.
3. Move the magnet in the space in and around the coil, keeping an eye on the galvanometer.
4. Summarize your observations.

Activity 1.3: Problem Solving

1. A circular antenna of area 3 m^2 is installed at a place in NAIA. The plane of the area of antenna is inclined at 47° with the direction of Earth's magnetic field. If the magnitude of Earth's field at that place is 40773.9 nT find the magnetic flux linked with the antenna. (1 nT = 1×10^{-9} T).

2. An emf is induced by rotating a 1000-turn, 20.0 cm diameter coil in the Earth's 5.00×10^{-5} T magnetic field. What average emf is induced, given the plane of the coil is originally perpendicular to the Earth's field and is rotated to be parallel to the field in 10.0 ms?

3. A coil replaced with another coil that has loops 2 times the initial loops and the rate of change of magnetic flux is constant. Determine the ratio of initial and final induced emf.

What I Have Learned

Activity 1.4: Faraday's Magnetic Induction Review

From the concepts that you have learned, answer the following questions:

1. What are the factors that affect the magnitude of an induced emf in a coil of wire?
2. A cylindrical bar magnet is kept along the axis of a circular solenoid. If the magnet is rotated about its axis, can the electric current be induced in the coil?
3. Compare and contrast electrostatic electric field and non-electrostatic/induced electric field.

What I Can Do

Activity 1.5:

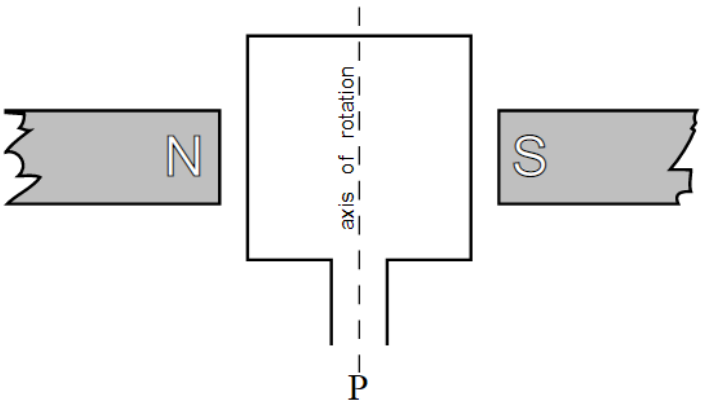
1. If you have a fixed magnetic field and a length of wire, how can you increase the induced emf across the end of the wire?

2. The figure on the right shows a map of a non-uniform magnetic field measured near a sheet of magnetic material. If the line inside that encloses the numbers represents a loop of wire, what is the magnetic flux through the loop?
(1 mT = 1×10^{-3} T)

6	6	6	6	6	5	5	6	6	6
6	6	6	6	6	5	5	6	6	6
5	5	6	5	6	6	5	5	5	5
5	6	5	5	5	4	4	5	5	6
5	5	4	4	5	3	5	5	5	5
5	5	4	4	3	4	4	3	5	5
4	4	4	4	3	3	3	3	3	4
3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3

All numbers represent mT out of the page.
Grid lines drawn with 1 cm spacing.

3. The diagram at the right shows the instantaneous position of a rotating loop of wire between two bar magnets. The loop is rotating clockwise when viewed from P. The magnets and the loop all lie in the same plane. Indicate/Illustrate the direction of induced current flow in the loop.



4. Suppose you are wearing a bracelet that is made of unbroken ring of copper wire. If you walk briskly into a strong magnetic field while wearing the bracelet, how would you hold your wrist with respect to the magnetic field in order to avoid inducing a current in the bracelet?

ENRICHMENT ACTIVITY:

1. Discuss that the earth is a natural magnet and explain that the magnetic field B serves as its "shield".

2. Discuss that the aurora borealis/australis occur as a consequence of the presence of its magnetic field.

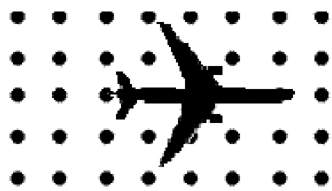
ASSESSMENT:

Direction: Read each question carefully. Choose the letter of the best answer.

1. The total number of magnetic field lines passing through a given area is called
   A. magnetic flux density C. emf
   B. magnetic flux D. voltage
2. In a circuit, two or more cells of the same emf connected in parallel order
   A. increases the potential difference across a resistance in the circuit.
   B. decreases potential difference across a resistance in the circuit.
   C. facilitate drawing more current from the battery system.
   D. change the emf across the system of batteries.
3. What is the SI unit for emf?
   A. Farad B. Ohm C. EMF D. Volt

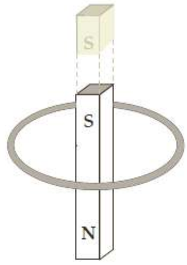
4-5. How can the magnetic flux through a coil of wire be increased? **Select two answers:**
A. Increase the magnitude of the magnetic field that passes outside the loop.
B. Increase the magnitude of the magnetic field that passes through the loop.
C. Increase the cross-sectional area of the loop.
D. Orient the loop so its normal vector is perpendicular to the external magnetic field direction.

6. A square coil of wire with a side length of 10 cm is looped around 10 times. The coil sits in an increasing magnetic field. The magnetic field increases linearly from 1T to 2T within 5 seconds. What is the induced emf of the coil?
   A. 200 V B. 20 V C. 2 V D. 0.02 V
7. As per Faraday's law of electromagnetic induction, an emf is induced in a conductor whenever it
   A. lies perpendicular to the magnetic flux.
   B. lies in a magnetic field.
   C. cuts magnetic flux.
   D. moves parallel to the direction of the magnetic field.
8. Why do you need to swipe your credit card in the credit card reader for it to accept your charge?
   A. The magnetic field in the reader only works when the credit card is moving.
   B. The current in the reader flows when the credit card strip is stationary.
   C. The magnetic field in the credit card strip needs to move to induce a current in the reader.
   D. The magnetic field in the credit card strip only exists when it is moving.
9. At the South Pole, the Earth's magnetic field is directed upwards. If a plane is flying over the South Pole, which wing will have the higher potential?



   A. The left wing
   B. The right wing.
   C. Both wings have the same potential.
   D. It is impossible to answer this question without knowing whether the plane is flying east or west.
10. A square loop of wire with 10 turns and a side length of 1 m is placed in a changing magnetic field. If the magnetic field changes from 2 T to 4 T within 8 seconds, what is the average induced emf?
    A. 1.25 V B. 2.5 V C. 0 V D. 5 V
11. A 500-turn solenoid develops an average induced voltage of 60 V. Over what time interval must a flux change by 0.06 Wb occur to produce such a voltage?
    A. 0.01 s B. 0.1 s C 0.5 s D. 5 s
12. A current may be induced in a coil by
    A. moving one end of the bar through the coil.
    B. moving the coil toward the one end of the bar magnet.
    C. holding the coil near a second coil while the electric current in the second.
    D. all of the above.

13. An induced emf is produced in
    A. a close loop of wires when it remains at rest in a non-uniform static magnetic field.
    B. a close loop of wires when it remains at rest in a uniform static magnetic field.
    C. a close loop of wires moving at constant velocity in a non-uniform static magnetic field.
    D. all of the above.
14. A bar magnet is dropped from above and falls through the loop of wire shown below. The North pole of the bar magnet points downward towards the page as it falls. Which statement is correct?
    A. The current in the loop always flows in a clockwise direction.
    B. The current in the loop always flows in a counter-clockwise direction.
    C. The current in the loop flows first in a clockwise, then in a counter-clockwise direction.
    D. The current in the loop flows first in a counter-clockwise, then clockwise direction.



15. The magnetic flux through the loop perpendicular to a uniform magnetic field will change,
    A. if the loop is replaced by two loops, each of which has a half of the area of the original loop.
    B. if the loop moves at constant velocity while remaining perpendicular to and within the uniform magnetic field.
    C. if the loop moves at constant velocity in a direction parallel to the axis of the loop while remaining in the uniform magnetic field.
    D. In none of the above cases.

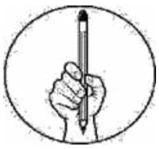
Lesson 2	Lenz's Law

Lesson 2: Lenz's Law

What I Need to Know

Lenz's law is based on Faraday's law of magnetic induction. Faraday's law tells us that a changing magnetic field will induce a current in a conductor. Lenz's law tells us the direction of this induced current, which opposes the initial changing magnetic field which produced it. This is signified in the formula for Faraday's law by the negative sign.

In this lesson, you will learn and describe the direction of the induced electric field, magnetic field, and current on a conducting/nonconducting loop using Lenz's Law, compare and contrast alternating current (AC) and direct current (DC).

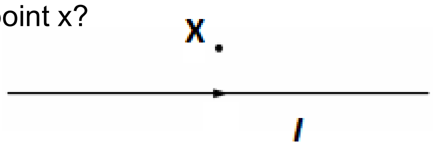


What I Know

For numbers 1 – 2:

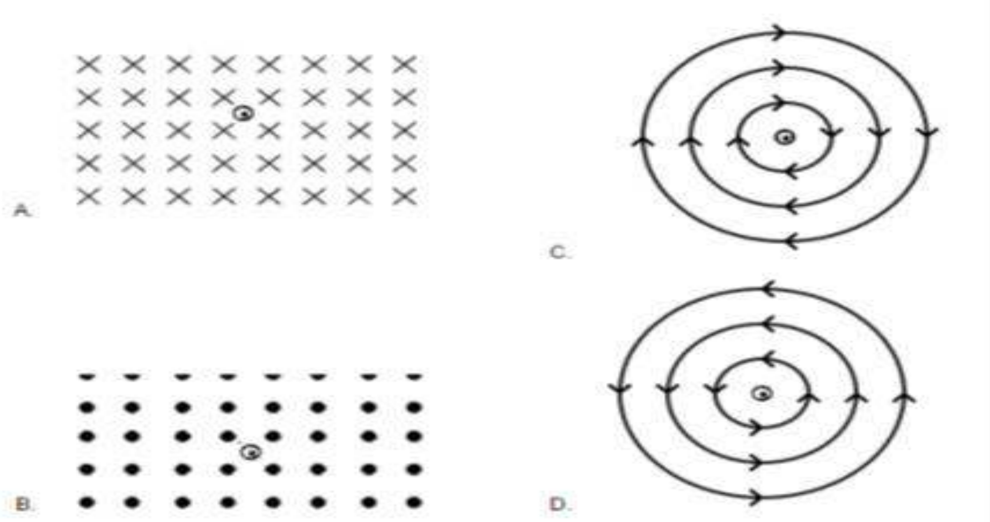
A. Law of conservation of energy
B. Faraday's Law
C. Lenz's Law
D. all of the above

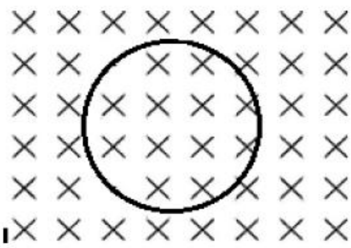
1. The Law that states that the direction of an induced current is such that its own magnetic field opposes the original change in magnetic flux that induced the current.
2. Because of the principle of energy conservation, this law allows you to determine the direction of the induced current in a circuit.
3. To determine the directions of the induced magnetic fields, currents, and emfs the following steps are observed **EXCEPT.**
   A. Make a sketch of the situation for use in visualizing and recording directions.
   B. Determine the direction of the magnetic field B.
   C. Determine whether the flux is increasing or decreasing.
   D. Use LHR-2 to determine the direction of the induced current I that is responsible for the induced magnetic field B.
4. Lenz's law concerning the direction of an induced current in a conductor by a magnetic field could be a restatement of?
   A. Ampere's Law B. Ohm's Law
   C. Tesla's Law D. The Law of Conservation of Energy
5. A long straight wire carries a current *I* toward the right. What is the direction of the magnetic field resulting from the wire at point x?



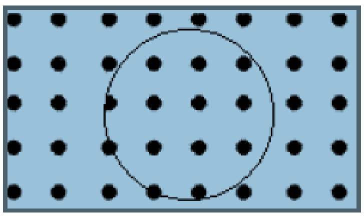
A. Out of the page B. Into of the page C. Toward the left D. Toward the right

6. Which of the following diagrams accurately portrays the magnetic field resulting from a wire directed out of the page?





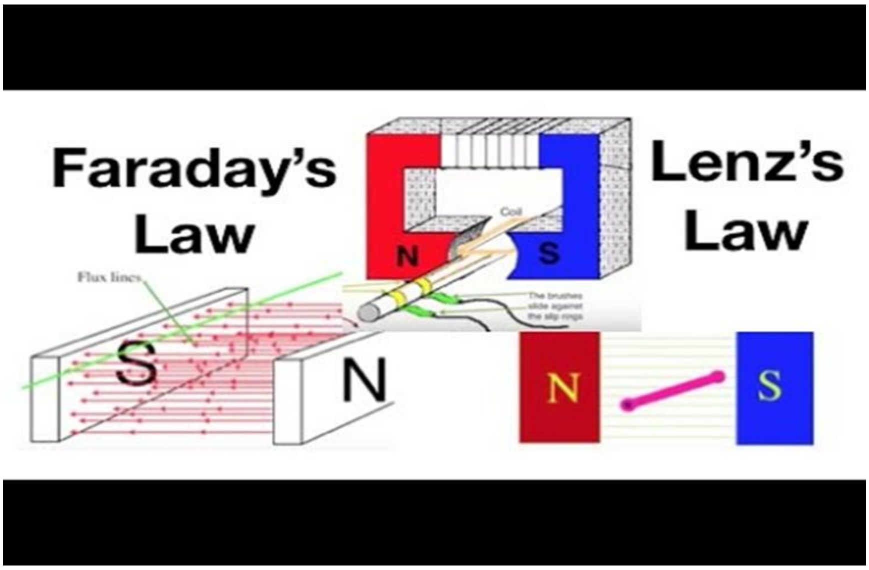
7. A conducting loop of wire with radius r is placed in an increasing magnetic field B directed into the page as shown in the figure at the right. What is the direction of the induced current in the wire?
   A. Clockwise B. Counterclockwise
   C. Up D. Down
8. A loop of conducting wire with length L and width W is entering a magnetic field B at velocity v.
   What direction will the induced current travel in?
   A. Clockwise B. Counterclockwise
   C. Up D. Down



9. A circular loop of wire is placed in a magnetic field as show in the figure at the right. If the magnetic field is increasing, what direction is the induced current in?
   A. Clockwise B. Counterclockwise
   C. Into the page D. Out of the page
10. A square loop of wire with 2 turns and a side length of 1 m is placed in a changing magnetic field. If the magnetic field changes from 2 T to 4 T within 8 seconds, what is the average induced emf?
   A. 0.25 V B. 0.5 V C. 0 V D. 2 V
11. The positive and negative terminals of direct current have
   A. no polarity. B. fixed polarity.
   C. variable polarity. D. negative polarity always.
12. The electric power enters our house through
   A. ground wire B. neutral wire C. live wire D. all of above
13. Power companies supply AC, not DC, because
   A. it is easier to transmit AC. B. there is no longer a need for DC.
   C. DC is more dangerous. D. there are not enough batteries.
14. With DC, electrons move in one direction from
   A. positive to negative. B. negative to negative.
   C. positive to positive. D. negative to positive.
15. When a circuit running on AC has a light bulb, it does not have a steady flow of positively charged ______running through it like it does on DC power.
   A. Electron B. Neutron C. Positron D. neutrino

What's In

You have learned in lesson 1 that it is also possible to induce current in a circuit without the use of a battery or an electrical power supply. You did activities and gain insights on Faraday's Law of magnetic induction and describe the factors which affects the magnitude of an induced emf. You also appreciated the importance to study magnetic induction and understand its concepts which can be applied in real life situations.



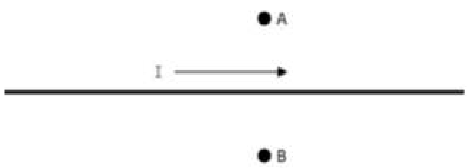
In this lesson, you will tackle thoroughly the direction that the current will flow and the 2 types of current.

What's New

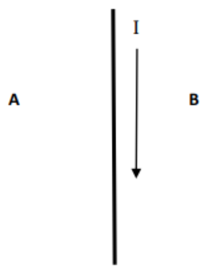
Activity 2.1: What's the direction?

For the following current-carrying wires, identify which direction the magnetic field is pointing at the specific locations. **<u>Into the page</u> and <u>out of the page</u> are the possible answers**.)

1. ________________



2. ________________



Activity 2.2: Look around you!

Direction: Look around you and list 5 things that use electricity. Identify each thing whether it is utilizing AC or DC.

What Is It

Lenz's Law

The minus sign in Faraday's law of induction is very important. The minus means that the emf creates a current, I, and magnetic field, B, that oppose the change in flux Δt. This is known as Lenz' law. **The direction (given by the minus sign) of the emf is so important that it is called Lenz' law** after the Russian Heinrich Lenz (1804–1865), who, like Faraday and Henry, independently investigated aspects of induction**. Faraday was aware of the direction, but Lenz stated it, so he is credited for its discovery.**

Lenz's Law states that the direction of an induced current is such that its own magnetic flux opposes the original change in magnetic flux that induced the current.

Lenz's law allows us to predict direction of an emf induced by changing magnetic field through a loop or coil of wire (see Faraday's Law). The emf will be directed so that if it were to cause a current to flow in a conductor in an external circuit, then that current would generate an extra magnetic field in a direction that would oppose the change in the original magnetic field.

Lenz's Law combined with Faraday's Law gives:

$$\mathcal{E} = -N(\Delta\Phi_B/\Delta t)$$

where the emf, $\mathcal{E}$, is induced in a coil of N turns by a change of magnetic flux, $\Delta\Phi$, through the coil in a time interval, Δt, and the minus sign indicates the sense of opposition to the change in the field. This negative sign, however, does not have meaning unless $\mathcal{E}$ and Φ have already been defined to be positive in the appropriate directions.

Consider a coil of wire (solenoid) and a bar magnet in **Figure 2.1**. Moving the bar magnet into the solenoid induces an emf in the solenoid (according to Faraday's law), and because the circuit is closed, a current flows and a magnetic field is induced.

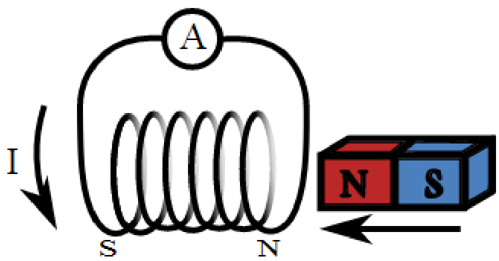
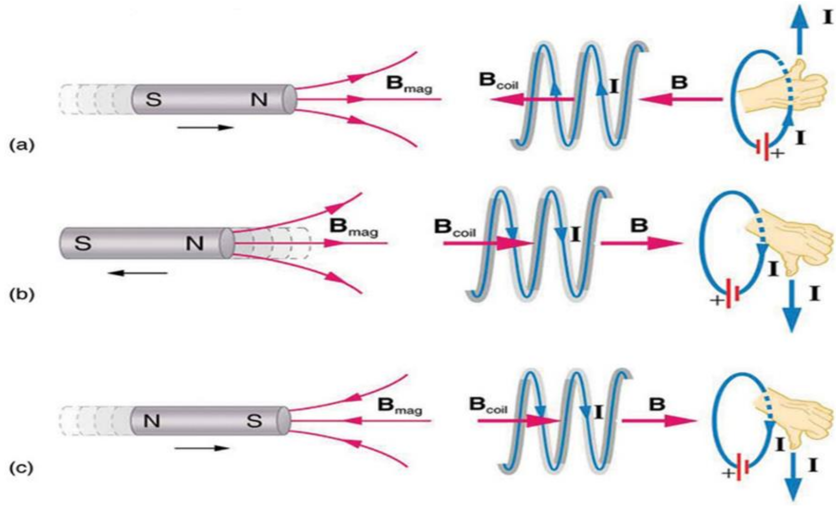


Figure 2.1: Diagram showing induced emf producing a magnetic field that opposes the magnetic field of the bar magnet as predicted by Lenz's law.

First think about what would happen if the opposite of Lenz's Law were true. Then the direction of the induced emf would be such that its magnetic field at the end of the solenoid nearest the N pole of the magnet, would resemble that of a south pole, and so the bar magnet would experience an attractive force directed into the solenoid. This would cause the bar magnet to accelerate, increasing the rate of change of magnetic flux linkage in the coil and consequently increasing the induced emf, the current and the attractive force.

In this scenario energy is being produced from nothing. Due to conservation of energy this is not possible and therefore the magnetic field due to the induced emf in the solenoid must oppose the magnetic field due to the bar magnet, as predicted by Lenz's law, as in **Figure 2.1**. This illustrates that Lenz's law is a result of energy conservation.

Below is the figure showing the right-hand rule to identify the direction of the induced emf.



Lenz' Law: (a) When the bar magnet is thrust into the coil, the strength of the magnetic field increases in the coil. The current induced in the coil creates another field, in the opposite direction of the bar magnet's field to oppose the increase. This is one aspect of Lenz's law—induction opposes any change in flux. (b) and (c) are two other situations. Verify for yourself that the direction of the induced B in the coil shown indeed opposes the change in flux and that the current direction shown is consistent with the right-hand rule.

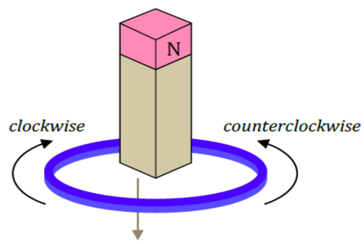
PROBLEM-SOLVING STRATEGY FOR LENZ'S LAW

To use Lenz's law to determine the directions of the induced magnetic fields, currents, and emfs:

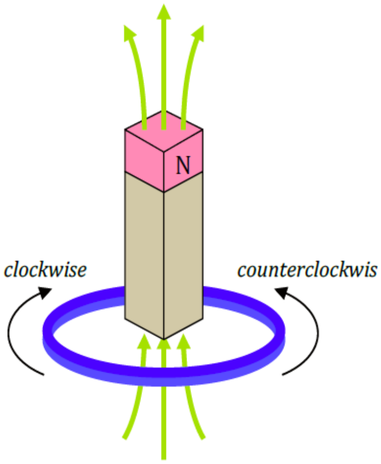
1. Make a sketch of the situation for use in visualizing and recording directions.
2. Determine the direction of the magnetic field B.
3. Determine whether the flux is increasing or decreasing.
4. Now determine the direction of the induced magnetic field B. It opposes the *change* in flux by adding or subtracting from the original field.
5. Use RHR-2 to determine the direction of the induced current I that is responsible for the induced magnetic field B.
6. The direction (or polarity) of the induced emf will now drive a current in this direction and can be represented as current emerging from the positive terminal of the emf and returning to its negative terminal.

Sample Problem:

A permanent magnet is dropped, south pole-down, through a conducting loop as shown. As the magnet falls toward—and then falls past—the area of the loop, what will be the direction of the current flow? Draw the pattern of the magnetic field produced by electric current. Explain your answer using the right-hand rule.



Solution:



Magnetic flux in the upward direction is increasing as the magnet falls toward the loop. Lenz's law predicts that the current in the loop will have a magnetic flux associated with it that *opposes* this increase in flux, i.e., in downward direction through the middle of the loop. The Right-Hand Rule indicates, then, that the direction of current flow is in the clockwise direction, as viewed from the top of the loop.

The same logic is followed to determine the current direction as the magnet falls away. Magnetic flux in the upward direction is decreasing now, inducing a current with a magnetic flux that opposes this decrease. The Right-Hand Rule reveals this current to be counterclockwise in orientation.

In Lenz's Law it did not only etermine the direction of the magnetic field but as well as the direction of current. But what is a current? What are the types of electrical current? Where are they applicable?

How Electrons Flow?

Electricity is the flow of electrons through a wire, but there are actually two different ways the electrons move within the wire. These are called **currents**. Much like an ocean current that moves in a definite direction, electricity has specific movements that it makes in the wire. These currents are **called alternating current (AC) and direct current (DC).**

Direct Current

With DC current, electrons move in one direction, from (-) negative to (+) positive. It's a constant current, flowing continuously until either it is switched off or its power source runs out of or stops generating power.

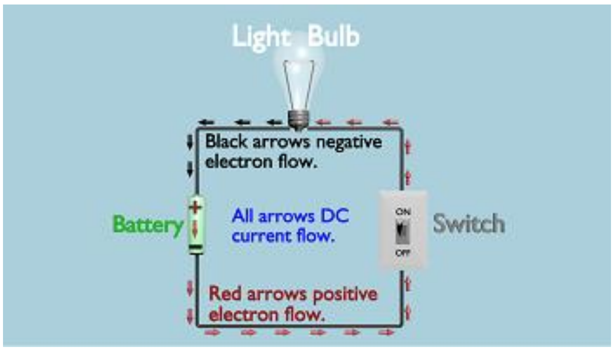


Figure 2.2. DC current flow through a simple circuit.

Let's say we're looking at a circuit with a light bulb. As noted, direct current flows from negative to positive, and the on/off switch acts as a gate for this electron flow. When it's on, the circuit is complete, allowing the electrons to flow. After passing through the switch, electrons flow to the light bulb. The filament in the bulb lights up, taking the charge from the electrons, which are then drawn to the positive terminal on the battery to be charged once again. This process continues until the battery eventually loses its charge.

Alternating Current

With AC current, electrons don't really flow, they simply vibrate back and forth from negative to positive and positive to negative. It isn't a continuous vibration either, like the constant flow in DC. The electrons vibrate in time or in sync with one another, and this timing is controlled by modifying the speed of the generator. We call this electrical timing **hertz**.

In the U.S., AC electricity is generated at 60 hertz. The electrons vibrate and bang into each other, transferring their charge from positive to negative and back again 60 times per second. This means that when a circuit running on AC has a light bulb, it doesn't have a steady flow of positively charged electrons running through it like it does on DC power, so the light is not constant either. It flickers on and off for every cycle of electron charge transfer, at 60 complete cycles per second. However, this is too fast for the human eye to see, so it appears to be a constant light.

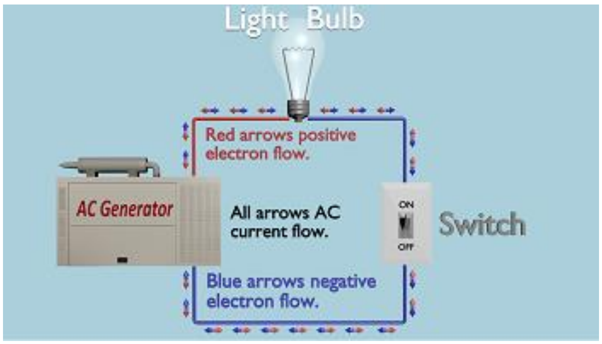
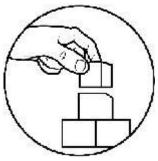


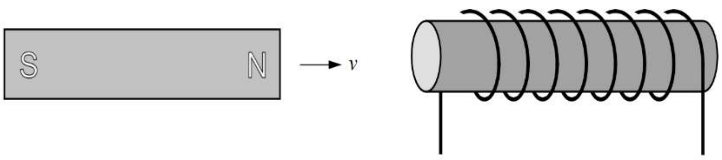
Figure 2.3. AC current flow through a simple circuit



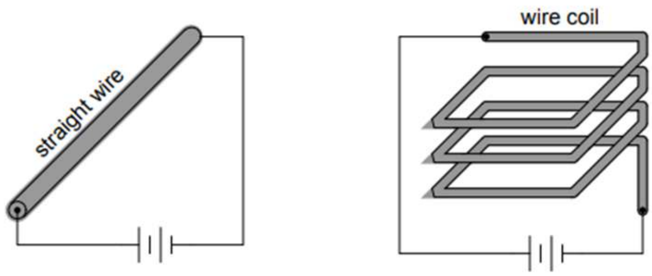
What's More

Activity 2.3: **Show me the direction.**

1. Indicate the direction of the induced current in the solenoid as the bar magnet is moved to the right.



2. Draw the pattern of the magnetic field produced by electric current through a straight wire and through a wire coil. Explain your answer using the right-hand rule.



What I Have Learned

A. From the concepts that you have learned, answer the following:

1. What is Lenz's Law? To which basic principle of physics is it most closely related?
2. Explain how Lenz's Law allows you to determine the direction of an induced current.
3. A straight conducting wire is dropped horizontally from a certain height with its length along east – west direction. Will an emf be induced in it? Justify your answer.

B. Fill in the blanks

The following activity will test your knowledge of the main points in the lesson about alternating and direct current. Fill in the blanks in the following statements.

1. AC electricity flows in a ________ pattern.
2. When a circuit running on AC has a light bulb, it doesn't have a steady flow of positively charged ________ running through it like it does on ______ power.
3. With DC, electrons move in one direction, from ________ to _________.
4. With AC, electrons don't really flow, they simply vibrate back and forth from ________ to _______ and _______to ________.
5. AC is produced by a ________ and its charge is both _______ and ________.
6. The amount of force the electrons are moved with is called _______.
7. The voltage in AC power can be changed easily with a ________, making that current ideal for providing electrical service to our homes.
8. Power makes it easy to transport electricity using batteries, like the ones we use in our cell phones, laptops, tablets, flashlights, and vehicles, because they don't need a very high ________.

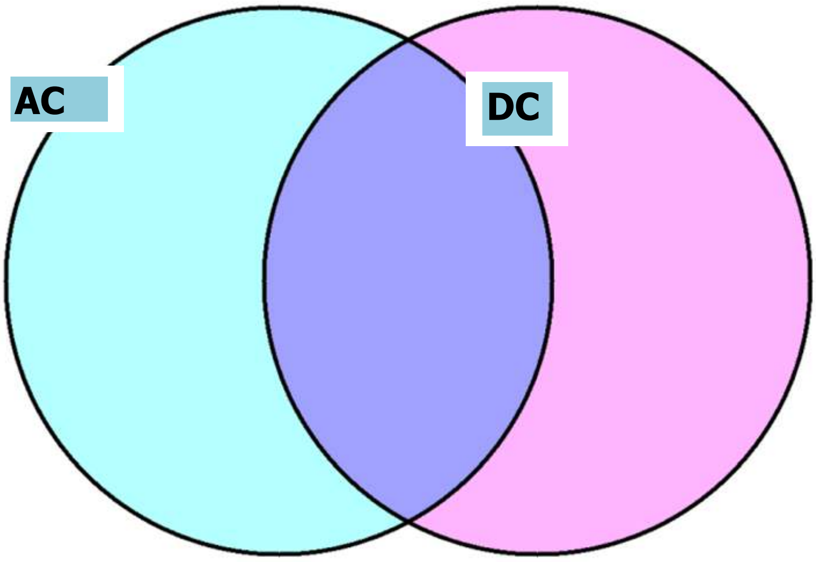
What I Can Do

Activity 2.4:

A. Identify and illustrate the chain of electromagnetic energy transformations involved in making the blades of a ceiling fan spin. include the fan's motor, the transformers bringing electricity to the house, and the turbines generating electricity.

B. Just as electricity may be harnessed to produce magnetism, magnetism may also be harnessed to produce electricity. The latter process is known as electromagnetic induction. Design a simple experiment to explore the phenomenon of electromagnetic induction.

Activity 2.5: Compare and Contrast
Direction: Using the Venn diagram, compare and contrast Alternating Current and Direct Current

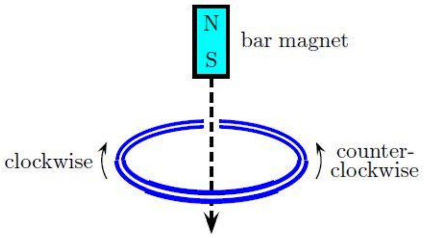


Enrichment Activity:

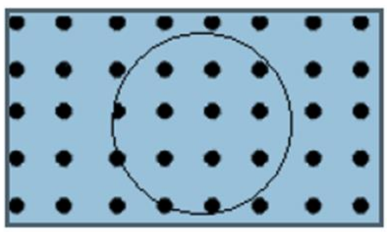
1. Explore the relationship of Lenz Law to Newton's 3rd Law of Motion, Energy Conservation, and the 2nd Law of Thermodynamics (impossibility of a perpetual motion machine).

ASSESSMENT:

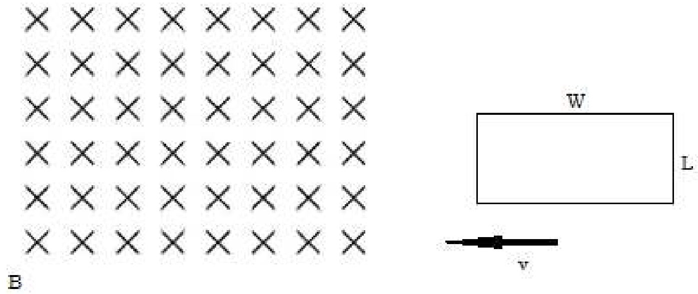
1. A strong permanent magnet is plunged into a coil and left in the coil. What is the effect produced on the coil after a short time?
   A. The coil winding becomes hot   C. A high voltage is induced
   B. The insulation of the coil burns out   D. There is no effect
2. The Law that states that the direction can induced current is such that its own magnetic field opposes the original change in magnetic flux that induced the current.
   A. Law of conservation of energy   C. Lenz's Law
   B. Faraday's Law   D. all of the above
3. Lenz's law concerning the direction of an induced current in a conductor by a magnetic field could be a restatement of?
   A. Ampere's Law   B. Ohm's Law   C. Tesla's Law   D. Law of Conservation of Energy
4. To determine the directions of the induced magnetic fields, currents, and emfs the following steps are observed **EXCEPT**
   A. Make a sketch of the situation for use in visualizing and recording directions.
   B. Determine the direction of the magnetic field B.
   C. Determine whether the flux is increasing or decreasing.
   D. Use LHR-2 to determine the direction of the induced current I that is responsible for the induced magnetic field B.
5. A permanent magnet is dropped, south pole-down, through a conducting loop as shown. As the magnet falls toward—and then falls past—the area of the loop, what will be the direction of the current flow?



   A. Clockwise when falling toward, but counterclockwise as falling away.
   B. Clockwise when falling toward, and clockwise as falling away.
   C. Counterclockwise when falling toward, but clockwise as falling away.
   D. Counterclockwise when falling toward, and counterclockwise as falling away.
6. A circular loop of wire is placed in a magnetic field as show below. If the magnetic field is Increasing, what direction is the induced current in?
   A. Clockwise   B. Counterclockwise   C. Into the page   D. Out of the page



For numbers 7 and 8:



7. A loop of conducting wire with length L and width W is entering a magnetic field B at velocity v. What direction will the induced current travel in?
   A. Clockwise B. Counterclockwise C. Up D. Down
8. What is the direction of the magnetic force on the loop as it enters magnetic field B?
   A. Up B. Down C. Right D. Left
9. A loop of wire sits in an unchanging magnetic field. Which of the following is a **NOT** a way to induce a current through the loop?
   A. Rotate the loop about its diameter
   B. Spin the loop about its center
   C. Stretch the loop
   D. Squeeze the loop
10. Which of the following statements is NOT true about DC current flow?
    A. DC current flows from negative to positive.
    B. DC current flows at a constant rate.
    C. Battery operated items are examples of DC power.
    D. All DC powered items need to be plugged in.
11. The unidirectional current is called
    A. alternating current
    B. electric charge
    C. direct current
    D. indirect current
12. The supply of electrical energy for a consumer is usually by AC because
    A. transmission and distribution are easily done.
    B. it most suitable for variable speed motor.
    C. the voltage drop in cables is minimal.
    D. cable power losses are negligible.
13. Why is alternating current transfer more effective than dc current transfer over long distances?
    A. due to the height of power lines
    B. due to the use of ac generators
    C. due to step-up and step-down transformers reducing I^2R losses
    D. due to very high voltages
14. AC is produced by a generator and its charge is
    A. positive or negative.
    B. positive and neutral.
    C. negative and positive.
    D. negative and negative.
15. The amount of force the electrons are moved in a circuit is called _______.
    A. ampere B. current C. emf D. voltage

Key to Answers

LESSON 1:

What I know (Pre-Test)

1. A
2. A
3. D
4. D
5. B
6. C
7. D
8. B
9. A. and C
10. B

WHAT'S New:

1. SOLENOID
2. MAGNETS
3. MAGNETIC FIELD
4. GALVANOMETER
5. MAGNETIC FLUX

WHAT'S MORE:

Activity 1.3

1. **Solution**

$B = 40773.9$ nT; $\theta = 90^o - 47^o = 43°$;

$A = 3m^2$

We know that $\Phi_B = BA\cos\theta$

$= 4.0773.9 \times 10^{-8} \times 3 \times \cos 43^0$

$= 4.0773.9 \times 10^{-8} \times 3 \times 0.7314$

$= 89.47 \times 10^{-6}$ Wb

$\Phi_B = 89.47\mu$Wb

2. Solution:

The Faraday's law of electromagnetic induction says

$$\text{emf} = -\frac{\Delta\Phi}{\Delta t}.$$

The change of magnetic field

$$\begin{aligned}\Delta\Phi &= NBA(\cos 90^\circ - \cos 0^\circ) \\ &= -NBA = -\pi r^2 NB \\ &= -\pi \times (0.1)^2 \times 10^3 \times 5 \times 10^{-5} = -1.6 \times 10^{-3}\,\text{Wb}\end{aligned}$$

Hence

$$\text{emf} = \frac{1.6\times10^{-3}}{10\times10^{-3}} = 0.16\ \text{V}.$$

3. 1 : 2 ratio

ASSESSMENT (Post-test):

1. B	6. D	11. C
2. C	7. C	12. D
3. D	8. C	13. C
4. B	9. B	14. D
5. C	10. B	15. D

Lesson 2

WHAT I KNOW:

1. C	6. D	11. B
2. A	7. B	12. D
3. D	8. B	13. A
4. D	9. A	14. D
5. A	10. D	15. A

WHAT'S NEW:

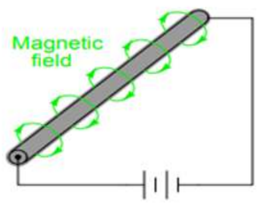
1. **Into the page** 2. **Out of the page**

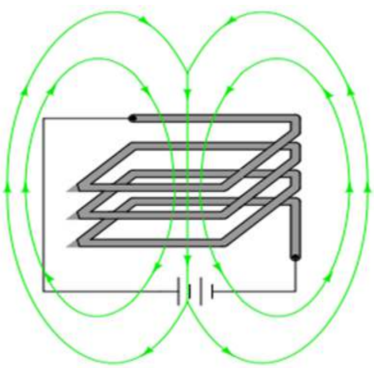
WHAT'S MORE:

Activity 2.3

1.

2.





WHAT I HAVE LEARNED:

A.

1.*Lenz's law = The induced current in a loop is in the direction that creates a magnetic field that opposes the change in magnetic flux through the area enclosed by the loop.

*It is closely related to conservation of energy.

B.FILL IN THE BLANKS

1. wave
2.electrons; DC
3. negative; positive
4 negative; positive; positive; negative
5.generator; positive; negative
6. voltage
7 transformer
8 voltage

ASSESSMENT:

1. D	6. A	11. C
2. C	7. B	12. A
3. D	8. D	13. C
4. D	9. B	14. C
5. A	10. D	15. D

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