13 Electromagnetic Induction

Content Area:	**Science**
Course(s):	**AP Physics C**
Time Period:	**Semester 2**
Length:	**3 weeks**
Status:	**Published**

Standards

SCI.HS.PS2.B	Types of Interactions
SCI.HS.PS3.A	Definitions of Energy
SCI.HS.PS3.B	Conservation of Energy and Energy Transfer
SCI.HS.PS3.C	Relationship Between Energy and Forces
SCI.HS-PS3-3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
SCI.HS-PS3-5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.
SCI.HS-PS3-1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
SCI.HS-PS2-5	Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
	Developing and Using Models
	Planning and Carrying Out Investigations
	Systems and System Models
	Using Mathematics and Computational Thinking
	Cause and Effect

AP Physics C Learning Objectives

Note: Learning Objectives are taken verbatim from the AP Physics C - Mechanics Course and Exam Description. The verb "describe" could refer to a variety of different methods of expression (e.g. words, diagrams, graphs, mathematical expressions), as appropriate.

Describe the magnetic flux through an arbitrary area of geometric shape.

Describe the induced electric potential difference resulting from a change in magnetic flux.

Describe the force exerted on a conductor due to the interaction between an external magnetic field and an induced current within that conductor.

Describe the physical and electrical properties of an inductor.

Describe the physical and electrical properties of a circuit containing a combination of resistors and a single inductor.

Describe the physical and electrical properties of a circuit containing a combination of capacitors and a single inductor.

Enduring Understandings

Fields predict and describe interactions.

Conservation laws constrain interactions.

There are laws that use symmetry and calculus to derive mathematical relationships that are applied to physical systems containing a magnetic field.

In a closed circuit containing inductors and resistors, energy and charge are conserved.

Electric and magnetic fields that change over time can mutually induce other electric and magnetic fields.

Essential Questions

How does an electric motor work?

How does pushing the doorbell produce a sound inside the house?

How does an antenna work?

How are sound waves generated by your headphones or speakers from a digital recording of a song?

How does a Wi-Fi internet connection work?

Knowledge and Skills

Topic 13.1 Magnetic Flux

Knowledge:

- For a magnetic field B that is constant across an area A, the magnetic flux through the area is defined as .
- The area vector is defined as perpendicular to the plane of the surface and outward from a closed surface.
- The sign of flux is given by the dot product of the magnetic field vector and the area vector.
- The total magnetic flux passing through a surface is defined by the surface integral of the magnetic field over the surface area.

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 13.2 Electromagnetic Induction
Knowledge:

- Faraday's law describes the relationship between changing magnetic flux and the resulting induced emf in a system.
- When the area of the surface being considered is constant, the induced emf is equal to the area multiplied by the rate of change in the component of the magnetic field perpendicular to the surface.
- When the magnetic field is constant, the induced emf is equal to the magnetic field multiplied by the rate of change in area perpendicular to the magnetic field.
- When an emf is induced in a long solenoid, the total induced emf is equal to the induced emf in a single loop multiplied by the number of loops in the solenoid.
- Lenz's law is used to determine the direction of an induced emf resulting from a changing magnetic flux.
- An induced emf generates a current that creates a magnetic field that opposes the change in magnetic flux.
- The right-hand rule is used to determine the relationships between current, emf, and magnetic flux.
- Maxwell's equations are the collection of equations that fully describe electromagnetism. Maxwell's third equation is Faraday's law of induction, which describes the relationship between a changing magnetic flux and an induced electric field.
- Maxwell's equations can be used to show that electric and magnetic fields obey wave equations and that electromagnetic waves travel at a constant speed in free space.

Skills:

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Create experimental procedures that are appropriate for a given scientific question.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 13.3 Induced Currents and Magnetic Forces
Knowledge:

- When an induced current is created in a conductive loop, the already-present magnetic field will exert a magnetic force on the moving charge carriers within the loop.
- When current is induced in a conducting loop, magnetic forces are only exerted on the segments of the loop that are within the external magnetic field. These magnetic forces may cause translational or rotational
- acceleration.

- The force on a conducting loop is proportional to the induced current in the loop, which depends on the rate of change of magnetic flux, the resistance of the loop, and the velocity of the loop.
- Newton's second law can be applied to a conducting loop moving in a magnetic field as it experiences an induced emf .

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Calculate or estimate an unknown quantity with units from known quantities by selecting and following a logical computational pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 13.4 Inductance
Knowledge:

- Inductance is the tendency of a conductor to oppose a change in electrical current.
- Inductance of a conductor depends on the physical properties of the conductor.
- Straight wires are typically modeled as having zero inductance.
- An inductor, such as a solenoid, is a circuit element that has significant inductance.
- The inductance of a solenoid is dependent on the total number of turns, the length of the solenoid, the cross-sectional area of the solenoid, and magnetic permeability of the solenoid's core.
- Inductors store energy in the magnetic field that is generated by current in the inductor.
- The energy stored in the magnetic field generated by an inductor in which current is flowing can be dissipated through a resistor or used to charge a capacitor.
- The transfer of energy generated in an inductor to other forms of energy obeys conservation laws.
- By applying Faraday's law to an inductor and using the definition of inductance, induced emf can be related to inductance and the rate of change of current.

Skills:

- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 13.5 Circuits with Resistors and Inductors (LR Circuits)
Knowledge:

- A resistor will dissipate energy that was stored in an inductor as the current changes.
- Kirchhoff's loop rule can be applied to a series LR circuit with a battery of emf, resulting in a differential equation that describes the current in the loop.
- The time constant is a significant feature of the behavior of an LR circuit.
- The time constant of a circuit is a measure of how quickly an LR circuit will reach a steady state and is

described with the equation .

- The time constant represents the time an LR circuit would take to reach a steady state if the system continued to change at the initial rate of change.
- For an inductor that has zero initial current, the time constant represents the time required for the current in the inductor to reach approximately 63 percent of its final asymptotic value.
- For an inductor with an initial current, the time constant represents the time required for the current in the inductor to reach approximately 37 percent of its initial value.
- The electric properties of inductors change during the time interval in which the current in the inductor changes, but will exhibit steady state behavior after a long time interval.
- When a switch is initially closed or opened in a circuit containing an inductor, the induced emf will be equal in magnitude and opposite in direction to the applied potential difference across the branch containing the inductor.
- The potential difference across an inductor, the current in the inductor, and the energy stored in the inductor are exponential with respect to time and have asymptotes that are determined by the initial conditions of the circuit.
- After a time much greater than the time constant of the circuit, an inductor will behave as a conducting wire with zero resistance.

Skills:

- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 13.6 Circuits with Capacitors and Inductors (LC Circuits)
Knowledge:

- In circuits containing only a charged capacitor and an inductor (LC circuits), the maximum current in the inductor can be determined using conservation of energy within the circuit.
- In LC circuits, the time dependence of the charge stored in the capacitor can be modeled as simple harmonic motion.
- The angular frequency of an oscillating LC circuit can be derived from the differential equation that describes an LC circuit.

Skills:

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Calculate or estimate an unknown quantity with units from known quantities by selecting and following a logical computational pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Transfer Goals

Throughout the course, students explored the vital roles electricity and magnetism play in our daily lives. Unit 13 examines electromagnetism through the concept of electromagnetic induction and the application of Maxwell's equations. Through classroom discussions and problem-solving, students will study, apply, and analyze the concept of induction, as well as investigate the relationship between Faraday's Law and Lenz's Law. Additionally, students are expected to call upon their knowledge obtained in earlier units—particularly that of charges, currents, and electric and magnetic fields—to better understand Maxwell's equations and to be able to mathematically demonstrate, as well as reason with, how these fields are generated.

Assessments

https://docs.google.com/document/d/1wR7bQF-8AQoRrt0g4C3hKja0yjwDjC9_BiAmONWbTcI/edit?usp=sharing

Modifications

https://docs.google.com/document/d/1ODqaPP69YkcFiyG72fIT8XsUIe3K1VSG7nxuc4CpCec/edit?usp=sharing