12 Magnetic Fields and Electromagnetism

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

Standards

SCI.HS.PS2.A	Forces and Motion
SCI.HS.PS2.B	Types of Interactions
SCI.HS.PS3.A	Definitions of Energy
SCI.HS.PS3.C	Relationship Between Energy and Forces
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.
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-PS2-1	Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
	Developing and Using Models
	Cause and Effect
	Analyzing and Interpreting Data
	Planning and Carrying Out Investigations

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 properties of a magnetic field.

Describe the magnetic behavior of a material as a result of the configuration of magnetic dipoles in the material.

Describe the magnetic permeability of a material.

Describe the magnetic field produced by moving charged objects.

Describe the force exerted on moving charged objects by a magnetic field.

Describe the magnetic field produced by a current-carrying wire.

Describe the force exerted on a current-carrying wire by a magnetic field.

Use Ampère’s Law to describe the magnetic field created by a moving charge carrier.

Enduring Understandings

Interactions produce changes in motion.

Forces characterize interactions between objects or systems.

Fields predict and describe interactions.

Charged particles moving through a magnetic field may change the direction of their motion.

A magnetic field can interact with a straight conducting wire with current.

Current-carrying conductors create magnetic fields that allow them to interact at a distance with other magnetic fields.

There are laws that use symmetry and calculus to derive mathematical relationships that are applied to physical systems containing moving charge.

Essential Questions

Why are large-scale, charged-particle accelerators, such as those at CERN, in the shape of a circle?

How does a guitar pickup work?

Why does an electric current deflect the needle of a compass?

Why does the deflection of a pair of parallel conducting wires depend on the direction of current in the wires?

Knowledge and Skills

Topic 12.1 Magnetic Fields

Knowledge:

- A magnetic field is a vector field that can be used to determine the magnetic force exerted on moving electric charges, electric currents, or magnetic materials.
- Magnetic fields can be produced by magnetic dipoles or combinations of dipoles, but never by monopoles.
- Magnetic dipoles have north and south polarity.
- A magnetic field is a vector quantity and can be represented using vector field maps.
- Magnetic field lines must form closed loops, as described by Gauss’s law for magnetism.

- Maxwell’s equations are the collection of equations that fully describe electromagnetism. Gauss’s law for magnetism is Maxwell’s second equation.
- Magnetic fields in a bar magnet form closed loops, with the external magnetic field pointing away from one end (defined as the north pole) and returning to the other end (defined as the south pole).
- Magnetic dipoles result from the circular or rotational motion of electric charges. In magnetic materials, this can be the motion of electrons.
- Permanent magnetism and induced magnetism are system properties that both result from the alignment of magnetic dipoles within a system.
- No magnetic north pole is ever found in isolation from a south pole. For example, if a bar magnet is broken in half, both halves are magnetic dipoles.
- Magnetic poles of the same polarity will repel; magnetic poles of opposite polarity will attract.
- The magnitude of the magnetic field from a magnetic dipole decreases with increasing distance from the dipole.
- A magnetic dipole, such as a magnetic compass, placed in a magnetic field will tend to align with the magnetic field.
- A material’s composition influences its magnetic behavior in the presence of an external magnetic field.
- Ferromagnetic materials such as iron, nickel, and cobalt can be permanently magnetized by an external field that causes the alignment of magnetic domains or atomic magnetic dipoles.
- Paramagnetic materials such as aluminum, titanium, and magnesium interact weakly with an external magnetic field, in that the magnetic dipoles of the material do not remain aligned after the external field is removed.
- All materials have the property of diamagnetism, in that their electronic structure creates a usually weak alignment of the dipole moments of the material opposite the external magnetic field.
- Earth’s magnetic field may be approximated as a magnetic dipole.
- Magnetic permeability is a measurement of the amount of magnetization in a material in response to an external magnetic field.
- Free space has a constant value of magnetic permeability, known as the vacuum permeability, that appears in equations representing physical relationships.
- The permeability of matter has values different from that of free space and arises from the matter’s composition and arrangement. It is not a constant for a material and varies based on many factors, including temperature, orientation, and strength of the external field.

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- 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.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 12.2 Magnetism and Moving Charges

Knowledge:

- A single moving charged object produces a magnetic field.
- The magnetic field at a particular point produced by a moving charged object depends on the object’s velocity and the distance between the point and the object.

- At a point in space, the direction of the magnetic field produced by a moving charged object is perpendicular to both the velocity of the object and the position vector from the object to that point in space and can be determined using the right-hand rule.
- The magnitude of the magnetic field is a maximum when the velocity vector and the position vector from the object to that point in space are perpendicular.
- A magnetic field will exert a force on a charged object moving within that field, with magnitude and direction that depend on the cross-product of the charge's velocity and the magnetic field.
- In a region containing both a magnetic field and an electric field, a moving charged object will experience independent forces from each field.
- The Hall effect describes the potential difference created in a conductor by an external magnetic field that has a component perpendicular to the direction of charges moving in the conductor.

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.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 12.3 Magnetic Fields of Current-Carrying Wires and the Biot-Savart Law
Knowledge:

- The Biot-Savart law defines the magnitude and direction of a magnetic field created by an electrical current.
- The magnetic field vectors around a small segment of a current-carrying wire are tangent to concentric circles centered on that wire. The field has no component toward, away from, or parallel to the segment of the current-carrying wire.
- The Biot-Savart law can be used to derive the magnitudes and directions of magnetic fields around segments of current-carrying wires, for example at the center of a circular loop of wire.
- A magnetic field will exert a force on a current-carrying wire.

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.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 12.4 Ampere's Law
Knowledge:

- Ampère's law relates the magnitude of the magnetic field to the current enclosed by a closed imaginary path called an Amperian loop.
- Ampère's law can be used to determine the magnetic field near a long, straight current-carrying wire.

- Unless otherwise stated, all solenoids are assumed to be very long, with uniform magnetic fields inside the solenoids and negligible magnetic fields outside the solenoids.
- Ampère’s law can be used to determine the magnetic field inside of a long solenoid.
- An Amperian loop is a closed path around a current-carrying conductor.
- The principle of superposition can be used to determine the net magnetic field at a point in space created by various combinations of current-carrying conductors, or conducting loops, segments, or cylinders.
- Maxwell’s equations are the collection of equations that fully describe electromagnetism. Maxwell’s fourth equation is Ampère’s law with Maxwell’s addition; it states that magnetic fields can be generated by electric current (Ampère’s law) and that a changing electric field creates a magnetic field, similar to the way a moving charge creates a magnetic field (Maxwell’s addition).

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.
- Calculate or estimate an unknown quantity with units from known quantities by selecting and following a logical computational pathway.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Transfer Goals

In previous units, students discovered that the electric field allows charged objects to interact without contact. Unit 12 introduces students to magnetism and how magnetic fields are generated, behave, and relate to electricity. Students will learn how magnetic fields impact motion and interact with other magnetic fields. Laboratory investigations and/or activities should be provided for students to apply both the Biot–Savart Law (using calculations to determine the strength of a magnetic field) and Ampère’s Law (deriving mathematical relationships which relate the magnitude of the magnetic field to current). This knowledge from previous units helps students to make connections between electric fields and magnetic fields as well as between Gauss’s Law and Ampère’s Law.

Assessments

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

Modifications

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