Physics Unit 8
Electricity and Magnetism

Overview

Unit abstract

In this unit of study, the performance expectations support students' understanding of how forces at a distance can be explained by fields, why some materials are attracted to each other while other are not, how magnets or electric currents cause magnetic fields, and how charges or changing magnetic fields cause electric fields. The crosscutting concept of cause and effect is called out as an organizing concept. Students are expected to demonstrate proficiency in planning and conducting investigations and developing and using models.

Essential question

- How can one explain and predict interactions between objects and within systems of objects?

Written Curriculum

Next Generation Science Standards

HS. Forces and Interactions

Students who demonstrate understanding can:

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. [Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical and empirical models. ▪ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS2-5)	**PS2.B: Types of Interactions** ▪ Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. (HS-PS2-5) **PS3.A: Definitions of Energy** ▪ “Electrical energy” may mean energy stored in a battery or energy transmitted by electric currents. *(secondary to HS-PS2-5)*	**Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2-5)

Connections to other DCIs in this grade-band: **HS.PS3.A** (HS-PS2-5); **HS.PS4.B** (HS-PS2-5); **HS.ESS2.A** (HS-PS2-5); **HS.ESS3.A** (HS-PS2-5)

Articulation to DCIs across grade-bands: **MS.PS2.B** (HS-PS2-5); **MS.ESS1.B** (HS-PS2-5)

Common Core State Standards Connections:

ELA/Literacy –

WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS2-5)

WHST.11-12.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. *(HS-PS2-5)*

WHST.9-12.9 Draw evidence from informational texts to support analysis, reflection, and research. *(HS-PS2-5)*

Mathematics –

HSN-Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. *(HS-PS2-5)*

HSN-Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. *(HS-PS2-5)*

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS2-5)*

HS. Energy		
Students who demonstrate understanding can: **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.** [Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.] [Assessment Boundary: Assessment is limited to systems containing two objects.]		
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. ▪ Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS3-5)	**PS3.C: Relationship Between Energy and Forces** ▪ When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5)	**Cause and Effect** ▪ Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. (HS-PS3-5)
Connections to other DCIs in this grade-band: **HS.PS2.B** (HS-PS3-5)		
Articulation to DCIs across grade-bands: **MS.PS2.B** (HS-PS3-5); **MS.PS3.C** (HS-PS3-5)		
Common Core State Standards Connections: *ELA/Literacy –* **WHST.9-12.7** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. *(HS-PS3-5)* **WHST.11-12.8** Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. *(HS-PS3-5)* **WHST.9-12.9** Draw evidence from informational texts to support analysis, reflection, and research. *(HS-PS3-5)* **SL.11-12.5** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-PS3-5)* *Mathematics –* **MP.2** Reason abstractly and quantitatively. (HS-PS3-5) **MP.4** Model with mathematics. (HS-PS3-5)		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Physical science

- Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.
- Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass—e.g., Earth and the sun.
- Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space, and they can be mapped by their effect on a test object (a charged object or a ball, respectively).
- When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.

Earth and space science

- The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids, that are held in orbit around the sun by its gravitational pull on them.
- This model of the solar system can explain eclipses of the sun and the moon. Earth's spin axis is fixed in direction over the short term but tilted relative to its orbit around the sun. The seasons are a result of that tilt and are caused by the differential intensity of sunlight on different areas of Earth across the year.
- The solar system appears to have formed from a disk of dust and gas drawn together by gravity.

Progression of current learning

Driving question 1
What are the relationships between electric currents and magnetic fields?

Concepts

- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space.
- Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.
- "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents.

Practices

- Plan and conduct an investigation individually and collaboratively to produce data that can serve as the basis for evidence that an electric current can produce a magnetic field.
- Plan and conduct an investigation individually and collaboratively to produce data that can serve as the basis for evidence that a changing magnetic field can produce an electric current.
- In experimental design, decide on the types, amounts, and accuracy of data

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

needed to produce reliable measurements, consider limitations on the precision of the data, and refine the design accordingly.

- Collect empirical evidence to support the claim that an electric current can produce a magnetic field.
- Collect empirical evidence to support the claim that a changing magnetic field can produce an electric current.

Driving question 2
How do the forces between objects and the energy of objects change when interacting through electric or magnetic fields?

Concepts

- When two objects interacting through a field change relative position, the energy stored in the field is changed.
- Cause-and-effect relationships between electrical and magnetic fields can be predicted through an understanding of inter- and intra-molecular forces (protons and electrons).

Practices

- Develop and use an evidence-based 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.
- Suggest and predict cause-and-effect relationships for two objects interacting through electric or magnetic fields.

Integration of content, practices, and crosscutting concepts

In order to build an understanding of forces at a distance and the transfer of energy through space, students should examine the relationships between flowing current and magnetic fields. Students should know that forces at a distance are explained by fields (gravitational, electric, and magnetic). These fields permeate space and can transfer energy through space.

Students should plan and carry out investigations to explore the relationships between electrical currents and magnetic fields. In their experimental design, students should decide on the types, amount, and accuracy of the data needed to produce reliable measurements, and they should consider limitations on the precision of the data and refine the design accordingly. Examples of investigations students might plan and carry out include:

- Students can map the magnetic field around a bar magnet with a compass or iron filings. Students should observe how distance from the magnet affects the field lines. They should also observe the directionality of the field lines.
- Students can deflect a compass needle with a current0carrying wire. Students might analyze how distance, current strength, and current direction affect the compass needle.
- Students can put a bar magnet through a solenoid and measuring the current in the wire. Students could also experiment with the number of loops, radius of the coil, gauge of wire, or length of the coil.
- Students can design and build a motor or generator. They might also observe a premade toy motor.
- Students can create a basic electromagnet by wrapping an iron nail in coiled wire and connecting the ends of the wire to a battery. Students could explore how changing the number of coils, length of the nail, polarity of the nail, or thickness of the nail affects the magnetic field. This will allow students to

see how a magnetic field can be measured by how many washers/paperclips the electromagnet can pick up.

- Students can build a basic battery with lemon juice, pennies, sand paper, and construction paper and use it to power an LED bulb. Students should understand that "electrical energy" may mean energy stored in a battery or energy transmitted by electric currents.
- Students should investigate and construct a simple mag-lev train and explore what variables (mass, magnetic field strength, etc.) affect the speed and running efficiency of the train.
- Using field-mapping kits with silver oxide pens and conductive gridded paper, students could map electromagnetic fields and examine any change in electrical potential energy.

Experimental evidence should allow students to support claims about how an electric current can produce a magnetic field, and how a changing magnetic field can produce an electric current. Claims should be supported and modeled mathematically when appropriate. Students should choose and interpret units consistently and organize and analyze data in graphs.

Students might also conduct short or more sustained research projects around the concepts of electric current and magnetic fields. They should collect relevant data from a broad spectrum of sources, examine adequate evidence, and construct rigorous explanations for how electric currents produce magnetic fields and how changing magnetic fields can produce electric currents.

Students should be able to develop descriptive (and in some cases quantitative) models, based on the evidence from their investigations 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. This could include using Coulomb's law from Unit 2 to mathematically explain some observed phenomena. Students should have an understanding of what happens when two charges of opposite polarity are near each other. Students should be able to predict cause-and-effect relationships for two objects interacting through electric or magnetic fields. Student models might be mathematical models, drawings, diagrams, or text.

Students should examine relevant text about objects interacting through electric or magnetic fields, draw evidence, assess strengths and limitations of sources, and integrate information into written explanations (models). Students might use digital media in presentations of their models to enhance understanding. This might include textual, graphical, audio, visual, and interactive elements.

Depending on the sequence of courses, students may or may not have an understanding of the structure of the atom. This concept is covered in the chemistry course. Appropriate descriptions about electricity and the flow of electrons should be provided based on students' level of understanding. Teachers might draw an analogy between thermal conductivity and electrical conductivity.

It is important to note that this unit does not require the teaching of simple electrical circuits, Ohm's law, the right-hand rule, or Maxwell's equations. For enrichment, the instructor might, at his or her discretion, introduce these concepts through the analogy of water flowing through a pipe. This unit does not address dipoles, directionality of magnetic fields, and the causes for magnetism in certain substances. The unit focuses on a conceptual overview of electricity and magnetism.

Integration of DCI from prior units within this grade level

Students will build on their previous experiences with Coulomb's law and Newton's laws regarding forces as they develop an understanding of relationships between electric and magnetic fields, and how objects interact with each other and with electric and magnetic fields. Students have an understanding of how gravitational forces at a distance are explained by fields, and they have previously looked at energy transfer through space.

Integration of mathematics and/or English language arts/literacy

Mathematics

- Use units as a way to understand the claim that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current; choose and interpret units consistently in formulas representing the production of a magnetic field from an electric current and the production of an electric current from a changing magnetic field; choose and interpret the scale and origin in graphs and data displays representing magnetic fields and electric currents.
- Define appropriate quantities for the purpose of descriptive modeling of the production of a magnetic field from an electric current and the production of an electric current from a changing magnetic field.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities of the production of a magnetic field from an electric current and the production of an electric current from a changing magnetic field.
- Represent symbolically two objects interacting through electric or magnetic fields, the forces between objects, the changes in energy of the objects due to the interaction, and manipulate the representing symbols. Make sense of quantities and relationships between two objects interacting through electric or magnetic fields, the forces between objects, the changes in energy of the objects due to the interaction.
- Use a mathematical 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. Identify important quantities representing two objects interacting through electric or magnetic fields, the forces between objects, and the changes in energy of the objects due to the interaction, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

English language arts/literacy

- Conduct short as well as more sustained research projects to support the claim that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
- Collect relevant data from a broad spectrum of sources about the claim that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current, and assess the strengths and limitations of each source.
- Collect and examine adequate empirical evidence to construct a rigorous explanation for the claim that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
- Conduct short as well as more sustained research projects to determine the forces between objects and the changes in energy of the objects as they interact through electric or magnetic fields; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the interaction of two objects through electric or magnetic fields, demonstrating understanding of the interaction of two objects through electric or magnetic fields.
- Gather relevant information on the interaction of two objects through electric or magnetic fields from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the development of a model to illustrate the forces between objects and the changes in energy of the objects as they interact through electric or magnetic fields; integrate information into text describing the interaction of two objects through electric or

magnetic fields selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

- Draw evidence from informational texts to support analysis, reflection, and research about two objects interacting through electric or magnetic fields and the forces between objects and the changes in energy of the objects due to the interaction.
- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to model two objects interacting through electric or magnetic fields, and illustrate the forces between objects and the changes in energy of the objects due to the interaction to enhance understanding of findings, reasoning, and evidence and to add interest.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Physical science

- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects.
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.
- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved even as, within the system, energy is continually transferred from one object to another and between its various possible forms.
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.
- Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.
- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.
- Photoelectric materials emit electrons when they absorb light of a high enough frequency.

Earth and space science

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.
- Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, and a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior.
- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output, Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long term tectonic cycles.
- Resource availability has guided the development of human society.
- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.

Number of Instructional Days

Recommended number of instructional days: 12 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were consulted during the writing of this unit:

- NGSS Appendices L and M
- A Framework for K-12 Science Education
- Common Core State Standards for Mathematics and Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects
- Next Generation Science Standards, www.nextgenscience.org/next-generation-science-standards
- The Physics Classroom, www.physicsclassroom.com/
- PhET Interactive Simulations, https://phet.colorado.edu/en/simulations/category/physics
- PASCO, www.pasco.com/prodCatalog/PK/PK-9023_field-mapper-kit/