

## HIGH SCHOOL PHYSICS: ELECTROMAGNETISM

### Standards Bundle

*Standards are listed within the bundle. Bundles are created with potential instructional use in mind, based upon the potential for related phenomena that can be used throughout a unit.*

HS-PS2-4 (a) Use mathematical representations of Newton's Law of Gravitation to describe and predict a gravitational force between objects. (b) Use mathematical representations of Coulomb's Law to describe and predict electrostatic forces between objects. (SEP:5; DCI: PS2.B; CCC: Patterns) **[Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.]** **[Assessment Boundary: Assessment is limited to systems with two objects.]**

HS-PS2-5 Plan and carry out 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. (SEP:3; DCI: PS2.B, PS3.A; CCC: Cause/Effect) **[Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]**

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. (SEP:2; DCI: PS3.C; CCC: Cause/Effect) **[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.]**

### Content Overview

*This section provides a generic overview of the content or disciplinary core ideas as an entry point to the standards.*

Newton's Law of Gravitation and Coulomb's Law describe and predict the gravitational and electrostatic forces between objects. Forces at a distance are explained by fields that can transfer energy and can be described in terms of the arrangement and properties of the interacting objects and the distance between them. These forces can be described both quantitatively and conceptually. The forces can be used to describe the relationship between electrical and magnetic fields.

Investigations can be carried out to show the relationship between changing magnetic fields and the production of an electric current. Models can also be developed to illustrate the forces and changes in energy because of their interactions. All these relationships, investigations, and models are limited to two object systems.

### Phenomena

*Phenomena can be used at varying levels of instruction. One could be used to anchor an entire unit, while another might be more supplemental for anchoring just a unit. Please remember that phenomena should allow students to engage in the SEP and use the CCC/DCI to understand and explain the phenomenon.*

- As a child you remember a balloon being rubbed on your head and being stuck on the ceiling. The balloon defied the force of gravity and stuck there on the ceiling. A force greater than gravity kept it there.
- Iron filings are sprinkled on a clear sheet of acetate. A bar magnet is placed beneath the acetate sheet and the iron filings form a pattern.
- While putting away leftovers from your family supper, you notice that the saran wrap keeps sticking to your hand for no apparent reason.
- A local newspaper headline talks about a grain bin explosion and warns about static electricity.
- During a tour of a manufacturing plant floor in tech class, students had to put special strips of material on their shoes before walking on the plant floor.

### Storyline

*This section aims to decode not only the DCI connections but also the SEP and CCC in a detailed account of how they possibly fit together in a progression for student learning, including both rationale and context for the bundle.*

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p><b>Using Mathematics and Computational Thinking</b></p> <ul style="list-style-type: none"> <li>● Use mathematical representations of phenomena to describe explanations.</li> </ul> <p><b>Planning and Carrying Out Investigations</b></p> <ul style="list-style-type: none"> <li>● 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.</li> </ul> <p><b>Developing and Using Models</b></p> <ul style="list-style-type: none"> <li>● Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.</li> </ul>	<p><b>PS2.B Types of Interactions</b></p> <ul style="list-style-type: none"> <li>● 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.</li> <li>● 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.</li> </ul> <p><b>PS3.A: Definitions of Energy</b></p> <ul style="list-style-type: none"> <li>● “Electrical energy” may mean energy stored in a battery or energy transmitted by electric currents. <i>(Secondary)</i></li> </ul> <p><b>PS3.C: Relationship Between Energy and Forces</b></p> <ul style="list-style-type: none"> <li>● When two objects interacting through a field change relative position, the energy stored in the field is changed.</li> </ul>	<p><b>Patterns</b></p> <ul style="list-style-type: none"> <li>● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.</li> </ul> <p><b>Cause and Effect</b></p> <ul style="list-style-type: none"> <li>● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.</li> <li>● 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.</li> </ul>

As forces are observed at the macroscopic level, they can be explained by fields such as gravitational, electric, or magnetic fields. When objects interact in a system, energy is conserved and can be transferred between objects through the interaction of these fields. To provide evidence that these two items are directly related, investigations can be planned and conducted to observe the relationship between the strength of electric current and the strength of a magnetic field induced in an electromagnet, considering the possible confounding variables, and evaluating the design of their electromagnet. Inversely, evidence can be used to show that electric currents can be induced by changing magnetic fields. Magnetic fields can apply a force- through the movement of charged particles (i.e., at the most basic level electrons and protons)- that can permeate through space and transfer energy. An explanation can be constructed using a model about how this relationship between electric current and magnetic field functions.

Mathematical models following Newton's law of universal gravitation and Coulomb's law can be used to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance can be explained through gravitational, electric, and magnetic fields that permeate space and transfer energy through space. Magnets or electric currents can cause magnetic fields. Electric charges or changing magnetic fields cause electric fields.

Cause and effect relationships exist as objects and fields interact at varying scales. For example, magnets apply forces to objects, causing them to accelerate, which requires an energy input. Planning and carrying out investigations can collect empirical data about the relationship between force, mass, and acceleration. Analyzing the data from these investigations allows the discovery of patterns that help define the relationship between the force, mass, and acceleration of an object. As forces are observed at the macroscopic level, they can be explained by fields such as gravitational, electric, or magnetic.

When objects interact in a system, energy is conserved and can be transferred between objects through the interaction of these fields. To provide evidence that these two items are directly related, investigations can be planned and carried out to observe the relationship between the strength of electric current and the strength of a magnetic field induced in an electromagnet, considering the possible confounding variables, and evaluating the design of their electromagnet. Inversely investigations should also be able to explain, using evidence, that electric currents can be induced by changing magnetic fields. Magnetic fields can apply a force- through the movement of charged particles (i.e., at the most basic level electrons and protons)- that can permeate through space and can transfer energy. Explanation using a model can be developed about how this relationship between electric current and magnetic field functions.

### **Formative Assessment**

*Formative assessment is crucial because all learners benefit from timely and focused feedback from others. It promotes self-reflection, self-explanation, and social learning. It can also make learning more relevant. Each of the questions below might be used throughout the formative assessment process. Specific prompts may focus on individual practices, core ideas, or crosscutting concepts, but, together, the components need to support inferences about students' three-dimensional science learning as described in a given bundle, standard, or lesson-level performance expectation.*

### **SEP Using Mathematics and Computational Thinking**

- Use the given mathematical representation to identify and describe the gravitational attraction between two objects as the product of their masses divided by the separation distance squared where a negative force is understood to be attractive.
- Use the given mathematical representation to identify and describe the electrostatic force between two objects as the product of their charges divided by the separation distance squared where the negative force is understood to be attractive.
- Use a mathematical representation to predict the gravitational force between objects or the electrostatic force between charged objects.
- Describe the ratio between gravitational and electric forces between objects with a given charge that is independent of distance.
- Describe the mathematical representation of the gravitational field that predicts the attractive force because mass is always positive.
- Describe the mathematical representation of the electric field that predicts both attraction and repulsion because electric charge can be either positive or negative.
- Use the given mathematical formulas for the forces as evidence to describe that the charge in the energy of objects interacting through electric or gravitational forces depends on the distance between the objects.

### **SEP Planning and Carrying Out Investigations**

- Describe the phenomenon under investigation of an electric current causing a magnetic field and a changing magnetic field causing an electric current.
- Develop an investigation plan that will collect evidence from the data about an observable effect of a magnetic field that is uniquely related to the presence of an electric current in the circuit, and an electric current in the circuit that is uniquely related to the presence of a changing magnetic field near the circuit.
- Plan an investigation that will include the use of an electric circuit through which electric current can flow, a source of electrical energy that can be placed in the circuit, the shape and orientation of the wire, types, and positions of detectors, a means to measure electric current, a means to measure the presence of a local magnetic field, a means to change the magnetic field in a nearby circuit, and a means to measure when the magnetic field is changing and then evaluate the investigation, including an evaluation of the accuracy and precision of the data collected, as well as limitations of the investigation; and if necessary refine the investigation plan to produce more accurate, precise, and useful data.

### **SEP Developing and Using Models**

- Use a model to determine whether the energy stored in the field increased, decreased, or remained the same when the objects interacted.
- Develop a model and identify and describe the relevant components to illustrate the forces and changes in energy involved when two objects interact, including the two objects in the system, their initial positions and velocities (limited to one dimension), the nature of the interaction (electric or magnetic) between the two objects, the relative magnitude and the direction of the net force on each of the objects, and the representation of a field as a quantity that has a magnitude and direction at all points in space which contain energy.
- Describe using the model, the relationship between components, including the change in the energy of the objects, given the initial and final positions and velocities of the objects.
- Describe using the model, the relationship between components, including the change in the energy of the objects, given the initial and final positions and velocities of the objects.

- Use the model to determine the energy stored in the field when the objects interacted.

### CCC Patterns

- What is the relationship between the gravitational attraction between two objects?
- What is the relationship between the electrostatic force between two objects?
- What is the ratio between gravitational and electric forces between objects with a given charge and mass?

### CCC Cause and Effect

- What does an electric current change? What does a changing magnetic field cause?
- How can a model be used to determine the effect on the energy stored in the field when the objects interact?
- How can the change in the energy of the objects be determined, given the initial and final positions and velocities of the objects?

### Performance Outcomes

*These are statements of how students use knowledge and are similar to the standards in how they blend DCI, SEP, and CCC, but at a smaller grain size. These are potential outcomes for instruction as it plays out in lessons and activities in the classroom. It is important to also think of these as smaller outcomes that build toward the larger goal of mastering the standards.*

- **Using the given mathematical representations, identify and describe** *the patterns between the gravitational attraction between two objects as the product of their masses divided by the separation distance squared where a negative force is understood to be attractive.*
- **Using the given mathematical representations, identify and describe** *the patterns between the electrostatic force between two objects as the product of their charges divided by the separation distance squared where the negative force is understood to be attractive.*
- **Use mathematical representations to predict** *the patterns of the gravitational force between objects or the electrostatic force between charged objects.*
- **Based mathematical models describe** *the ratio between gravitational and electric forces between objects with a given charge and mass as a pattern that is independent of distance.*
- **Describe that the mathematical representation of the gravitational field only predicts** *the pattern of attractive force because mass is always positive, however, the mathematical representation of the electric field predicts the pattern of both attraction and repulsion because electric charge can be either positive or negative.*
- **Use the given mathematical formulas** *for the forces as evidence to describe that the change in the energy of objects interacting through electric or gravitational forces depends on the distance between the objects and can be seen as a pattern.*
- **Describe the phenomenon under investigation which includes the following data:** *an electric current causes a magnetic field, and a changing magnetic field causes an electric current.*
- **Develop an investigation plan and describe** *the cause and effect shown in the data that will be collected and the evidence to be derived from the data about an observable effect of a magnetic field that is uniquely related to the presence of an electric current in the circuit, and an electric current in the circuit that is uniquely related to the presence of a changing magnetic field near the circuit and describe why these effects must be causal and not correlational, citing specific cause and effect relationships.*

- **Plan an investigation that will include the use of** an electric circuit through which electric current can flow, a source of electrical energy that can be placed in the circuit, the shape and orientation of the wire, types, and positions of detectors, a means to measure electric current, a means to measure the presence of a local magnetic field, a means to change the magnetic field in a nearby circuit, and a means to measure when the magnetic field is changing to look at *the cause and effect between the variables.*
- **Evaluate their investigation, including an evaluation of the accuracy and precision of the data collected, as well as limitations of the investigation; and the ability of the data to provide the evidence of** *cause and effect required* **and if necessary refine the investigation plan to produce more accurate, precise, and useful data** such that the measurements or indicators of the presence of an electric current in the circuit and a magnetic field near the circuit can provide the required evidence.
- **Develop a model and identify and describe** *the cause and effects* of the relevant components to illustrate the forces and changes in energy involved when two objects interact, including the two objects in the system, their initial positions, and velocities (limited to one dimension), the nature of the interaction (electric or magnetic) between the two objects, the relative magnitude and the direction of the net force on each of the objects, and the representation of a field as a quantity that has a magnitude and direction at all points in space which contain energy.
- **Describe using the model,** *the cause-and-effect relationship* between components, including the change in the energy of the objects, given the initial and final positions and velocities of the objects.
- **Use the model to determine** *the effect on the energy stored in the field when the objects interacted.*
- **Use the model to support** *the cause and effect claim that the change in the energy stored in the field (which is qualitatively determined to be either positive, negative, or zero) is consistent with the change in energy of the objects.*
- **Use the model, to describe** *the cause-and-effect relationships* on a qualitative level between forces produced by electric or magnetic fields and the change of energy of the objects in the system.