

PhET and NGSS Fields

Part A: Gather and Filter information from NGSS and PhET Interactive Simulations

Step 1: Select PEs and PhET Simulation(s) that work together.

- a. *Select PEs and Identify the associated Clarification Statements and Assessment Boundaries.*
- b. *Evaluate PhET sims for alignment with PEs, Clarifications, Boundaries.*

HS PS2-4

Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. HS-PS2-4

Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.

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. HS-PS2-5

Assessment Boundary: Assessment is limited to systems with two objects.

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. HS-PS3-5

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.

HS PS3-2

Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects) HS-PS3-2

Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.

PhET simulations used in this lesson (link to [others](#) that were examined and not used)

Sim Name	Brief Summary	Main Topics	Sample Learning Goals PhET
Electric Field Hockey	Students position charges (source of field) on screen to direct motion of puck (test charge). Field lines can be seen or hidden.	Electricity, Electric Charges, Electric Field	Determine the variables that affect how charged bodies interact. Predict how charged bodies will interact. Describe the strength and direction of the electric field around a charged body. Use free-body diagrams and vector addition to help explain the interactions.
Magnets and Electromagnet	Shows mag field of bar magnet in background (optional) and with compass. Overlays Earth outline on bar magnet.	Magnetic Field, Magnets, Electromagnet	Predict the direction of the magnet field for different locations around a bar magnet and electromagnet Compare and contrast bar magnets and electromagnets Identify the characteristics of electromagnets that are variable and what effects each variable has on the magnetic field's strength and direction Relate magnetic field strength to distance quantitatively and qualitatively

Step 2: Collect and Filter NGSS specifics for lesson.

- a. Identify the three dimensions that are coded to the PEs.
- b. ~~Use DCI grade band progressions and/or Appendix E for previous and future grades. (This step is below)~~
- c. Select additional Science and Engineering Practices that support your chosen DCIs and CCs.
- d. ~~Select related Common Core Mathematics Standards (CCSS-M) and Common Core Literacy Standards (CCSS-L) related to the PE's selected: (This step is below)~~

DCIs

PS2.B Types of Interactions

- 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. (HS-PS2-4)
- 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-PS2-4), (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)

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)

PS3.A: Definitions of Energy

- 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. (HS-PS3-1), (HS-PS3-2)
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2), (HS-PS3-3)
- 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. (HS-PS3-2)

Practices

Practice: Planning and Carrying Out Investigations

- 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)

Practice: Asking Questions and Defining Problems (additional practices)

- Ask questions that require sufficient and appropriate empirical evidence to answer.
- Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships.
- Evaluate a question to determine if it is testable and relevant.
- Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory.

Practice: Develop and use Models (additional practices, also coded to PS3)

- Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS3-2), (HS-PS3-5)
- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
- Use a model to provide mechanistic accounts of phenomena.

Engaging in Argument from Evidence

- Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.
- Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining what additional information is required to resolve contradictions.
- Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.
- Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge, and student-generated evidence.

Constructing Explanations (and Designing Solutions)

- Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.

- Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

CCs

CC Patterns

- 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.

CC 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)
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2-1), (HS-PS2-5)

CC Energy and Matter

- Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. (HS-PS3-2)

b. Use DCI grade band progressions and/or Appendix E for previous and future grades.

Gradeband Endpoints (6-8)

- 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 can be mapped by their effect on a test object (a charged object, or a ball, respectively).

d. Select related Common Core Mathematics Standards (CCSS-M) and Common Core Literacy Standards (CCSS-L) related to the PE's selected.

ELA/Literacy

- WHST.11-12.7 - 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-PS2-2), (HS-PS2-5)

Mathematics

- MP.2 - Reason abstractly and quantitatively. (HS-PS2-1), (HS-PS2-2), (HS-PS2-4)

Part B: Plan your lesson using Part A and PhET’s teacher tools.

Step 3: Refine lesson focus

a. Break the DCI into lesson segments

Table 3a: DCI Analysis for grade level

DCI code(s)	Previous Segment(s)	Target Segment(s)	Future Segment(s)
PS2.B	<p>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. (HS-PS2-4)</p> <p>Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.</p>	<p>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. (HS-PS2-4)</p> <p>Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.</p>	<p>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. (HS-PS2-4)</p> <p>Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.</p>
PS2.B	<p>Forces at a distance are explained by fields (gravitational, electric, and magnetic) (Middle School) 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-PS2-4), (HS-PS2-5)</p>	<p>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-PS2-4), (HS-PS2-5)</p>	<p>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-PS2-4), (HS-PS2-5)</p>
PS3.A	<p>“Electrical energy” may mean energy stored in a battery or energy transmitted by electric currents. (secondary to HS-PS2-5)</p>	<p>“Electrical energy” may mean energy stored in a battery or energy transmitted by electric currents. (secondary to HS-PS2-5)</p>	<p>“Electrical energy” may mean energy stored in a battery or energy transmitted by electric currents. (secondary to HS-PS2-5)</p>
PS3.C	<p>When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5)</p>	<p>When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5)</p>	<p>When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5)</p>
PS3.A last part	<p>In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This</p>	<p>In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This</p>	<p>In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last</p>

	last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2)	last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2)	concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2)
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b. Blend the Practices, DCI Target Segments, and CCs into lesson-specific PEs and sequence the lesson progression.

Table 3b: Develop Lesson Level PEs

Practices	DCI Target Segment(s)	CCs	Lesson-specific PEs	Learning Ideas
<p>Asking Questions and Defining Problems Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships.</p> <p>Evaluate a question to determine if it is testable and relevant. Ask questions that can be investigated within the scope of the school laboratory,</p> <p>frame a hypothesis based on a model or theory.</p> <p>Constructing Explanations Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.</p> <p>Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.</p> <p>Develop and use a model based on evidence to illustrate the relationships between</p>	<p>Part A Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. (HS-PS2-4), (HS-PS2-5)</p>	<p>Cause and Effect</p>	<p>Ask and evaluate clarifying questions about “action at a distance”. (That is, how objects can apply forces to one another when they do not even touch.)</p> <p>Evaluate questions (testable, relevant, and can be investigated at school or with sim).</p> <p>Frame and evaluate a hypothesis about the mechanism for “action at a distance” from questions and explorations.</p> <p>Use a model to make and illustrate qualitative claims regarding the relationship between force and field.</p>	<p>Teacher introduces question about action at a distance. Students brainstorm questions. Gather questions for whole class to see. Students explore E-field sim. Class discussion of exploration including introduction of terminology and evaluate questions for testability with sim. Students frame a hypothesis about the relationship between force and field. Class consensus on hypothesis. Use E-field hockey sim to test and modify hypothesis. Regroup and retest as needed.</p>

<p>systems or between components of a system.</p>				
<p>Develop and use Models Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.</p> <p>Use a model to provide mechanistic accounts of phenomena.</p> <p>Engaging in Argument from Evidence Make and defend a claim based on evidence about the natural world</p>	<p>Part B (Electric and gravitational) models describe and predict the effects of gravitational and electrostatic forces between distant objects. Emphasis is on conceptual descriptions of gravitational and electric fields. (HS-PS2-4)</p>	<p>Patterns Cause and Effect</p>	<p>Make, explain, and defend drawings or other models of E-field around one or two charges, B-field around a magnet, and gravitational field around a planet.</p> <p>Predict the effects of forces on charged particles or masses in the fields and what happens to the forces when the fields change. (Demonstrate predictions on drawings)</p> <p>Make and test hypotheses to specify what happens to field strength when mass/charge/magnetic strength of the cause and of the victim are varied. (Field does not change when victim properties are changed).</p>	<p>Magnet and Electromagnet</p> <p>Magnet tab - Shape and strength of field around a static bar magnet.</p> <p>Electromagnet tab - change B-field strength. Include extension - students propose what is needed for E-field and grav field strengths to change. Doesn't work: E-field lab - put multiple like charges together.</p>
<p>Engaging in Argument from Evidence Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments. Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining what additional information is required to resolve contradictions.</p>	<p>Part C When two objects interacting through field change relative position, the energy stored in the field is changed. (HS-PS3-5)</p> <p>In some cases the relative position energy can be thought of as stored in fields (with mediate interactions between particles). (HS-PS3-2)</p>	<p>Energy and Matter</p>	<p>Investigate, draw conclusions, and defend conclusions about energy and fields (hopefully come up with energy due to position can be thought of as stored in fields, and energy stored in fields changes when two interacting objects in the field change relative position)</p>	<p>Optional Electric Field Hockey and Magnet and Electromagnet simulations, drawing field lines. Consider changes in energy.</p>

<p>Planning and Carrying Out Investigations Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated.</p>				
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Step 4: Determine evidence for formative and summative assessment

Table 4: Assessment Evidence (No cues/prompts listed because this was done before that column was added.)

Lesson Segment	Lesson-specific PEs	Specific Performance Evidence	PhET Learning Objectives (Student-Friendly Language)
<p>Part A Field and Force Relationship with Asking & Evaluating Questions</p>	<p>Ask and evaluate clarifying questions about fields and forces. how forces can be applied at a distance.</p> <p>Evaluate questions (testable, relevant, and can be investigated at school or with sim).</p> <p>Frame and evaluate a hypothesis about the mechanism for “action at a distance” from questions and explorations.</p> <p>Use a model to make and illustrate qualitative claims regarding the relationship between force and field.</p>	<p>The question: What is the mechanism for action at a distance? (How can objects apply forces to one another, even when they are not touching?)</p> <p>Write 2 or 3 scientific questions that are “testable” with the simulation, and explain how to would use the sim to test/investigate them.</p> <p>Trade and grade - use the sim and evaluate someone else’s questions. Write 2 or 3 suggestions or clarifying comments about their list of questions</p> <p>Frame a hypothesis reflecting our scientific understanding of how forces can be applied when objects are at some distance from one another.</p>	<p>Electric Field Hockey Explain how objects apply forces to one another, even when the objects do not touch. Justify your explanation with diagrams (screenshots) and words.</p> <p>Write 2 or 3 scientific questions that are “testable” with the simulation.</p> <p>Evaluate another person’s questions to determine if they are testable, relevant, and can be investigated in the classroom or with the simulation.</p>
<p>Part B Relate E and B fields to grav fields. Draw and interpret field lines.</p>	<p>Make, explain, and defend drawings or other models of E-field around one or two charges, B-field around a magnet, and gravitational field around a planet.</p> <p>Use drawings to predict the effects of forces on charged particles or masses in the fields and what</p>	<p>The question: Can fields affect people? Do people have fields?</p> <p>Draw and explain the gravitational field, electric field, or magnetic field around a planet, one or two charges, and a magnet.</p> <p>Draw/discuss your prediction of the direction and relative magnitude of force on positive and</p>	<p>Electric Field Hockey and Magnets and Electromagnets Write a hypothesis about each item below, and devise a way to test each hypothesis.</p> <ul style="list-style-type: none"> • How field strength varies with source strength. • How field strength varies due to the test object.

<p>Differentiate between the cause and the effect of a field.</p>	<p>happens to the forces when the fields change.</p> <p>Make and test a hypothesis to specify what happens to field strength when mass/charge/magnetic strength of the cause and of the victim are varied. (Field does not change when victim properties are changed).</p>	<p>negative charges, masses, or the N pole of a compass at various positions in a field, given a drawing of the field (or drawing from above).</p> <p>Write a hypothesis and devise a way to use the sim to test it, about how field strength varies with mass, charge, or magnet strength of victim and cause.</p> <p>Define “field”.</p> <p>Formative assessment: Consider the gravitational pull of the Earth on a mass. How is the gravitational force different from electric or magnetic forces? (only pulls, no push). Draw the grav field around the Earth.</p> <p>Formative assessment: Magnet and Compass Sim - show field, turn on Earth view. List several ways this field is different than and similar to Earth’s gravitational field (Direction of field shows push AND pull, grav only pulls, this field affects a compass, direction is not inward.)</p>	<p>Draw and describe the electric field around one or two charges, and the magnetic field around a magnet.</p> <p>Draw the force vector on a test object in a field, given a drawing of a field.</p> <p>Extend your understanding of electric and magnetic fields to gravitational fields.</p>
<p>Part C</p> <p>Investigate and present conclusions about energy and fields.</p>	<p>Investigate, draw conclusions, and defend conclusions about energy and fields including that energy due to position can be thought of as stored in fields, and that the energy stored in fields changes when two interacting objects in the field change relative position.</p>	<p>The question: Two like charges are placed close together. They gain kinetic energy as they fly apart. Where did the energy come from?</p> <p>Investigate and draw conclusions the relationship between the changes in kinetic and potential energy due to relative positions of an object in a field.</p> <p>Express and defend conclusions using conservation of energy concepts with words, drawings, and screenshots from the simulation</p>	<p>Use the simulation to investigate changes in the kinetic energy of an object in a field.</p> <p>Connect the concept of conservation of energy to the kinetic and potential energy of an object in a field.</p> <p>Use screenshots, drawings, and words to defend, and communicate conclusions about potential energy and fields.</p>

Step 5: Develop a Big Idea and Lesson Plans

(See Teacher Guides and Student Sheets for detailed lesson plans)

Big Ideas (these were developed in conjunction with the lesson, then added to table 4 to keep the thoughts together):

Part A: How can objects apply forces to one another, even when they are not touching? (What is the mechanism for action at a distance?)

Part B: Can fields affect people? Do people have fields?

Part C: Two like charges are placed close together. They gain kinetic energy as they fly apart. Where did the energy come from?

Step 6: Re-examine lesson

This lesson has not been done in the classroom yet.

Table 6 Lesson Review and Summary

Lesson Level Expectations	Assessment Evidence
<p>Part A. Ask and evaluate clarifying questions about fields and forces. how forces can be applied at a distance.</p> <p>Evaluate questions (testable, relevant, and can be investigated at school or with sim).</p> <p>Frame and evaluate a hypothesis about the mechanism for “action at a distance” from questions and explorations.</p> <p>Use a model to make and illustrate qualitative claims regarding the relationship between force and field.</p>	<p>Big Question: What is the mechanism for action at a distance? (How can objects apply forces to one another, even when they are not touching?)</p> <p>Write 2 or 3 scientific questions that are "testable" with the simulation, and explain how to would use the sim to test/investigate them.</p> <p>Trade and grade - use the sim and evaluate someone else’s questions. Write 2 or 3 suggestions or clarifying comments about their list of questions</p> <p>Frame a hypothesis reflecting our scientific understanding of how forces can be applied when objects are at some distance from one another.</p>
<p>Part B. Make, explain, and defend drawings or other models of E-field around one or two charges, B-field around a magnet, and gravitational field around a planet.</p> <p>Use drawings to predict the effects of forces on charged particles or masses in the fields and what happens to the forces when the fields change.</p> <p>Make and test a hypothesis to specify what happens to field strength when mass/charge/ magnetic strength of the cause and of the victim are varied. (Field does not change when victim properties are changed).</p>	<p>Big Question: Can fields affect people? Do people have fields?</p> <p>Draw and explain the gravitational field, electric field, or magnetic field around a planet, one or two charges, and a magnet.</p> <p>Draw/discuss your prediction of the direction and relative magnitude of force on positive and negative charges, masses, or the N pole of a compass at various positions in a field, given a drawing of the field (or drawing from above).</p> <p>Write a hypothesis and devise a way to use the sim to test it, about how field strength varies with mass, charge, or magnet strength of victim and cause.</p> <p>Define “field”.</p> <p>Formative assessment: Consider the gravitational pull of the Earth on a mass. How is the gravitational force different from electric or magnetic forces? (only pulls, no push). Draw the grav field around the Earth.</p> <p>Formative assessment: Magnet and Compass Sim - show field, turn on Earth view. List several ways this field is different than and similar to Earth’s gravitational field (Direction of field shows push AND pull, grav only pulls, this field affects a compass, direction is not inward.)</p>

Part C.

Investigate, draw conclusions, and defend conclusions about energy and fields including that energy due to position can be thought of as stored in fields, and that the energy stored in fields changes when two interacting objects in the field change relative position.

Big Question: Two like charges are placed close together. They gain kinetic energy as they fly apart. Where did the energy come from?

Investigate and draw conclusions the relationship between the changes in kinetic and potential energy due to relative positions of an object in a field.

Express and defend conclusions using conservation of energy concepts with words, drawings, and screenshots from the simulation

Extra Information about possible PhET sims (compiled in Part A step 1 at top of this document - put here for space reasons).

Radio Waves and EM Fields

Goal is simply radio waves.

Kathy and Carl W have a good activity to follow when planning lesson: [Radio waves and EM Fields Simulation HW](#).

Charges and Fields 2.04

Can be used to make Equipotential plots around charges. Show vector strength of field by a moveable charge, shows pattern of E-field vectors.

Main Topics

- Electric Field
- Voltage
- Equipotential

Sample Learning Goals

- Determine the variables that affect how charged bodies interact.
- Predict how charged bodies will interact.
- Describe the strength and direction of the electric field around a charged body.
- Use free-body diagrams and vector addition to help explain the interactions.

Electric Field of Dreams

Shows a region of space. Can add external field. Can add charged particles and their fields shows and charges are forced to move by the field. Can vary charge (incl +, -, 0 charge) and mass.

Main Topics

- Electricity
- Electric Charges
- Electric Field

Sample Learning Goals

- Explain the relation between the size and direction of the blue electric field lines to the sign and magnitude of the charge of a particle.

- Explain the interactions between two charged particles and explain why they move as they do.
- Explain what happens when you apply different external electric fields.

Radiating Charge - what happens to shape of field (in time) when charge moves around.

Main Topics

- Electromagnetic Radiation
- Dipole Radiation
- Electric Field
- Speed of Light

Sample Learning Goals

- How the radial field line density depends on the speed of a charge in linear motion (compression of field lines).
- How the anisotropy of the field pattern depends on sinusoidal vs. circular motion.
- How the applied force and motion are related in relativistic dynamics (constant force does not result in faster-than-light travel).
- How acceleration produces transverse fields, while constant velocity produces radial fields.
- For sinusoidal motion, which produces dipole radiation, the field lines evolve from radial and static-like nearby, to transverse and plane-wave-like far away.
- How sudden deceleration of a charge produces bremsstrahlung (braking) radiation.