Unit Summary
How can one explain and predict interactions between objects and within systems of objects?   In this unit of study, students plan and conduct investigations and apply scientific ideas to make sense of Newton's law of gravitation and Coulomb's Law. They apply these laws to describe and predict the gravitational and electrostatic forces between objects. The crosscutting concept of *patterns* is called out as an organizing concept for this disciplinary core idea. Students are expected to demonstrate proficiency in *planning and conducting investigations* and *applying scientific ideas* to demonstrate an understanding of core ideas.
Student Learning Objectives
Make predictions about the sign and relative quantity of net charge of objects or systems after various charging processes. (PS2.B)
Construct an explanation of a model of electric charge, and make a qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes. *[Clarification Statement: The focus is on the mechanisms that explain conductors and insulators.]* (PS2.B)
Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. *[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-PS2-4)**

Quick Links		

Part A:

- ✓ *Why are people on Earth stuck here while astronauts appear to be weightless?*
- ✓ *How does the weight (force of gravity) of an astronaut of a specific mass (100 kg including gear) change at specific distances from Earth as the shuttle flies toward the moon?*

Concepts	Formative Assessment
• Newton's Law of Universal Gravitation provides the mathematical models to describe and predict the effects of gravitational forces between distant objects. • Forces at a distance are explained by fields (gravitational) permeating space that can transfer energy through space. • 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 the gravitational force between objects.	*Students who understand the concepts are able to:* • Use mathematical representations of phenomena to describe or explain how gravitational force is proportional to mass and inversely proportional to distance squared. • Demonstrate how Newton's Law of Universal Gravitation provides explanations for observed scientific phenomena. • Observe patterns at different scales to provide evidence for gravitational forces between two objects in a system with two objects.

Part B: *How far away can my finger be from my sister or brother if I want to zap them with static electricity?*

Concepts	Formative Assessment
• Coulomb's Law provides the mathematical models to describe and predict the effects of electrostatic forces between distant objects. • Forces at a distance are explained by fields (electric and magnetic) that permeate space and can transfer energy through space. • Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. • 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 electrostatic attraction and repulsion.	*Students who understand the concepts are able to:* • Use mathematical representations of phenomena to describe or explain how electrostatic force is proportional to charge and inversely proportional to distance squared. • Use mathematical representations of Coulomb's Law to predict the electrostatic forces between two objects in systems with two objects. • Observe patterns at different scales to provide evidence for electrostatic forces between two objects in systems with two objects.

What it Looks Like in the Classroom
In this unit of study, students will use quantitative and conceptual descriptions of gravitational and electric fields in systems with two objects. Students should be able to symbolically represent and manipulate the variables (charge, distance, and force) in the law of universal gravitation. They should also be able to demonstrate that the units (Coulomb, meter, and Newton) for these quantities can be used to check their mathematical computations.   Students should be able to use the law of universal gravitation as a mathematical model to accurately describe and predict the effects of gravitational forces between distant objects. This should be done both qualitatively and quantitatively. In order to explain and predict interactions between objects and within systems of objects, students might be given data (e.g., mass, separation distance, radius of body, etc.) and asked to perform calculations to show how the force of gravity is dependent upon the mass of the bodies and the distance between two bodies. Students can also perform calculations to show how the acceleration due to gravity changes for different celestial bodies and is dependent upon the mass of the body and its radius. Students should examine data to observe patterns at different scales and to provide evidence for gravitational forces between two objects in a system with two objects. Data that students are given may include natural satellites, man-made satellites, planets, comets, and other astronomical objects. Students should also use the universal gravitation equation to verify the value of 9.8 m/s^2 as being the average acceleration due to gravity on Earth. In all calculations and data sets, students should choose and interpret units consistently in formulas and choose and interpret the scale and origin in graphs and data displays representing their findings. These experiences will allow students to observe and consequently provide evidence for gravitational forces between two objects in a system.   Universal Gravitation Equation $(F_{gravity} = \frac{Gm_1 m_2}{d^2}, where\ G = 6.673\ x\ 10^{-11}\ \frac{Nm^2}{kg^2})$ Students should be able to explain the effects of forces at a distance by fields of force. For example, place objects of different masses on a bed sheet (a thin rubber sheet would be ideal) and ask students to make observations. Students should note that lighter mass objects slide toward heavier mass objects. Students may also observe the effect that distance factor into how quickly objects slide. Analogies can be drawn between this demonstration and the gravitational field model. This model may also be used during the second half of the unit for Coulomb's Law and charge.   It will be important for students to recognize that different patterns may be observed at each of the scales at which a system is studied. These patterns can provide evidence for cause-and-effect relationships in explanations of gravitational forces between objects. For example, students might consider the following questions: Why are people on earth stuck here while astronauts appear to be weightless? How does the weight (i.e., force of gravity) of an astronaut of a specific mass (100 kg including gear) change at specific distances from Earth as the shuttle flies toward the moon? Students can make a data table to track the changes in weight, paying attention to appropriate quantities, units, relationships, and scales.   Students should be able to understand and manipulate the variables in Coulomb's Law symbolically. They should also be able to demonstrate that the units for these quantities can be used to check their mathematical computations. Students must be able to explain relationships, similarities, and differences between the law of universal gravitation and Coulomb's Law. For example, while both laws are inverse square laws, Coulomb's Law allows for repulsion forces.   Coulombs Law $(F = \frac{kQ_1 Q_2}{d^2}, where\ k\ is\ Coulomb's\ law\ constant)$ Students should be able to use Coulomb's Law to accurately observe, describe, predict, and provide evidence for the effects of electrostatic forces between two objects at varying distances. This should be done both qualitatively and quantitatively. Students should be able to explain observed phenomena in the context of Coulomb's Law. Students should also be able to explain the effects of forces at a distance by fields of force. Students must be able to demonstrate that Coulomb's

Law is a statement or description of the relationships among observable electrostatic phenomena.

Students need to recognize that different patterns may be observed at each of the scales at which a system is studied and these different patterns can provide evidence for causality in explanations of phenomena. Opportunities to explore Coulomb's Law through various electrostatic activities (charged balloons on strings, electroscopes, computer simulations (PhET), videos, etc.) will give students a qualitative understanding of distance and magnitude of charge between two objects. At this point, students need only have enough exposure to electrostatics to understand Coulomb' Law. Electricity and magnetism will be addressed in depth in the Electricity and Magnetism Unit.

Connecting Mathematics

Mathematics

- Use symbols to represent Newton's law of gravitation, Coulomb's Law, gravitational forces between two objects in a system, and electrostatic forces between two objects in a system and manipulate the representing symbols. Make sense of quantities and relationships to describe and predict the gravitational and electrostatic forces between two objects in a system.
- Use a mathematical model of Newton's law of gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between two objects in a system. Identify important quantities representing the gravitational and electrostatic forces between two objects in a system 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.
- Use units as a way to understand the gravitational and electrostatic forces between two objects in a system; choose and interpret units consistently in formulas representing Newton's law of gravitation, Coulomb's Law, gravitational forces between two objects in a system, and electrostatic forces between two objects in a system. Choose and interpret the scale and origin in graphs and data displays representing the gravitational and electrostatic forces between two objects in a system.
- Define appropriate quantities for the purpose of descriptive modeling of the gravitational and electrostatic forces between two objects in a system.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the gravitational and electrostatic forces between two objects in a system.
- Interpret expressions that represent quantities of the gravitational and electrostatic forces between two objects in a system in terms of their context.
- Choose and produce an equivalent form of an expression to reveal and explain properties of the gravitational and electrostatic forces between two objects in a system.

Modifications

Teacher Note: Teachers identify the modifications that they will use in the unit. The unneeded modifications can then be deleted from the list.

- Restructure lesson using UDL principals (http://www.cast.org/our-work/about-udl.html#.VXmoXcfD_UA)
- Structure lessons around questions that are authentic, relate to students' interests, social/family background and knowledge of their community.
- Provide students with multiple choices for how they can represent their understandings (e.g. multisensory techniques-auditory/visual aids; pictures, illustrations, graphs, charts, data tables, multimedia, modeling).
- Provide opportunities for students to connect with people of similar backgrounds (e.g. conversations via digital tool such as SKYPE, experts from the community helping with a project, journal articles, and biographies).
- Provide multiple grouping opportunities for students to share their ideas and to encourage work among various backgrounds and cultures (e.g. multiple representation and multimodal experiences).
- Engage students with a variety of Science and Engineering practices to provide students with multiple entry points and multiple ways to demonstrate their understandings.
- Use project-based science learning to connect science with observable phenomena.
- Structure the learning around explaining or solving a social or community-based issue.
- Provide ELL students with multiple literacy strategies.
- Collaborate with after-school programs or clubs to extend learning opportunities.

Research on Student Learning

Students may hold misconceptions about the magnitude of the earth's gravitational force. Even after a physics course, many high-school students believe that gravity increases with height above the earth's surface. Many high-school students are not sure whether the force of gravity would be greater on a lead ball than on a wooden ball of the same size. High-school students also have difficulty in conceptualizing gravitational forces as interactions. In particular, they have difficulty in understanding that the magnitudes of the gravitational forces that two objects of different mass exert on each other are equal. These difficulties persist even after specially designed instruction. (NSDL, 2015).

Prior Learning

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

Earth and space sciences

- 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 the sun's 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.

Connections to Other Courses

Physical science

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That a single quantity called energy exists 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.

Earth and space science

- The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.
- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.
- The Big Bang theory is supported by observations of distant galaxies receding from our own, by the measured composition of stars and nonstellar gases, and by the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe.
- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.
- Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from or collisions with other objects in the solar system.
- Continental rocks, which can be more than 4 billion years old, are generally much older than the rocks of the ocean floor, which are less than 200 million years old.
- Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in

the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history.

- The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. Water's physical and chemical properties include its exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks.
- 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.

Samples of Open Education Resources for this unit:

Note- *These are student sense-making experiences that can be used after being modified to be three-dimensional. Teachers need to set up a free account with Phet in order to use the online simulations (*https://phet.colorado.edu*).*

Gravity Force Lab: Visualize the gravitational force that two objects exert on each other. Adjust properties of the objects to see how changing the properties affect the gravitational attraction.

Graphical Relationships in Electric Fields**:** Activity uses the simulations to generate data to be analyzed. Allows for graphical analysis and equations related to voltage and Coulombs Law.

Electrostatics: Use a series of interactive models and games to explore electrostatics. Learn about the effects positive and negative charges have on one another, and investigate these effects further through games. Learn about Coulomb's law and the concept that both the distance between the charges and the difference in the charges affect the strength of the force. Explore polarization at an atomic level, and learn how a material that does not hold any net charge can be attracted to a charged object.

Appendix A: NGSS and Foundations for the Unit

The Student Learning Objectives 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
Using Mathematics and Computational Thinking Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Use mathematical representations of phenomena to describe explanations. (HS-PS2-4)	**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)	**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. (HS-PS2-4) - ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** • Theories and laws provide explanations in science. (HS-PS2-4) • Laws are statements or descriptions of the relationships among observable phenomena. (HS-PS2-4)

Embedded English Language Arts/Literacy and Mathematics

English Language Arts/Literacy	Mathematics
English Language Arts/Literacy **N/A**	*Mathematics* Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS2-4) **HSN.Q.A.3** Interpret expressions that represent a quantity in terms of its context. (HS-PS2-4) **HSA.SSE.A.1** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. (HS-PS2-4) **HSA.SSE.B.3** Reason abstractly and quantitatively. (HS-PS2-4) **MP.2** Model with mathematics. (HS-PS2-4) **MP.4** 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-PS2-4) **HSN.Q.A.1** Define appropriate quantities for the purpose of descriptive modeling. (HS-PS2-4) **HSN.Q.A.2**