Physics, Unit 2
Fundamental Forces

Overview

Unit abstract

In this unit of study, students will use Newton's law of gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. In the PS2 performance expectations, students are expected to demonstrate proficiency in planning and conducting investigations and applying scientific ideas to demonstrate an understanding of core ideas. The crosscutting concept of patterns is called out as an organizing concept for this disciplinary core idea.

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

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
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) ------------------------------------- ***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)	**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 other DCIs in this grade-band: **HS.PS3.A** (HS-PS2-4); **HS.ESS1.A** (HS-PS2-4); **HS.ESS1.B** (HS-PS2-4); **HS.ESS1.C** (HS-PS2-4); **HS.ESS2.C** (HS-PS2-4); **HS.ESS3.A** (HS-PS2-4)

Articulation to DCIs across grade-bands: **MS.PS2.B** (HS-PS2-4); **MS.ESS1.B** (HS-PS2-4)

Common Core State Standards Connections:

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-PS2-4)
MP.4	Model with mathematics. (HS-PS2-4)
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-PS2-4)

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

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

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 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.

Progression of current learning

Driving question 1

What is the relationship between gravitational force between objects, mass and distance?

Concepts

- 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.

Practices

- 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.

Driving question 2

What is the relationship among the electrostatic force between two objects, charge, and distance?

Concepts

- 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.

Practices

- 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.

Integration of content, practices, and crosscutting concepts

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, manmade satellites, planets, comets, and other astronomical objects. Students should also use the universal gravitation Equation ($F_{gravity} = \frac{Gm_1\,m_2}{d^2}, where\ G = 6.673\ x\ 10^{-11}\ \frac{Nm^2}{kg^2}$) 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.

Students should be able to explain the effects of forces at a distance by fields of force. For example, use a bed sheet (a thin rubber sheet would be ideal), place objects of different masses on it, 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 plays in 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 (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 ($F = \frac{kQ_1\,Q_2}{d^2}, where\ k\ is\ Coulomb's\ law\ constant$) 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.

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's Law. Electricity and magnetism will be addressed in depth in Unit 8, Electricity and Magnetism.

Integration of 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.

Connected learning

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

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.

Number of Instructional Days

Recommended number of instructional days: 15 (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:

- Next Generation Science Standards, including Appendices I, L, and M
- *A Framework for K–12 Science Education*
- Common Core State Standards Appendices (Mathematics and English Language Arts/Literacy)
- The Physics Classroom website
- PhET Interactive Simulations