# 08 Electric Charges, Fields, and Gauss's Law

Content Area: **Science**
Course(s): **AP Physics C**
Time Period: **Semester 1**
Length: **3 weeks**
Status: **Published**

## Standards

| | |
|---|---|
| HS-PS1-3 | Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. |
| | Planning and Carrying Out Investigations |
| PS1.A | Structure and Properties of Matter |
| PS2.B | Types of Interactions |
| | Patterns |
| HS-PS2-1 | Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. |
| 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. |
| | Using Mathematics and Computational Thinking |
| HS-PS2-6 | Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. |
| | Structure and Function |
| 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. |
| | Developing and Using Models |
| PS3.C | Relationship Between Energy and Forces |
| | Cause and Effect |

## AP Physics C Learning Objectives

**Note: Learning Objectives are taken verbatim from the AP Physics C - Mechanics Course and Exam Description. The verb "describe" could refer to a variety of different methods of expression (e.g. words, diagrams, graphs, mathematical expressions), as appropriate.**

Describe the electric force that results from the interactions between charged objects or systems.

Describe the electric and gravitational forces that result from interactions between charged objects with mass.

Describe the electric permittivity of a material or medium.

Describe the behavior of a system using conservation of energy.

Describe the electric field produced by a charged object or configuration of point charges.

Describe the electric field generated by charged conductors or insulators.

Describe the electric field resulting from a given charge distribution.

Describe the electric flux through an arbitrary area of geometric shape.

Describe the properties of a charge distribution by applying Gauss's Law.

## Enduring Understandings

Interactions produce changes in motion.

Forces characterize interactions between objects or systems.

Fields predict and describe interactions.

Objects with an electric charge will interact with each other by exerting forces on each other.

Objects with an electric charge will create an electric field.

There are laws that use symmetry and calculus to derive mathematical relationships that can be applied to physical systems containing electrostatic charge.

There are laws that use calculus and symmetry to derive mathematical relationships that can be applied to electrostatic-charge distributions.

## Essential Questions

Why does hair stand up after brushing it with a plastic comb?

How does a charged rubber rod bend a stream of water?

How might it be possible to get a balloon to stick to the wall?

Why don't cell phones work in concrete buildings?

Why can a bird land safely on a high voltage wire?

## Knowledge and Skills

**Topic 8.1 Electric Charge and Electric Force**

**Knowledge:**

- Charge is a fundamental property of all matter.
- Charge is a scalar quantity and is described as positive or negative.
- The magnitude of the charge of a single electron or proton, the elementary charge $e$, can be considered to be the smallest indivisible amount of charge.
- The charge of an electron is −e and the charge of a proton is +e, and a neutron has no electric charge.
- A point charge is a model in which the physical size of a charged object or system is negligible in the context of the situation being analyzed.
- Coulomb's law describes the electrostatic force between two charged objects as directly proportional to the magnitude of each of the charges and inversely proportional to the square of the distance between the objects.
- The direction of the electrostatic force depends on the signs of the charges of the interacting objects and is along the line of separation between the objects.
- Two objects with charges of the same sign exert repulsive forces on each other.
- Two objects with charges of opposite signs exert attractive forces on each other.
- Electric forces are responsible for some of the macroscopic properties of objects in everyday experiences. However, the large number of particle interactions that occur make it more convenient to treat everyday forces in terms of nonfundamental forces called contact forces, such as normal force, friction, and tension.
- Electrostatic forces can be attractive or repulsive, while gravitational forces are always attractive.
- For any two objects that have mass and electric charge, the magnitude of the gravitational force is usually much smaller than the magnitude of the electrostatic force.
- Gravitational forces dominate at larger scales even though they are weaker than electrostatic forces, because systems at large scales tend to be electrically neutral.
- Electric permittivity is a measurement of the degree to which a material or medium is polarized in the presence of an electric field.
- Electric polarization can be modeled as the induced rearrangement of electrons by an external electric field, resulting in a separation of positive and negative charges within a material or medium.
- Free space has a constant value of electric permittivity, $\varepsilon_0$, that appears in physical relationships.
- The permittivity of matter has a value different from that of free space that arises from the matter's composition and arrangement.
- In a given material, electric permittivity is determined by the ease with which electrons can change configurations within the material.
- Conductors are made from electrically conducting materials in which charge carriers move easily; insulators are made from electrically nonconducting materials in which charge carriers cannot move easily.

**Skills:**

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Calculate or estimate an unknown quantity with units from known quantities by selecting and following a logical computational pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

## Topic 8.2 Conservation of Electric Charge and the Process of Charging

**Knowledge:**

- The net charge or charge distribution of a system can change in response to the presence of, or changes in, the net charge or charge distribution of other systems.
- The net charge of a system can change due to friction or contact between systems.
- Induced charge separation occurs when the electrostatic force between two systems alters the distribution of charges within the systems, resulting in the polarization of one or both systems.
- Induced charge separation can occur in neutral systems.
- Any change to a system's net charge is due to a transfer of charge between the system and its surroundings.
- The charging of a system typically involves the transfer of electrons to and from the system.
- The net charge of a system will be constant unless there is a transfer of charge to or from the system.
- Grounding involves electrically connecting a charged object to a much larger and approximately neutral system (e.g., Earth).

**Skills:**

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

**Topic 8.3 Electric Fields**

**Knowledge:**

- Electric fields may originate from charged objects.
- The electric field at a given point is the ratio of the electric force exerted on a test charge at the point to the charge of the test charge.
- A test charge is a point charge of small enough magnitude such that its presence does not significantly affect an electric field in its vicinity.
- An electric field points away from isolated positive charges and toward isolated negative charges.
- The electric force exerted on a positive test charge by an electric field is in the same direction as the electric field.
- The electric field is a vector quantity and can be represented in space using vector field maps.
- The net electric field at a given location is the vector sum of individual electric fields created by nearby charged objects.
- Electric field maps use vectors to depict the magnitude and direction of the electric field at many locations within a given region.
- Electric field line diagrams are simplified models of electric field maps and can be used to determine the relative magnitude and direction of the electric field at any position in the diagram.
- While in electrostatic equilibrium, the excess charge of a conductor is distributed on the surface of the conductor, and the electric field within the conductor is zero.
- At the surface of a charged conductor, the electric field is perpendicular to the surface.
- The electric field outside an isolated sphere with spherically symmetric charge distribution is the same as the electric field due to a point charge with the same net charge as the sphere located at the center
- of the sphere.

While in electrostatic equilibrium, the excess charge of an insulator is distributed throughout the interior of the insulator as well as at the surface, and the electric field within the insulator may have a nonzero value.

**Skills:**

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

### Topic 8.4 Electric Fields of Charge Distributions

**Knowledge:**

- Expressions for the electric field of specified charge distributions can be found using integration and the principle of superposition.
- Symmetry considerations of certain charge distributions can simplify analysis of the electric field resulting from those charge distributions.

**Skills:**

- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

### Topic 8.5 Electric Flux

**Knowledge:**

- Flux describes the amount of a given quantity that passes through a given area.
- For an electric field $E$ that is constant across an area $A$, the electric flux through the area is defined as .
- The direction of the area vector is defined as perpendicular to the plane of the surface and outward from a closed surface.
- The sign of flux is given by the dot product of the electric field vector and the area vector.
- The total electric flux passing through a surface is defined by the surface integral of the electric field over the surface.

**Skills:**

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

**Topic 8.6 Gauss's Law**

**Knowledge:**

- Gauss’s law relates electric flux through a Gaussian surface to the charge enclosed by that surface.
- A Gaussian surface is a three-dimensional, closed surface.
- The total electric flux through a Gaussian surface is independent of the size of the Gaussian surface if the amount of enclosed charge remains constant.
- Gaussian surfaces are typically constructed such that the electric field generated by the enclosed charge is either perpendicular or parallel to different regions of the Gaussian surface, resulting in a simplified surface
- integral.
- If a function of charge density is given for a charge distribution, the total charge can be determined by integrating the charge density over the length (one dimension), area (two dimensions), or volume (three dimensions) of the charge distribution.
- Maxwell’s equations are the collection of equations that fully describe electromagnetism. Gauss’s law is Maxwell’s first equation.

**Skills:**

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Calculate or estimate an unknown quantity with units from known quantities by selecting and following a logical computational pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.

## Transfer Goals

In Unit 8, students will begin the study of electric force, which is exerted on all objects with a property called charge. The electric force, in contrast to gravitational force, is one of attraction or repulsion and, therefore, leads to different effects on objects. This knowledge will help students understand the role electrostatics plays in common devices such as photocopiers, defibrillators, and printers, as well as television, radio, and radar industries. In the units that follow, students will apply their knowledge of electric charges and force to electric circuits, and how the motion of electric charges creates magnetic fields.

## Assessments

https://docs.google.com/document/d/1wR7bQF-8AQoRrt0g4C3hKja0yjwDjC9_BiAmONWbTcI/edit?usp=sharing

## Modifications

https://docs.google.com/document/d/1ODqaPP69YkcFiyG72fIT8XsUIe3K1VSG7nxuc4CpCec/edit?usp=sharing