Unit 10: Electricity and Magnetism – Electrostatics

OBJECTIVES

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.

Enduring Understanding 1.B: Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.

Essential Knowledge 1.B.1: Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.

a. An electrical current is a movement of charge through a conductor.

b. A circuit is a closed loop of electrical current.

Learning Objective 1.B.1.1: The student is able to make claims about natural phenomena based on conservation of electric charge.

Learning Objective 1.B.1.2: The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits.

Essential Knowledge 1.B.2: There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge.

a. Like-charged objects and systems repel, and unlike-charged objects and systems attract.

b. Charged objects or systems may attract neutral systems by changing the distribution of charge in the neutral system.

Learning Objective 1.B.2.1: The student is able to construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices.

Learning Objective 1.B.2.2: The student is able to make qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes.

Learning Objective 1.B.2.3: The student is able to challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object.

Essential Knowledge 1.B.3: The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.

a. The magnitude of the elementary charge is equal to 1.6×10^{-19} coulombs.

b. Electrons have a negative elementary charge; protons have a positive elementary charge of equal magnitude, although the mass of a proton is much larger than the mass of an electron.

Learning Objective 1.B.3.1: The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated.

Enduring Understanding 1.E: Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.

Essential Knowledge 1.E.4: Matter has a property called electric permittivity.

a. Free space has a constant value of the permittivity that appears in physical relationships.

b. The permittivity of matter has a value different from that of free space.

Big Idea 2: Fields existing in space can be used to explain interactions.

Enduring Understanding 2.A: A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.

Essential Knowledge 2.A.1: A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.

a. Vector fields are represented by field vectors indicating direction and magnitude.

b. When more than one source object with mass *or electric charge* is present, the field value can be determined by vector addition.

c. Conversely, a known vector field can be used to make inferences about the number, relative size, and location of sources.

Essential Knowledge 2.A.2: A scalar field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a scalar. *This should include electric potential.*

a. Scalar fields are represented by field values.

b. When more than one source object with mass *or charge* is present, the scalar field value can be determined by scalar addition.

c. Conversely, a known scalar field can be used to make inferences about the number, relative size, and location of sources.

Enduring Understanding 2.C: An electric field is caused by an object with electric charge.

Essential Knowledge 2.C.1: The magnitude of the electric force F exerted on an object with electric charge q by an electric field is $\vec{F} = q\vec{E}$. The direction of the force is determined by the direction of the field and the sign of the charge, with positively charged objects accelerating in the direction of the field and negatively charged objects accelerating in the direction opposite the field. This should include a vector field map for positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates.

Learning Objective 2.C.1.1: The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: $\vec{F} = q\vec{E}$; a vector relation.

Learning Objective 2.C.1.2: The student is able to calculate any one of the variables — electric force, electric charge, and electric field — at a point given the values and sign or direction of the other two quantities.

Essential Knowledge 2.C.2: The magnitude of the electric field vector is proportional to the net electric charge of the object(s) creating that field. This includes positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates.

Learning Objective 2.C.2.1: The student is able to qualitatively and semiquantitatively apply the vector relationship between the electric field and the net electric charge creating that field.

Essential Knowledge 2.C.3: The electric field outside a spherically symmetric charged object is radial and its magnitude varies as the inverse square of the radial distance from the center of that object. Electric field lines are not in the curriculum. Students will be expected to rely only on the rough intuitive sense underlying field lines, wherein the field is viewed as analogous to something emanating uniformly from a source.

a. The inverse square relation known as Coulomb's law gives the magnitude of the electric field at a distance r from the center of a source object of electric charge Q as $|E| = \frac{1}{4\pi\varepsilon_0}\frac{|Q|}{r^2}$.

b. This relation is based on a model of the space surrounding a charged source object by considering the radial dependence of the area of the surface of a sphere centered on the source object.

Learning Objective 2.C.3.1: The student is able to explain the inverse square dependence of the electric field surrounding a spherically symmetric electrically charged object.

Essential Knowledge 2.C.4: The electric field around dipoles and other systems of electrically charged objects (that can be modeled as point objects) is found by vector addition of the field of each individual object. Electric dipoles are treated qualitatively in this course as a teaching analogy to facilitate student understanding of magnetic dipoles.

a. When an object is small compared to the distances involved in the problem, or when a larger object is being modeled as a large number of very small constituent particles, these can be modeled as charged objects of negligible size, or "point charges."

b. The expression for the electric field due to a point charge can be used to determine the electric field, either qualitatively or quantitatively, around a simple, highly symmetric distribution of point charges.

Learning Objective 2.C.4.1: The student is able to distinguish the characteristics that differ between monopole fields (gravitational field of spherical mass and electrical field due to single point charge) and dipole fields (electric dipole field and magnetic field) and make claims about the spatial behavior of the fields using qualitative or semiquantitative arguments based on vector addition of fields due to each point source, including identifying the locations and signs of sources from a vector diagram of the field.

Learning Objective 2.C.4.2: The student is able to apply mathematical routines to determine the magnitude and direction of the electric field at specified points in the vicinity of a small set (2-4) of point charges, and express the results in terms of magnitude and direction of the field in a visual representation by drawing field vectors of appropriate length and direction at the specified points

Essential Knowledge 2.C.5: Between two oppositely charged parallel plates with uniformly distributed electric charge, at points far from the edges of the plates, the electric field is perpendicular to the plates and is constant in both magnitude and direction.

Learning Objective 2.C.5.1: The student is able to create representations of the magnitude and direction of the electric field at various distances (small compared to plate size) from two electrically charged plates of equal magnitude and opposite signs and is able to recognize that the assumption of uniform field is not appropriate near edges of plates.

Learning Objective 2.C.5.2: The student is able to calculate the magnitude and determine the direction of the electric field between two electrically charged parallel plates, given the charge of each plate, or the electric potential difference and plate separation.

Learning Objective 2.C.5.3: The student is able to represent the motion of an electrically charged particle in the uniform field between two oppositely charged plates and express the connection of this motion to projectile motion of an object with mass in the Earth's gravitational field.

Enduring Understanding 2.E: Physicists often construct a map of isolines connecting points of equal value for some quantity related to a field and use these maps to help visualize the field.

Essential Knowledge 2.E.1: Isolines on a topographic (elevation) map describe lines of approximately equal gravitational potential energy per unit mass (gravitational equipotential). As the distance between two different isolines decreases, the steepness of the surface increases. [Contour lines on topographic maps are useful teaching tools for introducing the concept of equipotential lines. Students are encouraged to use the analogy in their answers when explaining gravitational and electrical potential and potential differences.]

Learning Objective 2.E.1.1: The student is able to construct or interpret visual representations of the isolines of equal gravitational potential energy per unit mass and refer to each line as a gravitational equipotential.

Essential Knowledge 2.E.2: Isolines in a region where an electric field exists represent lines of equal electric potential referred to as equipotential lines.

a. An isoline map of electric potential can be constructed from an electric field vector map, using the fact that the isolines are perpendicular to the electric field vectors.

b. Since the electric potential has the same value along an isoline, there can be no component of the electric field along the isoline.

Learning Objective 2.E.2.1: The student is able to determine the structure of isolines of electric potential by constructing them in a given electric field.

Learning Objective 2.E.2.2: The student is able to predict the structure of isolines of electric potential by constructing them in a given electric field and make connections between these isolines and those found in a gravitational field.

Learning Objective 2.E.2.3: The student is able to qualitatively use the concept of isolines to construct isolines of electric potential in an electric field and determine the effect of that field on electrically charged objects.

Essential Knowledge 2.E.3: The average value of the electric field in a region equals the change in electric potential across that region divided by the change in position (displacement) in the relevant direction.

Learning Objective 2.E.3.1: The student is able to apply mathematical routines to calculate the average value of the magnitude of the electric field in a region from a description of the electric potential in that region using the displacement along the line on which the difference in potential is evaluated.

Learning Objective 2.E.3.2: The student is able to apply the concept of the isoline representation of electric potential for a given electric charge distribution to predict the average value of the electric field in the region.

Enduring Understanding 3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

Essential Knowledge 3.C.2: Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.

a. Electric forces dominate the properties of the objects in our 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.

b. Electric forces may be attractive or repulsive, depending upon the charges on the objects involved.

Learning Objective 3.C.2.1: The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges (interactions between collections of electric point charges are not covered in Physics 1 and instead are restricted to Physics 2).

Learning Objective 3.C.2.2: The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces.

Learning Objective 3.C.2.3: The student is able to use mathematics to describe the electric force that results from the interaction of several separated point charges (generally 2 to 4 point charges, though more are permitted in situations of high symmetry).

Enduring Understanding 3.G: Certain types of forces are considered fundamental.

Essential Knowledge 3.G.2: Electromagnetic forces are exerted at all scales and can dominate at the human scale.

Learning Objective 3.G.2.1: The student is able to connect the strength of electromagnetic forces with the spatial scale of the situation, the magnitude of the electric charges, and the motion of the electrically charged objects involved.

Enduring Understanding 4.E: The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.

Essential Knowledge 4.E.3: The charge distribution in a system can be altered by the effects of electric forces produced by a charged object.

a. Charging can take place by friction or by contact.

b. An induced charge separation can cause a neutral object to become polarized.

c. Charging by induction can occur when a polarizing conducting object is touched by another.

d. In solid conductors, some electrons are mobile. When no current flows, mobile charges are in static equilibrium, excess charge resides at the surface, and the interior field is zero. In solid insulators, excess (fixed) charge may reside in the interior as well as at the surface.

Learning Objective 4.E.3.1: The student is able to make predictions about the redistribution of charge during charging by friction, conduction, and induction.

Learning Objective 4.E.3.2: The student is able to make predictions about the redistribution of charge caused by the electric field due to other systems, resulting in charged or polarized objects.

Learning Objective 4.E.3.3: The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors.

Learning Objective 4.E.3.4: The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors that predicts charge distribution in processes involving induction or conduction.

Learning Objective 4.E.3.5: The student is able to explain and/or analyze the results of experiments in which electric charge rearrangement occurs by electrostatic induction, or is able to refine a scientific question relating to such an experiment by identifying anomalies in a data set or procedure.

Essential Knowledge 4.E.4: The resistance of a resistor and the capacitance of a capacitor can be understood from the basic properties of electric fields and forces as well as the properties of materials and their geometry.

a. The resistance of a resistor is proportional to its length and inversely proportional to its cross-sectional area. The constant of proportionality is the resistivity of the material.

b. The capacitance of a parallel plate capacitor is proportional to the area of one of its plates and inversely proportional to the separation between its plates. The constant of proportionality is the product of the dielectric constant, κ of the material between the plates and the electric permittivity,ε_0 .

c. The current through a resistor is equal to the potential difference across the resistor divided by its resistance.

d. The magnitude of charge of one of the plates of a parallel plate capacitor is directly proportional to the product of the potential difference across the capacitor and the capacitance. The plates have equal amounts of charge of opposite sign.

Learning Objective 4.E.4.1: The student is able to make predictions about the properties of resistors and/or capacitors when placed in a simple circuit based on the geometry of the circuit element and supported by scientific theories and mathematical relationships.

Learning Objective 4.E.4.2: The student is able to design a plan for the collection of data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors.

Learning Objective 4.E.4.3: The student is able to analyze data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors.

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.

Enduring Understanding 5.B: The energy of a system is conserved.

Essential Knowledge 5.B.3: A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces.

a. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential energy is used when the forces are internal interactions between parts of the system.

b. Changes in the internal structure can result in changes in potential energy. Examples should include mass-spring oscillators and objects falling in a gravitational field.

c. The change in electric potential in a circuit is the change in potential energy per unit charge.

Learning Objective 5.B.3.1: The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy.

Learning Objective 5.B.3.2: The student is able to make quantitative calculations of the internal potential energy of a system from a description or diagram of that system.

Learning Objective 5.B.3.3: The student is able to apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system.

Enduring Understanding 5.C: The electric charge of a system is conserved.

Essential Knowledge 5.C.2: The exchange of electric charges among a set of objects in a system conserves electric charge.

a. Charging by conduction between objects in a system conserves the electric charge of the entire system.

b. Charge separation in a neutral system can be induced by an external charged object placed close to the neutral system.

c. Grounding involves the transfer of excess charge to another larger system (e.g., the Earth).

Learning Objective 5.C.2.1: The student is able to predict electric charges on objects within a system by application of the principle of charge conservation within a system.

Learning Objective 5.C.2.2: The student is able to design a plan to collect data on the electrical charging of objects and electric charge induction on neutral objects and qualitatively analyze that data.

Learning Objective 5.C.2.3: The student is able to justify the selection of data relevant to an investigation of the electrical charging of objects and electric charge induction on neutral objects.

PROCEDURE:

1. Phase 1: Charge and Coulomb's Law
    - Notes: Roman numeral I
    - Homework 1: Chapter 18 Conceptual Questions 2, 3, 4, 6 and Problems 3, 5, 7, 9, 11, 13
2. Phase 2: Electric Field
    - Notes: Roman numeral II
    - Homework 2: Chapter 18 Conceptual Questions 8, 9, 10, 11[1], 12, 13, 14 and Problems 25, 27, 28, 29, 32, 33, 70 (conceptual only)
3. Phase 3: Electric Potential Energy and Electric Potential
    - Notes: Roman numeral III
    - Homework 3: Chapter 19 Conceptual Questions 1, 2, 7, 8, 12 and Problems 1, 3, 7, 9, 11, 13, 15, 27, 28, 29, 30, 34
4. Phase 4: Capacitors
    - Notes: Roman numeral IV
    - Homework 4: Chapter 18 Conceptual Question 15 and Chapter 19 Conceptual Questions 16, 17 and Problems 36-41 and 65 (conceptual only) and 68 (conceptual only)

LABORATORY COMPONENT:

- Methods of Charging
- Electric Fields

[1] For this question, instead of answering the book's question, simply state what, if any, combination of positive and negative configurations could create the zero field at the fourth corner.