Introduction: Electric Force, Field & Potential

Unit: Electric Force, Field & Potential

Topics covered in this chapter:

This chapter discusses static electric charges, how they behave, and how they relate to each other.

- *Electric Charge* and *Coulomb's Law* describe the behavior of individual charged particles and their effects on each other.
- *Electric Fields* describes the behavior of an electric force field on charged particles.
- *Electric Field Vectors* and *Equipotential Lines & Maps* describe ways of representing electric fields in two dimensions.

Standards addressed in this chapter:

NGSS Standards/MA Curriculum Frameworks (2016):

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-PS3-1. Use algebraic expressions and the principle of energy conservation to calculate the change in energy of one component of a system when the change in energy of the other component(s) of the system, as well as the total energy of the system including any energy entering or leaving the system, is known. Identify any transformations from one form of energy to another, including thermal, kinetic, gravitational, magnetic, or electrical energy, in the system.

HS-PS3-2. Develop and use a model to illustrate that energy at the macroscopic scale can be accounted for as either motions of particles and objects or energy stored in fields.

HS-PS3-5. Develop and use a model of magnetic or electric fields to illustrate the forces and changes in energy between two magnetically or electrically charged objects changing relative position in a magnetic or electric field, respectively.

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AP® Physics 2 Learning Objectives/Essential Knowledge (2024):

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

10.1.A.1: Charge is a fundamental property of all matter.

10.1.A.1.i: Charge is described as positive or negative.

10.1.A.1.ii: 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.

10.1.A.1.iii: The charge of an electron is $-e$, the charge of a proton is $+e$, and a neutron has no electric charge.

10.1.A.1.iv: 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.

10.1.A.2: 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.

10.1.A.3: The direction of the electrostatic force depends on the signs of the charges of the interacting objects and is parallel to the line of separation between the objects.

10.1.A.3.i: Two objects with charges of the same sign exert repulsive forces on each other.

10.1.A.3.ii: Two objects with charges of opposite signs exert attractive forces on each other.

10.1.A.4: 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.

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

10.1.B.1: Electrostatic forces can be attractive or repulsive, while gravitational forces are always attractive.

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10.1.B.2: 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.

10.1.B.3: Gravitational forces dominate at larger scales even though they are weaker than electrostatic forces, because systems at large scales tend to be electrically neutral.

10.1.C: Describe the electric permittivity of a material or medium.

10.1.C.1: Electric permittivity is a measurement of the degree to which a material or medium is polarized in the presence of an electric field.

10.1.C.2: 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.

10.1.C.3: Free space has a constant value of electric permittivity, ε_o, that appears in physical relationships.

10.1.C.4: The permittivity of matter has a value different from that of free space that arises from the matter's composition and arrangement.

10.1.C.4.i: In a given material, electric permittivity is determined by the ease with which electrons can change configurations within the material.

10.1.C.4.ii: 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.

10.2.A: Describe the behavior of a system using conservation of charge.

10.2.A.1: 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.

10.2.A.1.i: The net charge of a system can change due to friction or contact between systems.

10.2.A.1.ii: 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.

10.2.A.1.iii: Induced charge separation can occur in neutral systems.

10.2.A.2: Any change to a system's net charge is due to a transfer of charge between the system and its surroundings.

10.2.A.2.i: The charging of a system typically involves the transfer of electrons to and from the system.

10.2.A.2.ii: The net charge of a system will be constant unless there is a transfer of charge to or from the system.

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10.2.A.3: Grounding involves electrically connecting a charged system to a much larger and approximately neutral system (*e.g.,* Earth).

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

10.3.A.1: Electric fields may originate from charged objects.

10.3.A.2: The electric field at a given point is the ratio of the electric force exerted on a test charge at that point to the charge of the test charge.

10.3.A.2.i: 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.

10.3.A.2.ii: An electric field points away from isolated positive charges and toward isolated negative charges.

10.3.A.2.iii: The electric force exerted on a positive test charge by an electric field is in the same direction as the electric field.

10.3.A.3: The electric field is a vector quantity and can be represented in space using vector field maps

10.3.A.3.i: The net electric field at a given location is the vector sum of individual electric fields created by nearby charged objects.

10.3.A.3.ii: Electric field maps use vectors to depict the magnitude and direction of the electric field at many locations within a given region.

10.3.A.3.iii: 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.

10.3.B: Describe the electric field generated by charged conductors or insulators.

10.3.B.1: While in electrostatic equilibrium, the excess charge of a solid conductor is distributed on the surface of the conductor, and the electric field within the conductor is zero.

10.3.B.1.i: At the surface of a charged conductor, the electric field is perpendicular to the surface.

10.3.B.1.ii: 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.

10.3.B.2: 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.

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10.4.A: Describe the electric potential energy of a system.

10.4.A.1: The electric potential energy of a system of two point charges equals the amount of work required for an external force to bring the point charges to their current positions from infinitely far away.

10.4.A.2: The general form for the electric potential energy of two charged objects is given by the equation $U_E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r} = k\frac{q_1 q_2}{r}$.

10.4.A.3: The total electric potential energy of a system can be determined by finding the sum of the electric potential energies of the individual interactions between each pair of charged objects in the system.

10.5.A: Describe the electric potential due to a configuration of charged objects.

10.5.A.1: Electric potential describes the electric potential energy per unit charge at a point in space.

10.5.A.2: The electric potential due to multiple point charges can be determined by the principle of scalar superposition of the electric potential due to each of the point charges.

10.5.A.3: The electric potential difference between two points is the change in electric potential energy per unit charge when a test charge is moved between the two points.

10.5.A.3.i: Electric potential difference may also result from chemical processes that cause positive and negative charges to separate, such as in a battery.

10.5.A.4: When conductors are in electrical contact, electrons will be redistributed such that the surfaces of the conductors are at the same electric potential.

10.5.B: Describe the relationship between electric potential and electric field.

10.5.B.1: The average electric field between two points in space is equal to the electric potential difference between the two points divided by the distance between the two points.

10.5.B.2: Electric field vector maps and equipotential lines are tools to describe the field produced by a charge or configuration of charges and can be used to predict the motion of charged objects in the field.

10.5.B.2.i: Equipotential lines represent lines of equal electric potential in space. These lines are also referred to as isolines of electric potential.

10.5.B.2.ii: Isolines are perpendicular to electric field vectors. An isoline map of electric potential can be constructed from an electric field vector map, and an electric field map may be constructed from an isoline map.

10.5.B.2.iii: An electric field vector points in the direction of decreasing potential.

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10.5.B.2.iv: There is no component of an electric field along an isoline.

10.7.A: Describe changes in energy in a system due to a difference in electric potential between two locations.

10.7.A.1: When a charged object moves between two locations with different electric potentials, the resulting change in the electric potential energy of the object-field system is given by the following equation.

10.7.A.2: The movement of a charged object between two points with different electric potentials results in a change in kinetic energy of the object consistent with the conservation of energy.

Skills learned & applied in this chapter:

- Working with isolines.