

2.10: The Electric Field (Summary)

Key Terms

Table 1. Key Terms for Chapter 2

Term	Definition
charging by induction	process by which an electrically charged object brought near a neutral object creates a charge separation in that object
conduction electron	electron that is free to move away from its atomic orbit
conductor	material that allows electrons to move separately from their atomic orbits; object with properties that allow charges to move about freely within it
continuous charge distribution	total source charge composed of so large a number of elementary charges that it must be treated as continuous, rather than discrete
coulomb	SI unit of electric charge
Coulomb force	another term for the electrostatic force
Coulomb's law	mathematical equation calculating the electrostatic force vector between two charged particles
dipole	two equal and opposite charges that are fixed close to each other
electric charge	physical property of an object that causes it to be attracted toward or repelled from another charged object; each charged object generates and is influenced by a force called an electric force
electric field	physical phenomenon created by a charge; it "transmits" a force between a two charges
electric force	noncontact force observed between electrically charged objects
electron	particle surrounding the nucleus of an atom and carrying the smallest unit of negative charge
electrostatic attraction	phenomenon of two objects with opposite charges attracting each other
electrostatic force	amount and direction of attraction or repulsion between two charged bodies; the assumption is that the source charges have no acceleration
electrostatic repulsion	phenomenon of two objects with like charges repelling each other
electrostatics	study of charged objects which are not in motion
field line	smooth, usually curved line that indicates the direction of the electric field
field line density	number of field lines per square meter passing through an imaginary area; its purpose is to indicate the field strength at different points in space
induced dipole	typically an atom, or a spherically symmetric molecule; a dipole created due to opposite forces displacing the positive and negative charges

Term	Definition
infinite straight wire	straight wire whose length is much, much greater than either of its other dimensions, and also much, much greater than the distance at which the field is to be calculated
insulator	material that holds electrons securely within their atomic orbits
ion	atom or molecule with more or fewer electrons than protons
law of conservation of charge	net electric charge of a closed system is constant
linear charge density	amount of charge in an element of a charge distribution that is essentially one-dimensional (the width and height are much, much smaller than its length); its units are C/m
neutron	neutral particle in the nucleus of an atom, with (nearly) the same mass as a proton
permittivity of vacuum	also called the permittivity of free space, and constant describing the strength of the electric force in a vacuum
polarization	slight shifting of positive and negative charges to opposite sides of an object
principle of superposition	useful fact that we can simply add up all of the forces due to charges acting on an object
proton	particle in the nucleus of an atom and carrying a positive charge equal in magnitude to the amount of negative charge carried by an electron
static electricity	buildup of electric charge on the surface of an object; the arrangement of the charge remains constant (“static”)
superposition	concept that states that the net electric field of multiple source charges is the vector sum of the field of each source charge calculated individually
surface charge density	amount of charge in an element of a two-dimensional charge distribution (the thickness is small); its units are C/m^2

Key Equations

Table 2. Key Equations for Chapter 2

Description	Equation
Coulomb's law	$\vec{F}_{12}(r) = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}^2} \hat{r}_{12}$
Superposition of electric forces	$\vec{F}(r) = \frac{1}{4\pi\epsilon_0} Q \sum_{i=1}^N \frac{q_i}{r_i^2} \hat{r}_i$
Electric force due to an electric field	$\vec{F} = Q\vec{E}$
Electric field at point P	$\vec{E}(P) \equiv \frac{1}{4\pi\epsilon_0} \sum_{i=1}^N \frac{q_i}{r_i^2} \hat{r}_i$
Field of an infinite wire	$\vec{E}(z) = \frac{1}{4\pi\epsilon_0} \frac{2\lambda}{z} \hat{k}$
Field of an infinite plane	$\vec{E} = \frac{\sigma}{2\epsilon_0} \hat{k}$

Summary

Electric Charge Model

- There are only two types of charge, which we call positive and negative. Like charges repel, unlike charges attract, and the force between charges decreases with the square of the distance.
- Protons carry the vast majority of positive charge in nature, whereas electrons carry the vast majority of negative charge. The electric charge of one electron is equal in magnitude and opposite in sign to the charge of one proton.
- An ion is an atom or molecule that has nonzero total charge due to having unequal numbers of electrons and protons.
- The SI unit for charge is the coulomb (C), with protons and electrons having charges of opposite sign but equal magnitude; the magnitude of this basic charge is $e \equiv 1.602 \times 10^{-19} \text{ C}$
- Both positive and negative charges exist in neutral objects and can be separated by bringing the two objects into physical contact; rubbing the objects together can remove electrons from the bonds in one object and place them on the other object, increasing the charge separation.
- For macroscopic objects, negatively charged means an excess of electrons, and positively charged means a depletion of electrons.
- The law of conservation of charge states that the net charge of a closed system is constant.

Conduction and Charging

- A conductor is a substance that allows charge to flow freely through its atomic structure.
- An insulator holds charge fixed in place.
- Polarization is the separation of positive and negative charges in a neutral object. Polarized objects have their positive and negative charges concentrated in different areas, giving them a charge distribution.

Electric Fields and Forces

- The electric field is an alteration of space caused by the presence of an electric charge. The electric field mediates the electric force between a source charge and a test charge. The electric field of a point charge is given by

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r},$$

where q is the value of the charge, r is the distance away from the charge, and \hat{r} is the radial unit vector.

- The field is a vector; by definition, it points away from positive charges and toward negative charges
- Coulomb's law gives the magnitude of the force between point charges. It is

$$\vec{F}_{12}(r) = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}^2} \hat{r}_{12},$$

where q_1 and q_2 are two point charges separated by a distance \mathbf{r} . This Coulomb force is a fundamental force because most charges are due to point-like particles. It is responsible for all electrostatic effects and underlies most macroscopic forces.

Electric Fields and Forces of Multiple Charges

- The electric field obeys the superposition principle, which states that the electric fields from multiple source charges can be summed to give the total field at a test location.
- The electric force also obeys the superposition principle.

Electric Field Diagrams

- Electric field diagrams assist in visualizing the field of a source charge.
- The magnitude of the field is proportional to the field line density.
- Field vectors are everywhere tangent to field lines.

Common Electric Field Models

- A very large number of charges can be treated as a continuous charge distribution, where the calculation of the field requires integration. Common cases are:
 - one-dimensional (like a wire); uses a line charge density λ
 - two-dimensional (metal plate); uses surface charge density σ
- Electric field models can be constructed for charge distributions like the finite line segment, infinite line, ring, disk, and infinite plane.

Contributors and Attributions

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