### 5.S: Electric Charges and Fields (Summary)

#### Key Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>charging by induction</td>
<td>process by which an electrically charged object brought near a neutral object creates a charge separation in that object</td>
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<tr>
<td>conduction electron</td>
<td>electron that is free to move away from its atomic orbit</td>
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<tr>
<td>conductor</td>
<td>material that allows electrons to move separately from their atomic orbits; object with properties that allow charges to move about freely within it</td>
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<tr>
<td>continuous charge distribution</td>
<td>total source charge composed of so large a number of elementary charges that it must be treated as continuous, rather than discrete</td>
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<tr>
<td>coulomb</td>
<td>SI unit of electric charge</td>
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<tr>
<td>Coulomb force</td>
<td>another term for the electrostatic force</td>
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<tr>
<td>Coulomb's law</td>
<td>mathematical equation calculating the electrostatic force vector between two charged particles</td>
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<tr>
<td>dipole</td>
<td>two equal and opposite charges that are fixed close to each other</td>
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<tr>
<td>dipole moment</td>
<td>property of a dipole; it characterizes the combination of distance between the opposite charges, and the magnitude of the charges</td>
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<tr>
<td><strong>electric charge</strong></td>
<td>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</td>
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<tr>
<td><strong>electric field</strong></td>
<td>physical phenomenon created by a charge; it “transmits” a force between a two charges</td>
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<tr>
<td><strong>electric force</strong></td>
<td>noncontact force observed between electrically charged objects</td>
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<tr>
<td><strong>electron</strong></td>
<td>particle surrounding the nucleus of an atom and carrying the smallest unit of negative charge</td>
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<tr>
<td><strong>electrostatic attraction</strong></td>
<td>phenomenon of two objects with opposite charges attracting each other</td>
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<tr>
<td><strong>electrostatic force</strong></td>
<td>amount and direction of attraction or repulsion between two charged bodies; the assumption is that the source charges have no acceleration</td>
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<tr>
<td><strong>electrostatic repulsion</strong></td>
<td>phenomenon of two objects with like charges repelling each other</td>
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<tr>
<td><strong>electrostatics</strong></td>
<td>study of charged objects which are not in motion</td>
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<tr>
<td><strong>field line</strong></td>
<td>smooth, usually curved line that indicates the direction of the electric field</td>
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<tr>
<td><strong>field line density</strong></td>
<td>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</td>
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<td><strong>induced dipole</strong></td>
<td>typically an atom, or a spherically symmetric molecule; a dipole created due to opposite forces displacing the positive and negative charges</td>
</tr>
<tr>
<td><strong>infinite straight wire</strong></td>
<td>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</td>
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<tr>
<td><strong>insulator</strong></td>
<td>material that holds electrons securely within their atomic orbits</td>
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<tr>
<td><strong>ion</strong></td>
<td>atom or molecule with more or fewer electrons than protons</td>
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<tr>
<td><strong>law of conservation of charge</strong></td>
<td>net electric charge of a closed system is constant</td>
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<tr>
<td><strong>linear charge density</strong></td>
<td>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</td>
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<tr>
<td><strong>neutron</strong></td>
<td>neutral particle in the nucleus of an atom, with (nearly) the same mass as a proton</td>
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<tr>
<td><strong>permanent dipole</strong></td>
<td>typically a molecule; a dipole created by the arrangement of the charged particles from which the dipole is created</td>
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<tr>
<td><strong>permittivity of vacuum</strong></td>
<td>also called the permittivity of free space, and constant describing the strength of the electric force in a vacuum</td>
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</table>
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 $\text{C/m}^2$

volume charge density amount of charge in an element of a three-dimensional charge distribution; its units are $\text{C/m}^3$

Key Equations

Coulomb's law
$$\vec{F}_{12}(r)=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r_{12}^2}\hat{r}_{12}$$

Superposition of electric forces
$$\vec{F}(r)=\frac{1}{4\pi\varepsilon_0}Q \sum_{i=1}^N\frac{q_i}{r_i^2}\hat{r}_i$$

Electric force due to an electric field
$$\vec{F}=Q\vec{E}$$

Electric field at point $P$
$$\vec{E}(P)=\frac{1}{4\pi\varepsilon_0}\sum_{i=1}^N\frac{q_i}{r_i^2}\hat{r}_i$$

Field of an infinite wire
$$\vec{E}(z)=\frac{1}{4\pi\varepsilon_0}\frac{2\lambda}{z}\hat{k}$$

Field of an infinite plane
$$\vec{E}=-\frac{\sigma}{2\varepsilon_0}\hat{k}$$

Dipole moment
$$\vec{p}=q\vec{d}$$

Torque on dipole in external E-field
$$\vec{\tau} = \vec{p} \times \vec{E}$$

Summary
5.2 Electric Charge

- 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.
- The vast majority of positive charge in nature is carried by protons, whereas the vast majority of negative charge is carried by electrons. 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 \( e = 1.602 \times 10^{-19} \text{C} \)
- 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.

5.3 Conductors, Insulators, and Charging by Induction

- 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.

5.4 Coulomb's Law

- Coulomb's law gives the magnitude of the force between point charges. It is

\[
\vec{F}_{12}(r) = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r_{12}^2} \hat{r}_{12}
\]

where \( q_1 \) and \( q_2 \) are two point charges separated by a distance \( r \). This Coulomb force is extremely basic, since most charges are due to point-like particles. It is responsible for all electrostatic effects and underlies most macroscopic forces.

5.5 Electric Field

- 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, like the electric force, obeys the superposition principle.
- The field is a vector; by definition, it points away from positive charges and toward negative charges.
5.6 Calculating Electric Fields of Charge Distributions

- 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 \( \lambda \)
  - two-dimensional (metal plate); uses surface charge density \( \sigma \)
  - three-dimensional (metal sphere); uses volume charge density \( \rho \)
- The "source charge" is a differential amount of charge \( dq \). Calculating \( dq \) depends on the type of source charge distribution:
  \[
  dq = \lambda dl; \quad dq = \sigma dA; \quad dq = \rho dV.
  \]
- Symmetry of the charge distribution is usually key.
- Important special cases are the field of an "infinite" wire and the field of an "infinite" plane.

5.7 Electric Field Lines

- 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.

5.8 Electric Dipoles

- If a permanent dipole is placed in an external electric field, it results in a torque that aligns it with the external field.
- If a nonpolar atom (or molecule) is placed in an external field, it gains an induced dipole that is aligned with the external field.
- The net field is the vector sum of the external field plus the field of the dipole (physical or induced).
- The strength of the polarization is described by the dipole moment of the dipole, \( \vec{p} = q \vec{d} \).

Contributors and Attributions

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