Chapter 25 Electric Charges and Forces

Chapter Goal: To describe electric phenomena in terms of charges, forces, and fields.

Charge Model
Electric phenomena seem mysterious at first, but we’ll find that we can understand them in terms of a charge model:

- There are two kinds of charge, called positive and negative.
- Two charges of the same kind repel; two opposite charges attract.
- Small neutral objects are attracted to a charge of either sign.

You’ll learn how a comb rubbed through your hair picks up small pieces of paper.

Coulomb’s Law
The law governing the electric force is called Coulomb’s law. It tells us how the force between charged particles depends on their charge and on the distance between them.

You’ll find that Coulomb’s law, like Newton’s law of gravity, is an inverse-square law.
Chapter 25 Preview

Field Model

How is a long-range force transmitted from one charge to another? We’ll develop the idea that every charge alters the space around it by creating an electric field. It is the electric field that then exerts forces on other charges.

The liquid crystal displays (LCDs) of your calculator, your digital watch, and your computer screen use electric fields to turn the pixels on and off.

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Chapter 25 Preview

Charges and Atoms

Electrons and protons—the constituents of atoms—are the basic charges of ordinary matter.

You’ll learn that charging an object can be understood as the transfer of electrons from one material to another.

An object that is negative has an excess of electrons; a positively charged object is missing electrons.

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Chapter 25 Preview

Conductors and Insulators

There are two types of materials with very different electrical properties:

- Conductors are materials through or along which charge easily moves.
- Insulators are materials on or in which charge is immobile.

The metal wire—a conductor—carries a current of moving charges. It is separated from the support by a ceramic insulator.
Chapter 25 Preview

Point Charges
A charged particle, with no physical size, is called a point charge. You’ll learn that real objects can be modeled as point charges if they are very small compared to the distances between them.

The electric field of a point charge will be important throughout our study of electricity.

Chapter 25 Reading Quiz

Reading Question 25.1

What is the SI unit of charge?

A. Coulomb.
B. Faraday.
C. Ampere.
D. Ohm.
E. Volt
Reading Question 25.2

A charge alters the space around it. What is this alteration of space called?

A. Charged plasma.
B. Charge sphere.
C. Electric ether.
D. Electric field.
E. Electrophoresis.

Reading Question 25.3

If a negative charged rod is held near a neutral metal ball, the ball is attracted to the rod. This happens

A. Because of magnetic effects.
B. Because the ball tries to pull the rod's electrons over to it.
C. Because the rod polarizes the metal.
D. Because the rod and the ball have opposite charges.

Reading Question 25.4

The electric field of a charge is defined by the force on

A. An electron.
B. A proton.
C. A source charge.
D. A test charge.
Discovering Electricity: Experiment 1

- Take a plastic rod that has been undisturbed for a long period of time and hang it by a thread.
- Pick up another undisturbed plastic rod and bring it close to the hanging rod.
- Nothing happens to either rod.

- No forces are observed.
- We will say that the original objects are neutral.

Discovering Electricity: Experiment 2

- Rub both plastic rods with wool.
- Now the hanging rod tries to move away from the handheld rod when you bring the two close together.
- Two glass rods rubbed with silk also repel each other.

There is a long-range repulsive force, requiring no contact, between two identical objects that have been charged in the same way.
Discovering Electricity: Experiment 3

- Bring a glass rod that has been rubbed with silk close to a hanging plastic rod that has been rubbed with wool.
- These two rods attract each other.

These particular two types of rods are different materials, charged in a somewhat different way, and they attract each other rather than repel.

Discovering Electricity: Experiment 4

- Rub rods with wool or silk and observe the forces between them.
- These forces are greater for rods that have been rubbed more vigorously.
- The strength of the forces decreases as the separation between the rods increases.

The force between two charged objects depends on the distance between them.

Discovering Electricity: Experiment 5

- Hold a charged (i.e., rubbed) plastic rod over small pieces of paper on the table.
- The pieces of paper leap up and stick to the rod.
- A charged glass rod does the same.
- However, a neutral rod has no effect on the pieces of paper.

There is an attractive force between a charged object and a neutral (uncharged) object.
Discovering Electricity: Experiment 6

- Rub a plastic rod with wool and a glass rod with silk.
- Hang both by threads, some distance apart.
- Both rods are attracted to a neutral object that is held close.

There is an attractive force between a charged object and a neutral (uncharged) object.

Discovering Electricity: Experiment 7

- Rub a hanging plastic rod with wool and then hold the wool close to the rod.
- The rod is weakly attracted to the wool.
- The plastic rod is repelled by a piece of silk that has been used to rub glass.

The silk starts out with equal amounts of “glass charge” and “plastic charge” and the rubbing somehow transfers “glass charge” from the silk to the rod.

Discovering Electricity: Experiment 8

- Other objects, after being rubbed, attract one of the hanging charged rods (plastic or glass) and repel the other.
- These objects always pick up small pieces of paper.
- There appear to be no objects that, after being rubbed, pick up pieces of paper and attract both the charged plastic and glass rods.

There are only two types of charge: “like plastic” and “like glass”; there is no third kind of charge.
Charge Model, Part I

- Charge model, part I: The basic postulates of our model are:
  1. Frictional forces, such as rubbing, add something called charge to an object or remove it from the object. The process itself is called charging. More vigorous rubbing produces a larger quantity of charge.
  2. There are two and only two kinds of charge. For now we will call these “plastic charge” and “glass charge.” Other objects can sometimes be charged by rubbing, but the charge they receive is either “plastic charge” or “glass charge.”
  3. Two like charges (plastic/plastic or glass/glass) exert repulsive forces on each other. Two opposite charges (plastic/glass) attract each other.
  4. The force between two charges is a long-range force. The size of the force increases as the quantity of charge increases and decreases as the distance between the charges increases.
  5. Neutral objects have an equal mixture of both “plastic charge” and “glass charge.” The rubbing process somehow manages to separate the two.

Discovering Electricity: Experiment 9

- Charge a plastic rod by rubbing it with wool.
- Touch a neutral metal sphere with the rubbed area of the rod.
  - The metal sphere then picks up small pieces of paper and repels a charged, hanging plastic rod.
  - The metal sphere appears to have acquired “plastic charge”.
  - Charge can be transferred from one object to another, but only when the objects touch.

Discovering Electricity: Experiment 10

- Charge a plastic rod, then run your finger along it.
- After you’ve done so, the rod no longer picks up small pieces of paper or repels a charged, hanging plastic rod.
  - Similarly, the metal sphere of Experiment 9 no longer repels the plastic rod after you touch it with your finger.
  - Removing charge from an object, which you can do by touching it, is called discharging.
Discovering Electricity: Experiment 11

Place two metal spheres close together with a plastic rod connecting them.

- Charge a second plastic rod, by rubbing, and touch it to one of the metal spheres.
- Afterward, the metal sphere that was touched picks up small pieces of paper and repels a charged, hanging plastic rod.
- The other metal sphere does neither.

Discovering Electricity: Experiment 12

Repeat Experiment 11 with a metal rod connecting the two metal spheres.

- Touch one metal sphere with a charged plastic rod.
- Afterward, both metal spheres pick up small pieces of paper and repel a charged, hanging plastic rod.

Metal is a conductor: Charge moves easily through it.
Glass and plastic are insulators: Charges remain immobile.

Charge Model, Part II

- There are two types of materials. Conductors are materials through or along which charge easily moves. Insulators are materials on or in which charges remain fixed in place.
- Charge can be transferred from one object to another by contact.
The modern names for the two types of charge, coined by Benjamin Franklin, are **positive charge** and **negative charge**.

Franklin established the convention that a **glass rod that has been rubbed with silk is positively charged**.

Any other object that repels a charged glass rod is also positively charged, and any charged object that attracts a charged glass rod is negatively charged.

Thus a **plastic rod rubbed with wool is negative**.

This convention was established long before the discovery of electrons and protons.
QuickCheck 25.2

A rod attracts a positively charged hanging ball. The rod is

A. Positive.
B. Negative.
C. Neutral.
D. Either A or C.
E. Either B or C.

QuickCheck 25.2

A rod attracts a positively charged hanging ball. The rod is

A. Positive.
B. Negative.
C. Neutral.
D. Either A or C.
E. Either B or C.

Atoms and Electricity

- An atom consists of a very small and dense nucleus, surrounded by much less massive orbiting electrons.
- The nucleus contains both protons and neutrons.
- The electron cloud is negatively charged.
- The nucleus, exaggerated for clarity, contains positive protons.
Atoms and Electricity

- The atom is held together by the attractive electric force between the positive nucleus and the negative electrons.
- Electrons and protons have charges of opposite sign but exactly equal magnitude.
- This atomic-level unit of charge, called the **fundamental unit of charge**, is represented by the symbol \( e \).

<table>
<thead>
<tr>
<th>TABLE 25.1</th>
<th>Protons and electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle</td>
<td>Mass (kg)</td>
</tr>
<tr>
<td>Proton</td>
<td>( 1.67 \times 10^{-27} )</td>
</tr>
<tr>
<td>Electron</td>
<td>( 9.11 \times 10^{-31} )</td>
</tr>
</tbody>
</table>

Charge Quantization

- A macroscopic object has net charge:
  \[ q = N_p e - N_e e = (N_p - N_e)e \]
- Where \( N_p \) and \( N_e \) are the number of protons and electrons contained in the object.
- Most macroscopic objects have an equal number of protons and electrons and therefore have \( q = 0 \).
- A charged object has an unequal number of protons and electrons.
- Notice that an object’s charge is always an integer multiple of \( e \).
- This is called **charge quantization**.

Atoms and Electricity

The process of removing an electron from the electron cloud of an atom, or adding an electron to it, is called **ionization**.
Molecular ions can be created when one of the bonds in a large molecule is broken.

This is the way in which a plastic rod is charged by rubbing with wool or a comb is charged by passing through your hair.

In metals, the outer atomic electrons are only weakly bound to the nuclei.

These outer electrons become detached from their parent nuclei and are free to wander about through the entire solid.

The solid as a whole remains electrically neutral, but the electrons are now like a negatively charged liquid permeating an array of positively charged ion cores.
Charging

- The figure shows how a conductor is charged by contact with a charged plastic rod.
- Electrons in a conductor are free to move.
- Once charge is transferred to the metal, repulsive forces between the electrons cause them to move apart from each other.

Discharging

- The figure shows how touching a charged metal discharges it.
- Any excess charge that was initially confined to the metal can now spread over the larger metal + human conductor.

Charge Polarization

- The figure shows how a charged rod held close to an electroscope causes the leaves to repel each other.
- How do charged objects of either sign exert an attractive force on a neutral object?
Although the metal as a whole is still electrically neutral, we say that the object has been polarized. Charge polarization is a slight separation of the positive and negative charges in a neutral object.

Charge polarization produces an excess positive charge on the leaves of the electroscope, so they repel each other. Because the electroscope has no net charge, the electron sea quickly readjusts once the rod is removed.

The figure below shows a positively charged rod near a neutral piece of metal. Because the electric force decreases with distance, the attractive force on the electrons at the top surface is slightly greater than the repulsive force on the ions at the bottom. The net force toward the charged rod is called a polarization force.
The Electric Dipole

The figure below shows how a neutral atom is polarized by an external charge, forming an electric dipole.

- When an insulator is brought near an external charge, all the individual atoms inside the insulator become polarized.
- The polarization force acting on each atom produces a net polarization force toward the external charge.

Charging by Induction, Step 1

1. The charged rod polarizes the electroscope + person conductor. The leaves repel slightly due to polarization, but overall the electroscope has an excess of electrons and the person has a deficit of electrons.
Charging by Induction, Step 2

2. The negative charge on the electroscope is isolated when contact is broken.

Charging by Induction, Step 3

3. When the rod is removed, the leaves first collapse as the polarization vanishes, then repel as the excess negative charge spreads out. The electroscope has been negatively charged.

QuickCheck 25.3

Metal spheres 1 and 2 are touching. Both are initially neutral.

a. The charged rod is brought near.
b. The charged rod is then removed.
c. The spheres are separated.

Afterward, the charges on the sphere are:

A. \( Q_1 \) is + and \( Q_2 \) is +.
B. \( Q_1 \) is + and \( Q_2 \) is –.
C. \( Q_1 \) is – and \( Q_2 \) is +.
D. \( Q_1 \) is – and \( Q_2 \) is –.
E. \( Q_1 \) is 0 and \( Q_2 \) is 0.
Metal spheres 1 and 2 are touching. Both are initially neutral.

a. The charged rod is brought near.
b. The charged rod is then removed.
c. The spheres are separated.

Afterward, the charges on the sphere are:

A. $Q_1$ is + and $Q_2$ is +.
B. $Q_1$ is + and $Q_2$ is –.
C. $Q_1$ is – and $Q_2$ is +.
D. $Q_1$ is – and $Q_2$ is –.

**E. $Q_1$ is 0 and $Q_2$ is 0.**
Based on the last experiment, where two spheres were charged by induction, we can conclude that

A. Only the – charges move.
B. Only the + charges move.
C. Both the + and – charges move.
D. We can draw no conclusion about which charges move.

QuickCheck 25.5

Identical metal spheres are initially charged as shown. Spheres P and Q are touched together and then separated. Then spheres Q and R are touched together and separated. Afterward the charge on sphere R is

A. –1 nC or less.
B. –0.5 nC.
C. 0 nC.
D. +0.5 nC.
E. +1.0 nC or more.
QuickCheck 25.6

Identical metal spheres are initially charged as shown. Spheres P and Q are touched together and then separated. Then spheres Q and R are touched together and separated. Afterward the charge on sphere R is

A. \(-1\) nC or less.
B. \(-0.5\) nC.
C. \(0\) nC.
D. \(+0.5\) nC.
E. \(+1.0\) nC or more.

Coulomb’s Law

When two positively charged particles are a distance, \(r\), apart, they each experience a repulsive force.

\[
F_{1\to2} = F_{2\to1} = \frac{k|q_1q_2|}{r^2}
\]

In SI units \(k = 8.99 \times 10^9\) N m\(^2\)/C\(^2\).

Coulomb’s Law

When two negatively charged particles are a distance, \(r\), apart, they each experience a repulsive force.

\[
F_{1\to2} = F_{2\to1} = \frac{k|q_1q_2|}{r^2}
\]

In SI units \(k = 8.99 \times 10^9\) N m\(^2\)/C\(^2\).
Coulomb’s Law

When two oppositely charged particles are a distance, \( r \), apart, they each experience an attractive force.

\[
F_{1\rightarrow2} = F_{2\rightarrow1} = \frac{K|q_1q_2|}{r^2}
\]

In SI units \( K = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2 \).

QuickCheck 25.7

The charge of sphere 2 is twice that of sphere 1. Which vector below shows the force of 2 on 1?

A. 
B. 
C. 
D. 
E.
The charge of sphere 2 is twice that of sphere 1. Which vector below shows the force of 2 on 1?

A. B. Newton’s third law
C. D. E.

The charge of sphere 2 is twice that of sphere 1. Which vector below shows the force of 1 on 2 if the distance between the spheres is reduced to \(r/2\)?

A. B. C. D. None of the above.

At half the distance, the force is four times as large.
The Permittivity Constant

- We can make many future equations easier to use if we rewrite Coulomb’s law in a somewhat more complicated way.
- Let’s define a new constant, called the permittivity constant $\epsilon_0$:
  \[ \epsilon_0 = \frac{1}{4\pi K} = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \text{ m}^2 \]
- Rewriting Coulomb’s law in terms of $\epsilon_0$ gives us:
  \[ F = \frac{1}{4\pi \epsilon_0} \frac{|q_1| |q_2|}{r^2} \]

QuickCheck 25.10

Which is the direction of the net force on the charge at the top?

A. 
B. 
C. 
D. 
E. None of these.

QuickCheck 25.10

Which is the direction of the net force on the charge at the top?

A. 
B. 
C. 
D. 
E. None of these.
Example 25.5 Lifting a Glass Bead

**Example 25.5 Lifting a glass bead**

A small plastic sphere charged to $-10 \text{nC}$ is held 1.0 cm above a small glass bead at rest on a table. The bead has a mass of 15 mg and a charge of $+10 \text{nC}$. Will the glass bead "leap up" to the plastic sphere?

**MODEL** Model the plastic sphere and glass bead as point charges.

---

**Visualize** The figure below establishes a y-axis, identifies the plastic sphere as $q_1$, and the glass bead as $q_2$, and shows a free-body diagram.

---

**Solve** If $F_{12} > \frac{1}{2} m_{\text{bead}} g$, then the bead will remain at rest on the table with $F_{net} = F_1 + F_2 = 0$.

But if $F_{12} > m_{\text{bead}} g$, the glass bead will accelerate upward from the table. Using the values provided, we have

\[ F_{12} = \frac{k|q_1 q_2|}{r^2} = 9.0 \times 10^{-7} \text{ N} \]

\[ F_0 = m_{\text{bead}} g = 1.5 \times 10^{-4} \text{ N} \]

$F_{12}$ exceeds $m_{\text{bead}} g$ by a factor of 60, so the glass bead will leap upward.
**Example 25.5 Lifting a Glass Bead**

**Assess** The values used in this example are realistic for spheres \( \sim 2 \text{ mm} \) in diameter. In general, as in this example, electric forces are *significantly* larger than gravitational forces. Consequently, we can neglect gravity when working electric-force problems unless the particles are fairly massive.

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**QuickCheck 25.11**

The direction of the force on charge \(-q\) is

A. Up.
B. Down.
C. Left.
D. Right.
E. The force on \(-q\) is zero.

---

**QuickCheck 25.11**

The direction of the force on charge \(-q\) is

A. Up.
B. Down.
C. Left.
D. Right. \(-Q\) is slightly closer than \(+Q\).
E. The force on \(-q\) is zero.
The photos show the patterns that iron filings make when sprinkled around a magnet.

These patterns suggest that space itself around the magnet is filled with magnetic influence.

This is called the magnetic field.

The concept of such a “field” was first introduced by Michael Faraday in 1821.

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A field is a function that assigns a vector to every point in space.

The alteration of space around a mass is called the gravitational field.

Similarly, the space around a charge is altered to create the electric field.

---

If a probe charge $q$ experiences an electric force at a point in space, we say that there is an electric field $\mathbf{E}$ at that point causing the force.

$$\mathbf{E}(x, y, z) = \frac{\mathbf{F}_q}{q} = \frac{\mathbf{F}_q(x, y, z)}{q}$$

The units of the electric field are N/C. The magnitude $E$ of the electric field is called the electric field strength.
The Electric Field

A charged particle with charge \( q \) at a point in space where the electric field is \( \vec{E} \) experiences an electric force:

\[
\vec{F}_{\text{on},q} = q \vec{E}
\]

- If \( q \) is positive, the force on the particle is in the direction of \( \vec{E} \).
- The force on a negative charge is opposite the direction of \( \vec{E} \).

Example 25.7 Electric Forces in a Cell

**Example 25.7 Electric forces in a cell**

Every cell in your body is electrically active in various ways. For example, nerve propagation occurs when large electric fields in the cell membranes of neurons cause ions to move through the cell walls. The field strength in a typical cell membrane is \( 1.0 \times 10^7 \text{ N/C} \). What is the magnitude of the electric force on a singly charged calcium ion? (a)

**MODEL** The ion is a point charge in an electric field. A singly charged ion is missing one electron and has net charge \( q = +e \).

\[
F = qE = (1.6 \times 10^{-19} \text{ C})(1.0 \times 10^7 \text{ N/C}) = 1.6 \times 10^{-12} \text{ N}
\]

Example 25.7 Electric Forces in a Cell

**SOLVE** A charged particle in an electric field experiences an electric force \( \vec{F}_{\text{on}} = q \vec{E} \). In this case, the magnitude of the force is

\[
F = qE = (1.6 \times 10^{-19} \text{ C})(1.0 \times 10^7 \text{ N/C}) = 1.6 \times 10^{-12} \text{ N}
\]

**ASSESS** This may seem like an incredibly tiny force, but it is applicable to a particle with mass \( m \approx 10^{-26} \text{ kg} \). The ion would have an unimaginable acceleration \((\text{FWA} \approx 10^{12} \text{ m/s}^2)\) were it not for resistive forces as it moves through the membrane. Even so, an ion can cross the cell wall in less than 1 \( \mu \text{s} \).
The Electric Field of a Point Charge

- Figure (a) shows charge \( q \), and a point in space where we would like to know the electric field.
- We need a second charge, shown in figure (b), to serve as a probe for the electric field.
- The electric field, shown in figure (c), is given by:

\[
E = \frac{F_{\text{on } q'}}{q'} = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2}, \text{ away from } q
\]

- If we calculate the field at a sufficient number of points in space, we can draw a field diagram.
- Notice that the field vectors all point straight away from charge \( q \).
- Also notice how quickly the arrows decrease in length due to the inverse-square dependence on \( r \).

QuickCheck 25.12

At which point is the electric field stronger?

A. Point A.
B. Point B.
C. Not enough information to tell.
QuickCheck 25.12

At which point is the electric field stronger?

A. Point A.
B. Point B.
C. Not enough information to tell.

Unit Vector Notation

- Figure (a) shows unit vectors pointing toward points 1, 2, and 3.
- Unit vector $\hat{r}$ specifies the direction “straight outward from this point”.
- Figure (b) shows the electric fields at points 1, 2, and 3 due to a positive charge at the origin.
- The electric field $E$ points in the direction of the unit vector $\hat{r}$.

QuickCheck 25.13

The units of unit vector $\hat{r}$ are

A. Meters.
B. Coulombs.
C. The units depend on how it is used.
D. The unit vector has no units.
QuickCheck 25.13

The units of unit vector \( \vec{r} \) are

A. Meters.
B. Coulombs.
C. The units depend on how it is used.

\[ \checkmark \text{D. The unit vector has no units.} \]

The Electric Field of a Point Charge

- Using unit vector notation, the electric field at a distance \( r \) from a point charge \( q \) is:
  \[ \vec{E} = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} \vec{r} \]

- A negative sign in front of a vector simply reverses its direction.
- The figure shows the electric field of a negative point charge.

QuickCheck 25.14

Which is the electric field at the dot?

A. None of these.
QuickCheck 25.14

Which is the electric field at the dot?

A. 
B. 
C. 
D. 
E. None of these.

Example 25.9 The Electric Field of a Proton

Example 25.9 The Electric Field of a Proton
Example 25.9 The Electric Field of a Proton

**EXAMPLE 25.9 The electric field of a proton**

b. We could use Coulomb's law to find the force on the electron, but the whole point of knowing the electric field is that we can use it directly to find the force on a charge in the field. The magnitude of the force on the electron is

\[ F_{\text{elec}} = |q_e|E_{\text{field}} \]

\[ = (1.60 \times 10^{-19} \text{ C})(5.1 \times 10^3 \text{ N/C}) \]

\[ = 8.2 \times 10^{-16} \text{ N} \]

Chapter 25 Summary Slides

General Principles

**Coulomb's Law**

The forces between two charged particles \( q_1 \) and \( q_2 \) separated by distance \( r \) are

\[ F_{\text{1-2}} = F_{\text{2-1}} = \frac{|q_1 q_2|}{4\pi \varepsilon_0 r^2} \]

These forces are an action-reaction pair directed along the line joining the particles.

- The forces are repulsive for two like charges, attractive for two opposite charges.
- The net force on a charge is the sum of the forces from all other charges.
- The unit of charge is the coulomb (C).
- The electronic constant is \( \varepsilon_0 = 9.0 \times 10^{-12} \text{ N m}^2/\text{C}^2 \).
Important Concepts

The Charge Model

- There are two kinds of charge, positive and negative.
- Fundamental charges are protons and electrons, with charge \( \pm e \) where \( e = 1.60 \times 10^{-19} \text{C} \).
- Objects are charged by adding or removing electrons.
- The amount of charge is \( q = (N_p - N_n)e \).
- An object with an equal number of protons and electrons is neutral, meaning no net charge.

Charged objects exert electric forces on each other.
- Like charges repel, opposite charges attract.
- The force increases as the charge increases.
- The force decreases as the distance increases.

Important Concepts

There are two types of material, insulators and conductors.
- Charge remains fixed in or on an insulator.
- Charge moves easily through or along conductors.
- Charge is transferred by contact between objects.

Charged objects attract neutral objects.
- Charge polarizes metal by shifting the electron sea.
- Charge polarizes atoms, creating electric dipoles.
- The polarization force is always an attractive force.

Important Concepts

The Field Model

- Charges interact with each other via the electric field \( \vec{E} \).
- Charge \( A \) alters the space around it by creating an electric field.

- The field is the agent that exerts a force. The force on charge \( q \) is \( \vec{F}_{\text{net}} = q\vec{E} \).
- An electric field is identified and measured in terms of the force on a probe charge \( q' \):
  \[ E = \frac{F_{\text{net}}}{q'} \]
Important Concepts

An electric field is identified and measured in terms of the force on a probe charge \( q \):

\[
\vec{E} = \frac{\vec{F}}{q}
\]

- The electric field exists at all points in space.
- An electric field vector shows the field only at one point, the point at the tail of the vector.

The electric field of a point charge is

\[
\vec{E} = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} \hat{r}
\]