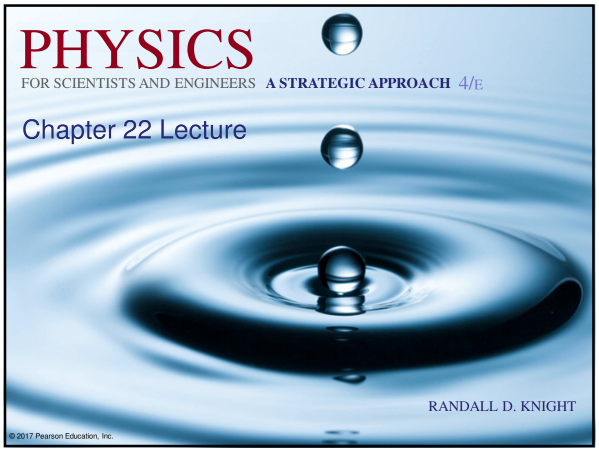


Chapter 22 Electric Charges and Forces

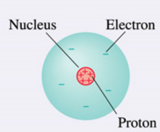
IN THIS CHAPTER, you will learn that electric phenomena are based on charges, forces, and fields.

Chapter 22 Preview

What is electric charge?

Electric phenomena depend on charge.

- There are two kinds of charge, called positive and negative.
- Electrons and protons—the constituents of atoms—are the basic charges of ordinary matter.
- Charging is the transfer of electrons from one object to another.

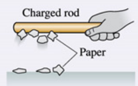


Chapter 22 Preview

How do charges behave?

Charges have well-established behaviors:

- Two charges of the same kind repel; two opposite charges attract.
- Small neutral objects are attracted to a charge of either sign.
- Charge can be transferred from one object to another.
- Charge is conserved.



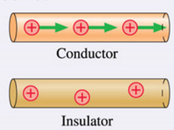
Slide 22-4

Chapter 22 Preview

What are conductors and insulators?

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

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

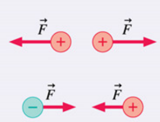


Slide 22-5

Chapter 22 Preview

What is Coulomb's law?

Coulomb's law is the fundamental law for the electric force between two charged particles. Coulomb's law, like Newton's law of gravity, is an inverse-square law: The electric force is inversely proportional to the *square* of the distance between charges.



« LOOKING BACK Sections 3.2–3.4 Vector addition

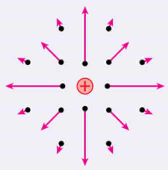
« LOOKING BACK Sections 13.2–13.4 Gravity

Slide 22-6

Chapter 22 Preview

What is an electric field?

How is a long-range force transmitted from one charge to another? We'll develop the idea that charges create an electric field, and the electric field of one charge is the agent that exerts a force on another charge. That is, charges interact via electric fields. The electric field is present at all points in space.



Slide 22-7

Chapter 22 Preview

Why are electric charges important?

Computers, cell phones, and optical fiber communications may seem to have little in common with the fact that you can get a shock when you touch a doorknob after walking across a carpet. But the physics of electric charges—how objects get charged and how charges interact with each other—is the foundation for all modern electronic devices and communications technology. Electricity and magnetism is a very large and very important topic, and it starts with simple observations of electric charges and forces.

Slide 22-8

Chapter 22 Reading Questions

Slide 22-9

Reading Question 22.1

What is the SI unit of charge?

A. Coulomb
B. Faraday
C. Ampere
D. Ohm
E. Volt

Reading Question 22.1

What is the SI unit of charge?

✔ **A. Coulomb**
B. Faraday
C. Ampere
D. Ohm
E. Volt

Reading Question 22.2

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 22.2

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 22.3

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 22.3

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A. Because of magnetic effects.
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✔**C. Because the rod polarizes the metal.**
D. Because the rod and the ball have opposite charges.

Reading Question 22.4

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

A. An electron.
B. A proton.
C. A source charge.
D. A probe charge.

 Slide 22-16

Reading Question 22.4

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

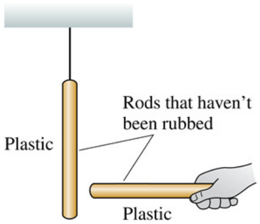
A. An electron.
B. A proton.
C. A source charge.
✔ **D. A probe charge.**

 Slide 22-17

Chapter 22 Content, Examples, and QuickCheck Questions

 Slide 22-18

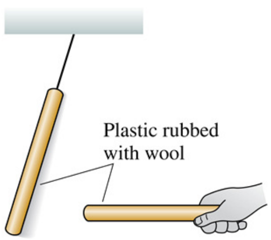
Discovering Electricity: Experiment 1



- 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**.

 Slide 22-19

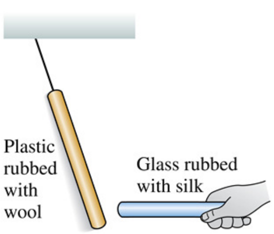
Discovering Electricity: Experiment 2



- 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.

 Slide 22-20

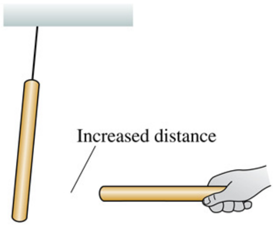
Discovering Electricity: Experiment 3



- 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.

 Slide 22-21

Discovering Electricity: Experiment 4

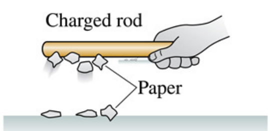


- Rub rods with wool or silk and observe the forces between them.
- These forces are greater for rods that have been rubbed more vigorously.
- The strength of the forces decreases as the separation between the rods increases.

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

 Slide 22-22

Discovering Electricity: Experiment 5



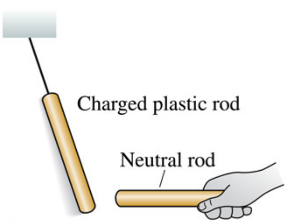
- Hold a charged (i.e., rubbed) plastic rod over small pieces of paper on the table.
- The pieces of paper leap up and stick to the rod.

- 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.

 Slide 22-23

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.

 Slide 22-24

QuickCheck 22.1

Charged glass and plastic rods hang by threads. An object attracts the glass rod. If this object is then held near the plastic rod, it will

A. Attract the plastic rod.
B. Repel the plastic rod.
C. Not affect the plastic rod.
D. Either A or B. There's not enough information to tell.

Slide 22-25

QuickCheck 22.1

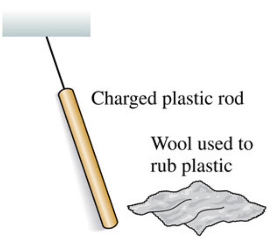
Charged glass and plastic rods hang by threads. An object attracts the glass rod. If this object is then held near the plastic rod, it will

A. Attract the plastic rod.
B. Repel the plastic rod.
C. Not affect the plastic rod.
✔**D. Either A or B. There's not enough information to tell.**

The object could have plastic charge, which would repel the plastic rod. Or it could be neutral and attract both charged rods.

Slide 22-26

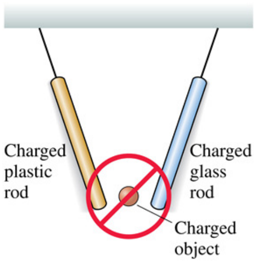
Discovering Electricity: Experiment 7



- 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.

Slide 22-27

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.

 Slide 22-28

Charge Model, Part I

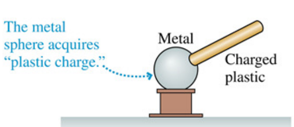
MODEL 22.1

Charge model, part I

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.

 Slide 22-29

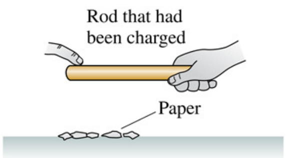
Discovering Electricity: Experiment 9



- 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*.

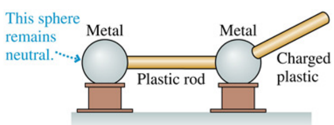
 Slide 22-30

Discovering Electricity: Experiment 10



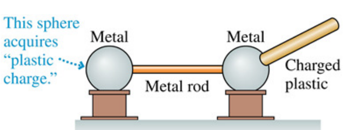
- Charge a plastic rod, then run your finger along it.
- After you've done so, the rod no longer picks up small pieces of paper or repels a charged, hanging plastic rod.
- Similarly, the metal sphere of Experiment 9 no longer repels the plastic rod after you touch it with your finger.
- Removing charge 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

MODEL 22.1

Charge model, part II

6. 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.
7. Charge can be transferred from one object to another by contact.

Example 22.1 Transferring Charge

EXAMPLE 22.1 **Transferring charge**

In Experiment 12, touching one metal sphere with a charged plastic rod caused a second metal sphere to become charged with the same type of charge as the rod. Use the postulates of the charge model to explain this.

Example 22.1 Transferring Charge

EXAMPLE 22.1 **Transferring charge**

SOLVE We need the following postulates from the charge model:

7. Charge is transferred upon contact.
6. Metal is a conductor, and charge moves through a conductor
3. Like charges repel.

The plastic rod was charged by rubbing with wool. The charge doesn't move around on the rod, because it is an insulator, but some of the "plastic charge" is transferred to the metal upon contact. Once in the metal, which is a conductor, the charges are free to move around. Furthermore, because like charges repel, these plastic charges quickly move as far apart as they possibly can. Some move through the connecting metal rod to the second sphere. Consequently, the second sphere acquires "plastic charge."

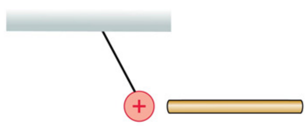
Charge

- 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.

Slide 22-37

QuickCheck 22.2

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

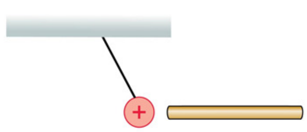


A. Positive.
B. Negative.
C. Neutral.
D. Either A or C.
E. Either B or C.

Slide 22-38

QuickCheck 22.2

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

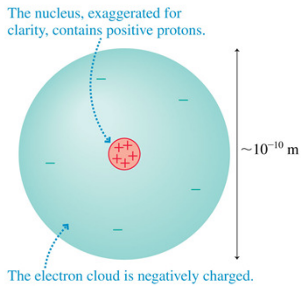


A. Positive.
B. Negative.
C. Neutral.
D. Either A or C.
✔**E. Either B or C.**

Slide 22-39

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*.



 Slide 22-40

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 22.1 Protons and electrons

Particle	Mass (kg)	Charge
Proton	1.67×10^{-27}	$+e$
Electron	9.11×10^{-31}	$-e$

 Slide 22-41

Charge Quantization

- A macroscopic object has net charge:

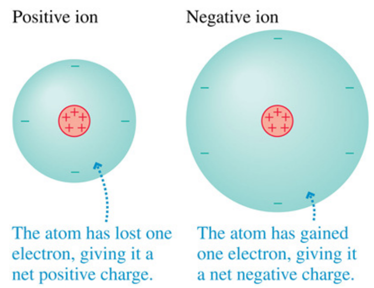
$$q = N_p e - N_e e = (N_p - N_e)e$$

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**.

 Slide 22-42

Atoms and Electricity

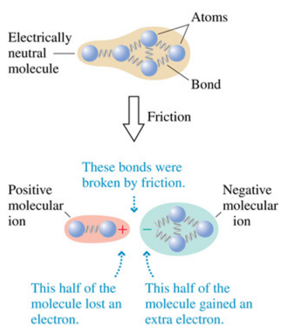
- The process of removing an electron from the electron cloud of an atom, or adding an electron to it, is called **ionization**.



 Slide 22-43

Atoms and Electricity

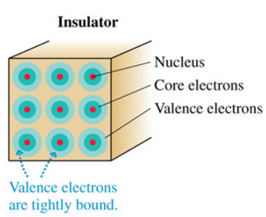
- *Molecular ions* can be created when one of the bonds in a large molecule is broken.
- This is the way in which a plastic rod is charged by rubbing with wool or a comb is charged by passing through your hair.



 Slide 22-44

Insulators

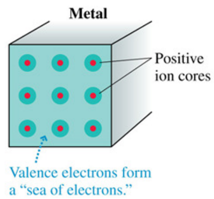
- The electrons in an **insulator** are all tightly bound to the positive nuclei and not free to move around.
- Charging an insulator by friction leaves patches of molecular ions on the surface, but these patches are immobile.



 Slide 22-45

Conductors

- 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.

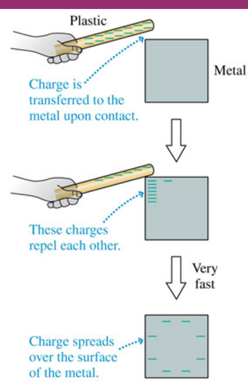


- The solid *as a whole* remains electrically neutral, but the electrons are now like a negatively charged liquid permeating an array of positively charged **ion cores**.

Slide 22-46

Charging

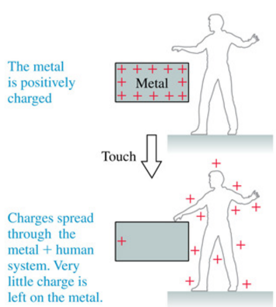
- The figure shows how a conductor is charged by contact with a charged plastic rod.
- Electrons in a conductor are free to move.
- Once charge is transferred to the metal, repulsive forces between the electrons cause them to move apart from each other.



Slide 22-47

Discharging

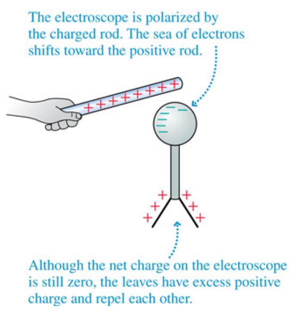
- The figure shows how touching a charged metal discharges it.
- Any excess charge that was initially confined to the metal can now spread over the larger metal + human conductor.



Slide 22-48

Charge Polarization

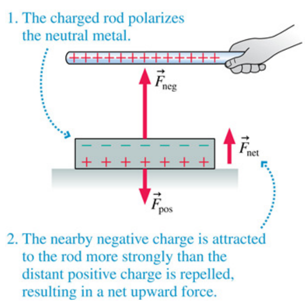
- The figure shows how a charged rod held close to an electroscope causes the leaves to repel each other.
- How do charged objects of either sign exert an attractive force on a *neutral* object?



 Slide 22-49

Charge Polarization

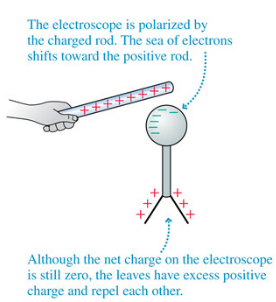
- Although the metal as a whole is still electrically neutral, we say that the object has been *polarized*.
- **Charge polarization** is a slight separation of the positive and negative charges in a neutral object.



 Slide 22-50

Charge Polarization

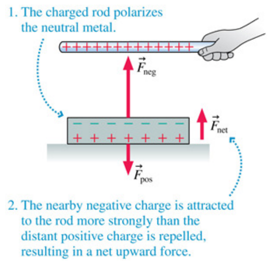
- Charge polarization produces an excess positive charge on the leaves of the electroscope, so they repel each other.
- Because the electroscope has no *net* charge, the electron sea quickly readjusts once the rod is removed.



 Slide 22-51

Polarization Force

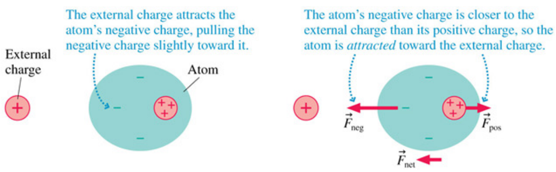
- The figure shows a positively charged rod near a neutral piece of metal.
- Because the electric force decreases with distance, the attractive force on the electrons at the top surface is *slightly greater* than the repulsive force on the ions at the bottom.
- The net force toward the charged rod is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



 Slide 22-52

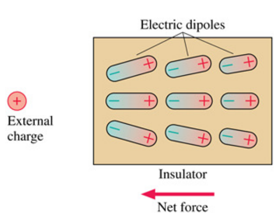
The Electric Dipole

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



 Slide 22-53

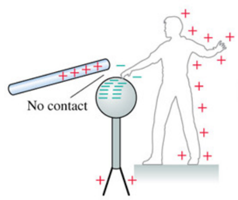
The Electric Dipole



- 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.

 Slide 22-54

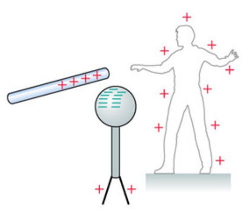
Charging by Induction: Step 1



1. The charged rod polarizes the electroscope + person conductor. The leaves repel slightly due to polarization.

Slide 22-55

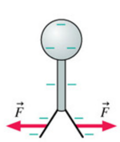
Charging by Induction: Step 2



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

Slide 22-56

Charging by Induction: Step 3

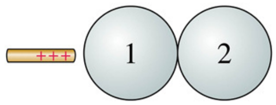


3. When the rod is removed, the leaves first collapse as the polarization vanishes, then repel as the excess negative charge spreads out.

Slide 22-57

QuickCheck 22.3

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

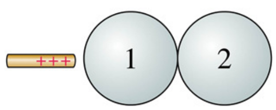


A. Q_1 is + and Q_2 is +
B. Q_1 is + and Q_2 is –
C. Q_1 is – and Q_2 is +
D. Q_1 is – and Q_2 is –
E. Q_1 is 0 and Q_2 is 0

Slide 22-58

QuickCheck 22.3

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

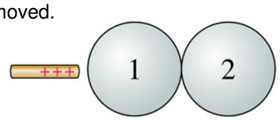


A. Q_1 is + and Q_2 is +
B. Q_1 is + and Q_2 is –
C. Q_1 is – and Q_2 is +
D. Q_1 is – and Q_2 is –
✔ **E. Q_1 is 0 and Q_2 is 0**

Slide 22-59

QuickCheck 22.4

Metal spheres 1 and 2 are touching. Both are initially neutral.
a. The charged rod is brought near.
b. The spheres are separated.
c. The charged rod is then removed.
Afterward, the charges on the sphere are

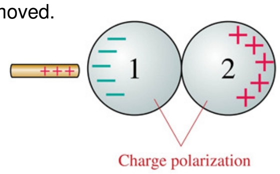


A. Q_1 is + and Q_2 is +
B. Q_1 is + and Q_2 is –
C. Q_1 is – and Q_2 is +
D. Q_1 is – and Q_2 is –
E. Q_1 is 0 and Q_2 is 0

Slide 22-60

QuickCheck 22.4

Metal spheres 1 and 2 are touching. Both are initially neutral.
a. The charged rod is brought near.
b. The spheres are separated.
c. The charged rod is then removed.
Afterward, the charges on the sphere are



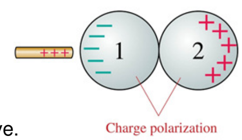
A. Q_1 is + and Q_2 is +
B. Q_1 is + and Q_2 is –
✔**C. Q_1 is – and Q_2 is +**
D. Q_1 is – and Q_2 is –
E. Q_1 is 0 and Q_2 is 0

Net charge is obtained if contact is broken while the spheres are polarized. This is *charging by induction.*

 Slide 22-61

QuickCheck 22.5

Based on the last experiment, where two spheres were charged by induction, we can conclude that

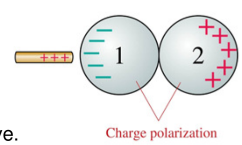


A. Only the – charges move.
B. Only the + charges move.
C. Both the + and – charges move.
D. We can draw no conclusion about which charges move.

 Slide 22-62

QuickCheck 22.5

Based on the last experiment, where two spheres were charged by induction, we can conclude that

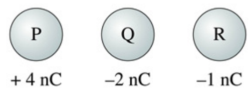


A. Only the – charges move.
B. Only the + charges move.
C. Both the + and – charges move.
✔**D. We can draw no conclusion about which charges move.**

 Slide 22-63

QuickCheck 22.6

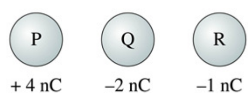
Identical metal spheres are initially charged as shown. Spheres P and Q are touched together and then separated. Then spheres Q and R are touched together and separated. Afterward the charge on sphere R is



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

QuickCheck 22.6

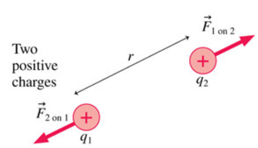
Identical metal spheres are initially charged as shown. Spheres P and Q are touched together and then separated. Then spheres Q and R are touched together and separated. Afterward the charge on sphere R is



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.

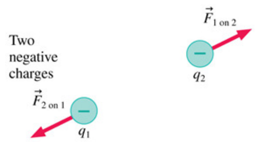


$$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{K|q_1||q_2|}{r^2}$$

- 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.



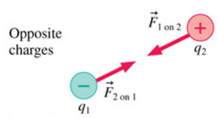
$$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{K|q_1||q_2|}{r^2}$$

- In SI units $K = 8.99 \times 10^9$ N m^2/C^2

Slide 22-67

Coulomb's Law

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



$$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{K|q_1||q_2|}{r^2}$$

- In SI units $K = 8.99 \times 10^9$ N m^2/C^2

Slide 22-68

Coulomb's Law

Coulomb's law

1. If two charged particles having charges q_1 and q_2 are a distance r apart, the particles exert forces on each other of magnitude

$$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{K|q_1||q_2|}{r^2}$$

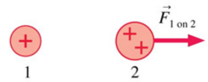
where K is called the **electrostatic constant.** These forces are an action/reaction pair, equal in magnitude and opposite in direction.
2. The forces are directed along the line joining the two particles. The forces are *repulsive* for two like charges and *attractive* for two opposite charges.

- In SI units $K = 8.99 \times 10^9$ N m^2/C^2

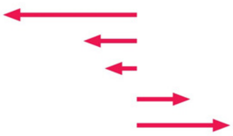
Slide 22-69

QuickCheck 22.7

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



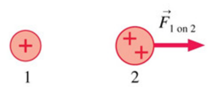
A.
B.
C.
D.
E.



Slide 22-70

QuickCheck 22.7

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

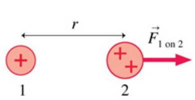


A.
✔**B.** Newton's third law
C.
D.
E.

Slide 22-71

QuickCheck 22.8

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 $r/2$?

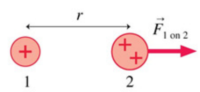


A.
B.
C.
D. None of the above.

Slide 22-72

QuickCheck 22.8

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 <u>four</u> times as large:

 Slide 22-73

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** ϵ_0:

$$\epsilon_0 = \frac{1}{4\pi K} = 8.85 \times 10^{-12}\ \mathrm{C^2/N\,m^2}$$

- Rewriting Coulomb's law in terms of ϵ_0 gives us

$$F = \frac{1}{4\pi\epsilon_0}\frac{|q_1||q_2|}{r^2}$$

 Slide 22-74

Problem-Solving Strategy: Electrostatic Forces and Coulomb's Law

PROBLEM-SOLVING STRATEGY 22.1

Electrostatic forces and Coulomb's law

MODEL Identify point charges or model objects as point charges.

VISUALIZE Use a *pictorial representation* to establish a coordinate system, show the positions of the charges, show the force vectors on the charges, define distances and angles, and identify what the problem is trying to find. This is the process of translating words to symbols.

 Slide 22-75

Problem-Solving Strategy: Electrostatic Forces and Coulomb's Law

PROBLEM-SOLVING STRATEGY 22.1

Electrostatic forces and Coulomb's law

SOLVE The mathematical representation is based on Coulomb's law:

$$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{K|q_1||q_2|}{r^2}$$

- Show the directions of the forces—repulsive for like charges, attractive for opposite charges—on the pictorial representation.
- When possible, do graphical vector addition on the pictorial representation. While not exact, it tells you the type of answer you should expect.
- Write each force vector in terms of its x- and y-components, then add the components to find the net force. Use the pictorial representation to determine which components are positive and which are negative.

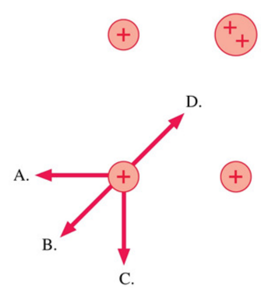
ASSESS Check that your result has correct units and significant figures, is reasonable, and answers the question.

Exercise 26

Slide 22-76

QuickCheck 22.9

Which is the direction of the net force on the charge at the lower left?

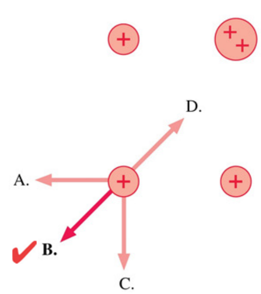


E. None of these.

Slide 22-77

QuickCheck 22.9

Which is the direction of the net force on the charge at the lower left?

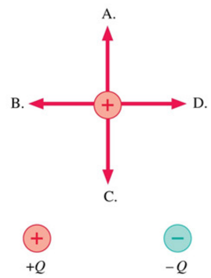


E. None of these.

Slide 22-78

QuickCheck 22.10

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

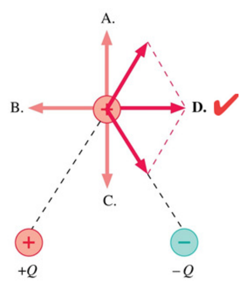


E. None of these.

Slide 22-79

QuickCheck 22.10

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



E. None of these.

Slide 22-80

Example 22.3 Lifting a Glass Bead

EXAMPLE 22.3 **Lifting a glass bead**

A small plastic sphere charged to −10 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 nC. Will the glass bead "leap up" to the plastic sphere?

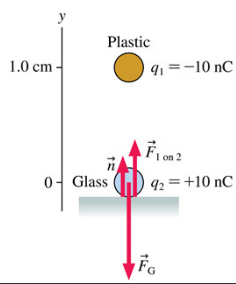
MODEL Model the plastic sphere and glass bead as point charges.

Slide 22-81

Example 22.3 Lifting a Glass Bead

EXAMPLE 22.3 Lifting a glass bead

VISUALIZE FIGURE 22.16 establishes a y-axis, identifies the plastic sphere as q_1 and the glass bead as q_2, and shows a free-body diagram.



Slide 22-82

Example 22.3 Lifting a Glass Bead

EXAMPLE 22.3 Lifting a glass bead

SOLVE If $F_{1\text{ on }2}$ is less than the gravitational force $F_G = m_{\text{bead}}g$, then the bead will remain at rest on the table with $\vec{F}_{1\text{ on }2} + \vec{F}_G + \vec{n} = \vec{0}$. But if $F_{1\text{ on }2}$ is greater than $m_{\text{bead}}g$, the glass bead will accelerate upward from the table. Using the values provided, we have

$$F_{1\text{ on }2} = \frac{K|q_1||q_2|}{r^2}$$

$$= \frac{(9.0\times10^9\ \text{N m}^2/\text{C}^2)(10\times10^{-9}\,\text{C})(10\times10^{-9}\,\text{C})}{(0.010\ \text{m})^2}$$

$$= 9.0\times10^{-3}\ \text{N}$$

$$F_G = m_{\text{bead}}g = 1.5\times10^{-4}\ \text{N}$$

$F_{1\text{ on }2}$ exceeds $m_{\text{bead}}g$ by a factor of 60, so the glass bead will leap upward.

Slide 22-83

Example 22.3 Lifting a Glass Bead

EXAMPLE 22.3 Lifting a glass bead

ASSESS The values used in this example are realistic for spheres ≈ 2 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.

Slide 22-84

QuickCheck 22.11

The direction of the force on charge $-q$ is

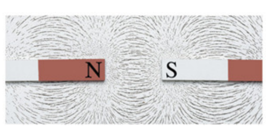
A. Up.
B. Down.
C. Left.
D. Right.
E. The force on $-q$ is zero.

QuickCheck 22.11

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.

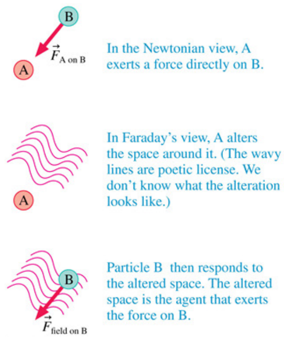
The Field Model



- 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.

The Field Model

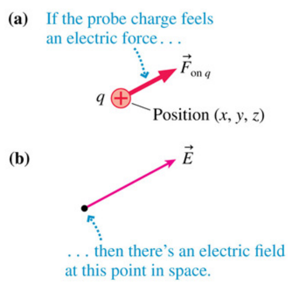
- A *field* is a function that assigns a vector to every point in space.
- The alteration of space around a mass is called the *gravitational field.*
- Similarly, the space around a charge is altered to create the **electric field**.



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 $\vec{E}$ at that point causing the force.

$$\vec{E}(x, y, z) = \frac{\vec{F}_{on\ q} \text{ at } (x, y, z)}{q}$$



- The units of the electric field are N/C. The magnitude E of the electric field is called the **electric field strength**.

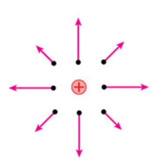
Electric Field

MODEL 22.2

Electric field

Charges interact via the electric field.

- The electric force on a charge is exerted by the electric field.
- The electric field is created by other charges, the **source charges.**
  - The electric force is a vector.
  - The field exists at all points in space.
  - A charge does not feel its own field.



- If the electric field at a point in space is $\vec{E}$, a particle with charge q experiences an electric force $\vec{F}_{on\ q} = q\vec{E}$.
  - The force on a positive charge is in the direction of the field.
  - The force on a negative charge is opposite the direction of the field.

Example 22.6 Electric Forces in a Cell

EXAMPLE 22.6 | **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 1.0×10^7 N/C. What is the magnitude of the electric force on a singly charged calcium ion?

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

Example 22.6 Electric Forces in a Cell

EXAMPLE 22.6 | **Electric forces in a cell**

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

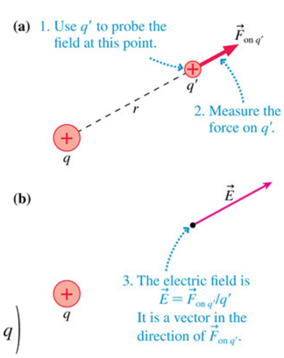
$$F = eE = (1.6 \times 10^{-19}\ \text{C})(1.0 \times 10^7\ \text{N/C}) = 1.6 \times 10^{-12}\ \text{N}$$

ASSESS This may seem like an incredibly tiny force, but it is applied to a particle with mass $m \sim 10^{-26}$ kg. The ion would have an unimaginable acceleration $(F/m \sim 10^{14}\ \text{m/s}^2)$ 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 μs.

The Electric Field of a Point Charge

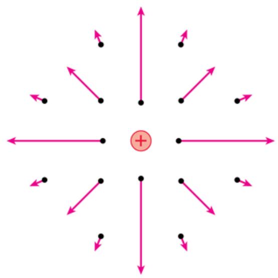
- Figure (a) shows charge q, and a point in space where we would like to know the electric field.
- We need a second charge, q', to serve as a probe for the electric field.
- The electric field, shown in figure (b), is given by

$$\vec{E} = \frac{\vec{F}_{\text{on } q'}}{q'} = \left(\frac{1}{4\pi\epsilon_0}\frac{q}{r^2}, \text{ away from } q\right)$$



The Electric Field of a Point Charge

- 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.



Slide 22-94

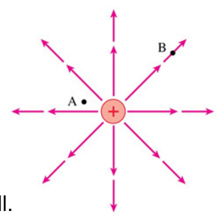
QuickCheck 22.12

At which point is the electric field stronger?

A. Point A

B. Point B

C. Not enough information to tell.



Slide 22-95

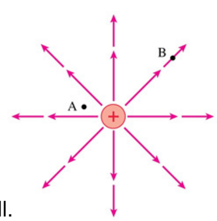
QuickCheck 22.12

At which point is the electric field stronger?

✔ **A. Point A**

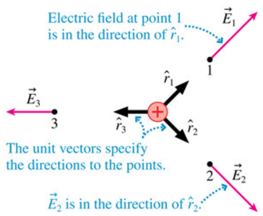
B. Point B

C. Not enough information to tell.



Slide 22-96

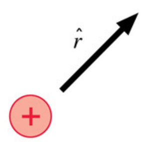
Unit Vector Notation



- The figure shows unit vectors pointing toward points 1, 2, and 3.
- Unit vector $\hat{r}$ specifies the direction "straight outward from this point."
- That's what we need to describe the electric field vector at points 1, 2 and 3 due to a positive charge at the origin.
- The electric field $\vec{E}$ points in the direction of the unit vector $\hat{r}$.

QuickCheck 22.13

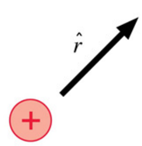
The units of unit vector $\hat{r}$ are



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

QuickCheck 22.13

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



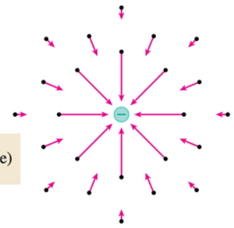
A. Meters.
B. Coulombs.
C. The units depend on how it is used.
✔ **D. The unit vector has no units.**

The Electric Field of a Point Charge

- Using unit vector notation, the electric field at a distance r from a point charge q is

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r} \quad \text{(electric field of a point charge)}$$

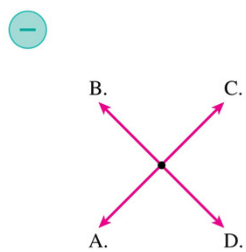
- A negative sign in front of a vector simply reverses its direction.
- The figure shows the electric field of a negative point charge.



Slide 22-100

QuickCheck 22.14

Which is the electric field at the dot?

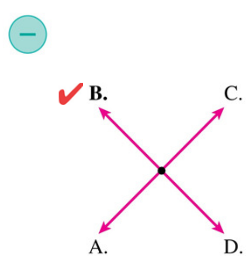


E. None of these.

Slide 22-101

QuickCheck 22.14

Which is the electric field at the dot?



E. None of these.

Slide 22-102

Example 22.8 The Electric Field of a Proton

EXAMPLE 22.8 The electric field of a proton

The electron in a hydrogen atom orbits the proton at a radius of 0.053 nm.

a. What is the proton's electric field strength at the position of the electron?

b. What is the magnitude of the electric force on the electron?

Example 22.8 The Electric Field of a Proton

EXAMPLE 22.8 The electric field of a proton

SOLVE a. The proton's charge is $q = e$. Its electric field strength at the distance of the electron is

$$E = \frac{1}{4\pi\epsilon_0}\frac{e}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{1.6 \times 10^{-19}\ \text{C}}{(5.3 \times 10^{-11}\ \text{m})^2} = 5.1 \times 10^{11}\ \text{N/C}$$

Note how large this field is compared to the field of Example 22.7.

Example 22.8 The Electric Field of a Proton

EXAMPLE 22.8 The electric field of a proton

SOLVE 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

$$\begin{aligned} F_{\text{on elec}} &= |q_e|E_{\text{of proton}} \\ &= (1.60 \times 10^{-19}\ \text{C})(5.1 \times 10^{11}\ \text{N/C}) \\ &= 8.2 \times 10^{-8}\ \text{N} \end{aligned}$$

Chapter 22 Summary Slides

Slide 22-106

General Principles

Coulomb's Law

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

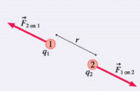
$$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{K|q_1||q_2|}{r^2}$$

The forces are repulsive for two like charges, attractive for two opposite charges.

To solve electrostatic force problems:

MODEL Model objects as point charges.

VISUALIZE Draw a picture showing charges and force vectors.



SOLVE Use Coulomb's law and the vector addition of forces.

ASSESS Is the result reasonable?

Slide 22-107

Important Concepts

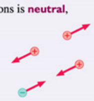
The Charge Model

There are two kinds of charge, positive and negative.

- Fundamental charges are protons and electrons, with charge $\pm e$ where $e = 1.60 \times 10^{-19}$ C.
- Objects are charged by adding or removing electrons.
- The amount of charge is $q = (N_p - N_e)e$.
- 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.



Slide 22-108

Important Concepts

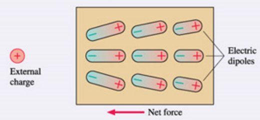
The Charge Model

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.



Slide 22-109

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_B is $\vec{F}_{\text{on B}} = q_B\vec{E}$.

Slide 22-110

Important Concepts

The Field Model

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

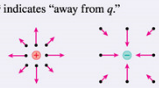
$$\vec{E} = \vec{F}_{\text{on } q}/q$$

- 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

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

Unit vector $\hat{r}$ indicates "away from q."



Slide 22-111