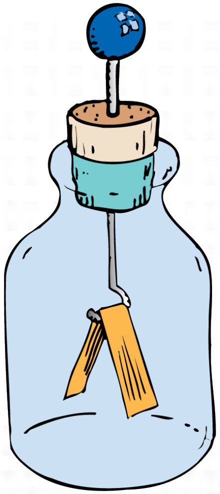


THE BIG IDEA

Electrostatics involves electric charges, the forces between them, and their behavior in materials.

Electrostatics, or electricity at rest, involves electric charges, the forces between them, and their behavior in materials. An understanding of electricity requires a step-by-step approach, for one concept is the building block for the next.

32.1 Electrical Forces and Charges

The fundamental rule at the base of all electrical phenomena is that like charges repel and opposite charges attract.

32.1 Electrical Forces and Charges

Consider a force acting on you that is billions upon billions of times stronger than gravity.

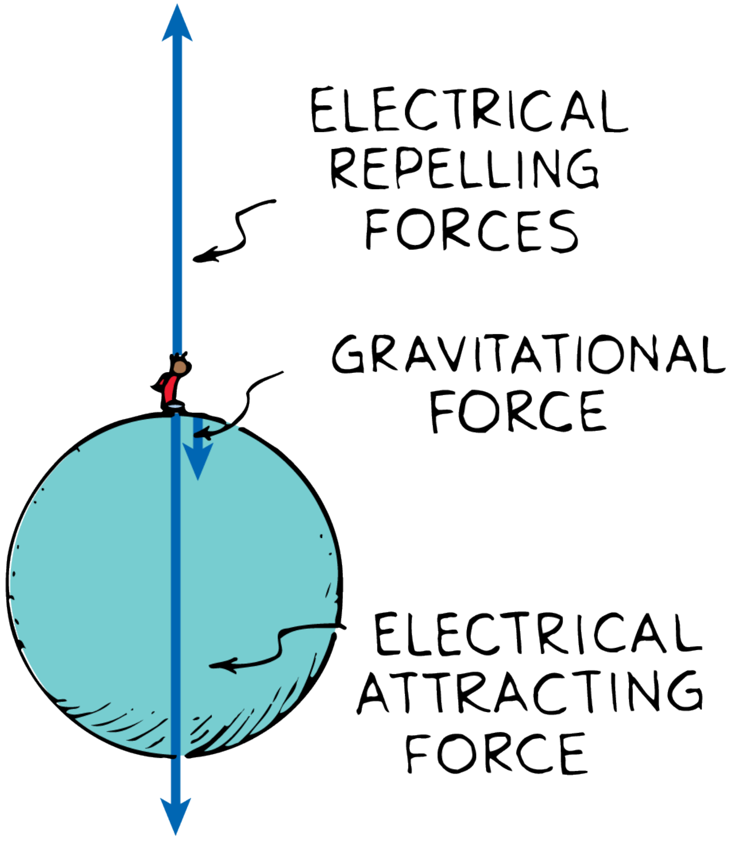
Suppose that in addition to this enormous force there is a repelling force, also billions upon billions of times stronger than gravity.

The two forces acting on you would balance each other and have no noticeable effect at all.

A pair of such forces acts on you all the time—electrical forces.

32.1 Electrical Forces and Charges

The enormous attractive and repulsive electrical forces between the charges in Earth and the charges in your body balance out, leaving the relatively weaker force of gravity, which only attracts.



32.1 Electrical Forces and Charges

The Atom

Electrical forces arise from particles in atoms.

The protons in the nucleus attract the electrons and hold them in orbit. Electrons are attracted to protons, but electrons repel other electrons.

32.1 Electrical Forces and Charges

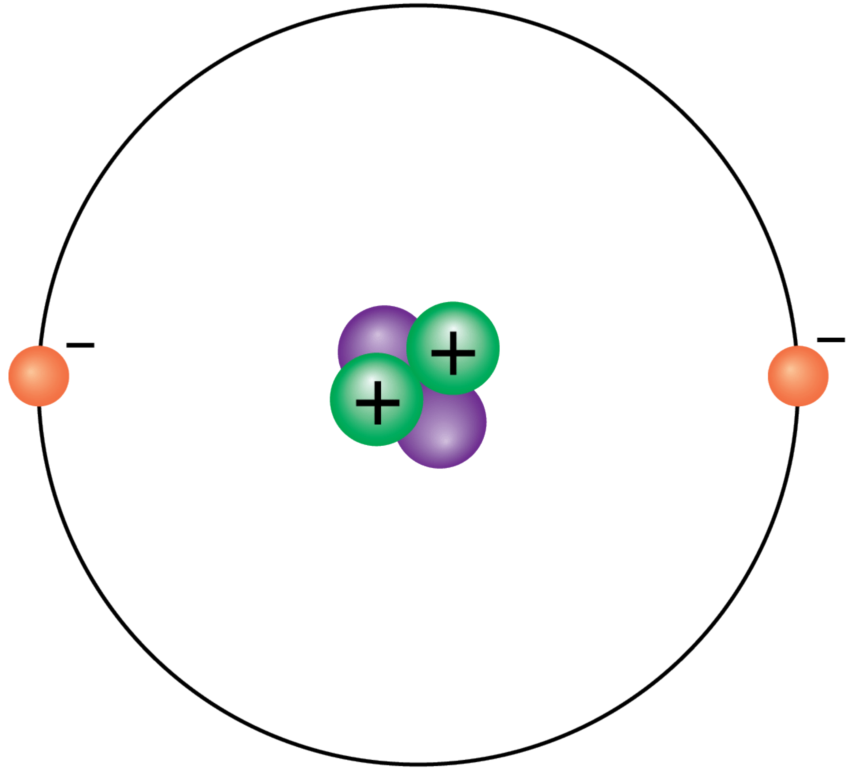
The fundamental electrical property to which the mutual attractions or repulsions between electrons or protons is attributed is called **charge.**

By convention, electrons are *negatively* charged and protons *positively* charged.

Neutrons have no charge, and are neither attracted nor repelled by charged particles.

32.1 Electrical Forces and Charges

The helium nucleus is composed of two protons and two neutrons. The positively charged protons attract two negative electrons.



32.1 Electrical Forces and Charges

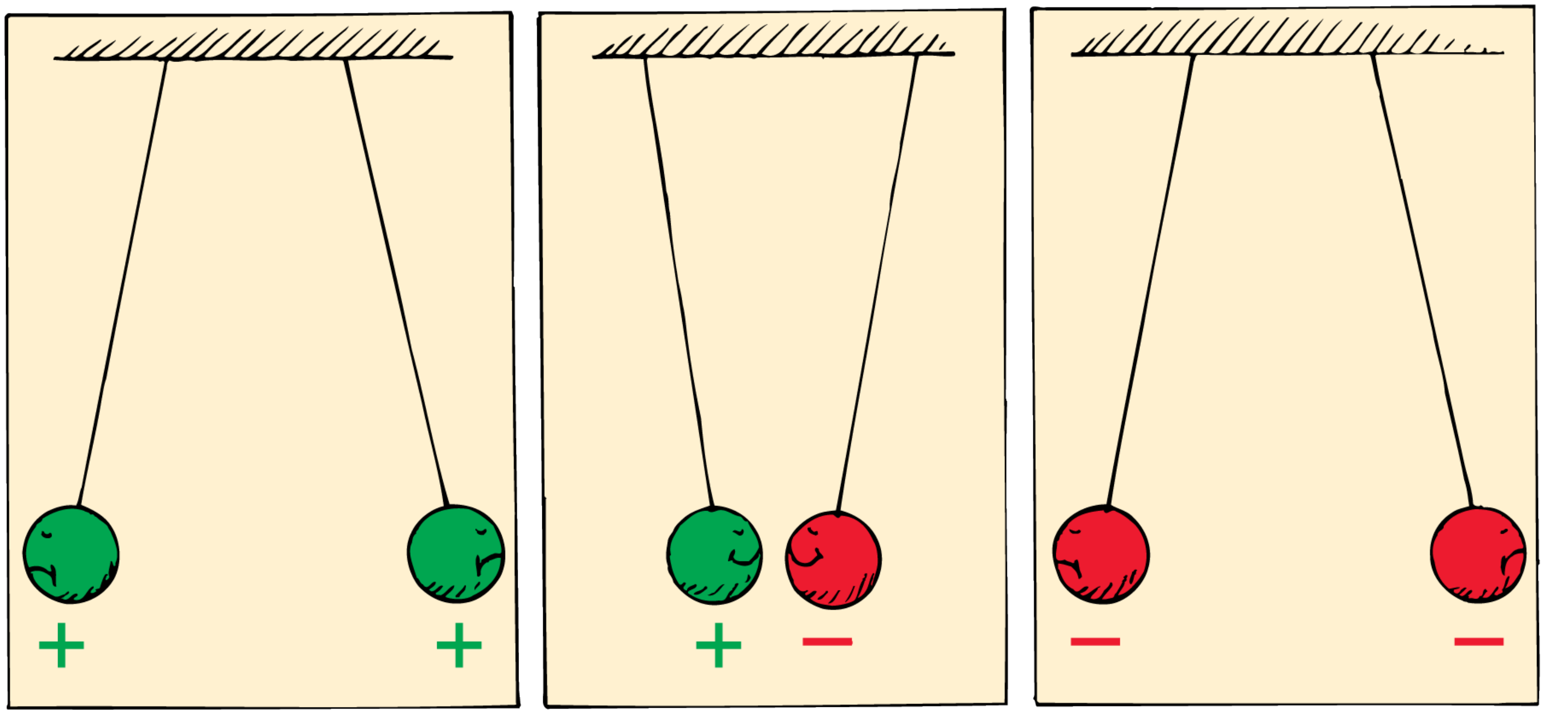
Here are some important facts about atoms:

- Every atom has a positively charged nucleus surrounded by negatively charged electrons.
- All electrons are identical.
- The nucleus is composed of protons and neutrons. All protons are identical; similarly, all neutrons are identical.
- Atoms usually have as many electrons as protons, so the atom has zero *net* charge.

A proton has nearly 2000 times the mass of an electron, but its positive charge is equal in magnitude to the negative charge of the electron.

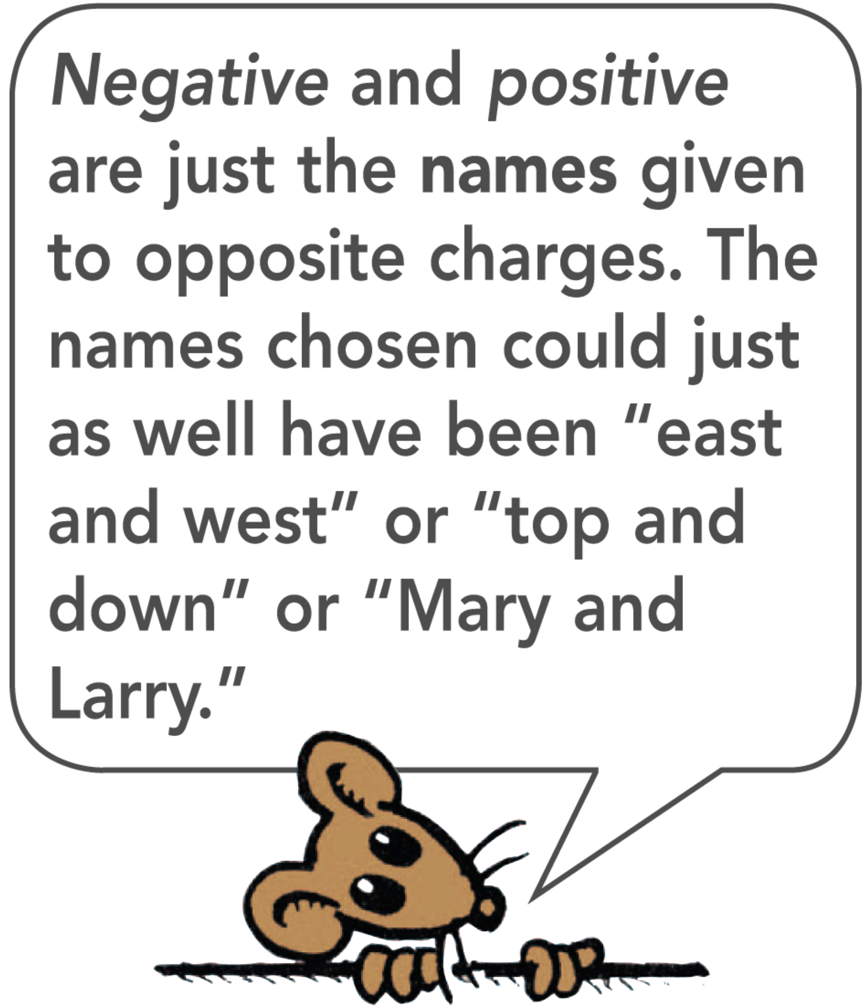
32.1 Electrical Forces and Charges

Attraction and Repulsion



32.1 Electrical Forces and Charges

The fundamental rule of all electrical phenomena is that like charges repel and opposite charges attract.



32.1 Electrical Forces and Charges

CONCEPT CHECK

What is the fundamental rule at the base of all electrical phenomena?

32.2 Conservation of Charge

An object that has unequal numbers of electrons and protons is electrically charged.

32.2 Conservation of Charge

Electrons and protons have electric charge.

In a neutral atom, there are as many electrons as protons, so there is no net charge.

32.2 Conservation of Charge

If an electron is removed from an atom, the atom is no longer neutral. It has one more positive charge than negative charge.

A charged atom is called an *ion.*

- A *positive ion* has a net positive charge; it has lost one or more electrons.
- A *negative ion* has a net negative charge; it has gained one or more extra electrons.

32.2 Conservation of Charge

Electrically Charged Objects

Matter is made of atoms, and atoms are made of electrons and protons.

An object that has equal numbers of electrons and protons has no net electric charge.

But if there is an imbalance in the numbers, the object is then electrically charged.

An imbalance comes about by adding or removing electrons.

32.2 Conservation of Charge

The innermost electrons in an atom are bound very tightly to the oppositely charged atomic nucleus.

The outermost electrons of many atoms are bound very loosely and can be easily dislodged.

How much energy is required to tear an electron away from an atom varies for different substances.

32.2 Conservation of Charge

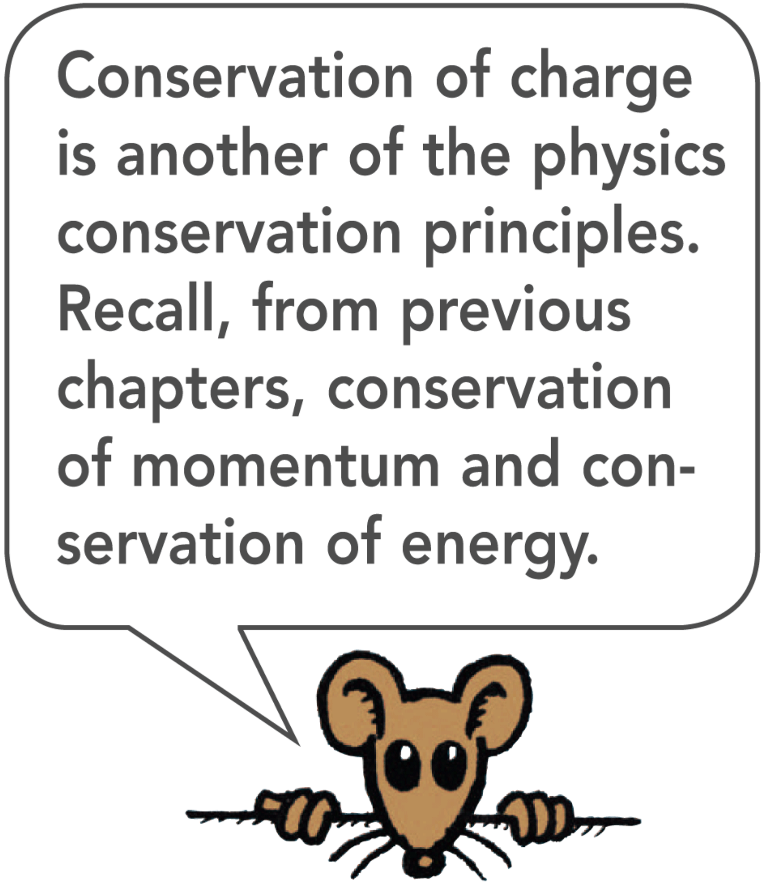
When electrons are transferred from the fur to the rod, the rod becomes negatively charged.

32.2 Conservation of Charge

Principle of Conservation of Charge

Electrons are neither created nor destroyed but are simply transferred from one material to another. This principle is known as **conservation of charge.**

In every event, whether large-scale or at the atomic and nuclear level, the principle of conservation of charge applies.



32.2 Conservation of Charge

Any object that is electrically charged has an excess or deficiency of some whole number of electrons—electrons cannot be divided into fractions of electrons.

This means that the charge of the object is a whole-number multiple of the charge of an electron.

32.2 Conservation of Charge

think!

If you scuff electrons onto your shoes while walking across a rug, are you negatively or positively charged?

32.2 Conservation of Charge

think!

If you scuff electrons onto your shoes while walking across a rug, are you negatively or positively charged?

Answer:

When your rubber- or plastic-soled shoes drag across the rug, they pick up electrons from the rug in the same way you charge a rubber or plastic rod by rubbing it with a cloth. You have more electrons after you scuff your shoes, so you are negatively charged (and the rug is positively charged).

32.2 Conservation of Charge

CONCEPT CHECK

What causes an object to become electrically charged?

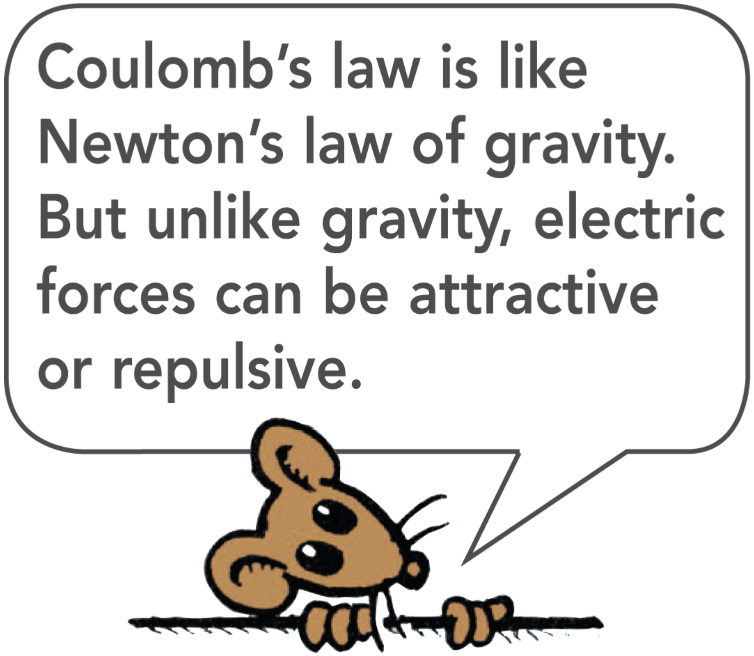
32.3 Coulomb's Law

Coulomb's law states that for charged particles or objects that are small compared with the distance between them, the force between the charges varies directly as the product of the charges and inversely as the square of the distance between them.

32.3 Coulomb's Law

Recall from Newton's law of gravitation that the gravitational force between two objects of mass m_1 and mass m_2 is proportional to the product of the masses and inversely proportional to the square of the distance d between them:

$$F = G\frac{m_1 m_2}{d^2}$$



32.3 Coulomb's Law

Force, Charges, and Distance

The electrical force between any two objects obeys a similar inverse-square relationship with distance.

The relationship among electrical force, charges, and distance—**Coulomb's law**—was discovered by the French physicist Charles Coulomb in the eighteenth century.

32.3 Coulomb's Law

For charged objects, the force between the charges varies directly as the product of the charges and inversely as the square of the distance between them.

$$F = k\frac{q_1 q_2}{d^2}$$

Where:
d is the distance between the charged particles.
q_1 represents the quantity of charge of one particle.
q_2 is the quantity of charge of the other particle.
k is the proportionality constant.

32.3 Coulomb's Law

The SI unit of charge is the **coulomb,** abbreviated C.

A charge of 1 C is the charge of 6.24×10^{18} electrons.

A coulomb represents the amount of charge that passes through a common 100-W light bulb in about one second.

32.3 Coulomb's Law

The Electrical Proportionality Constant

The proportionality constant *k* in Coulomb's law is similar to *G* in Newton's law of gravitation.

$k = 9{,}000{,}000{,}000\ \text{N}\cdot\text{m}^2/\text{C}^2$ or $9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$

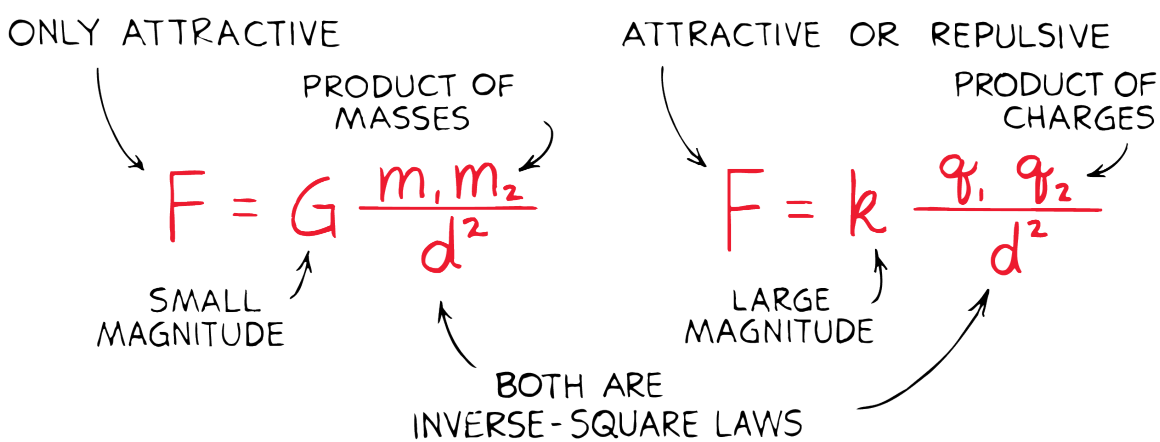
If a pair of charges of 1 C each were 1 m apart, the force of repulsion between the two charges would be
9 billion newtons.
That would be more than 10 times the weight of a battleship!

32.3 Coulomb's Law

Newton's law of gravitation for masses is similar to Coulomb's law for electric charges.

Whereas the gravitational force of attraction between a pair of one-kilogram masses is extremely small, the electrical force between a pair of one-coulomb charges is extremely large.

The greatest difference between gravitation and electrical forces is that gravity only attracts but electrical forces may attract or repel.



32.3 Coulomb's Law

Electrical Forces in Atoms

Because most objects have almost exactly equal numbers of electrons and protons, electrical forces usually balance out. Between Earth and the moon, for example, there is no measurable electrical force.

In general, the weak gravitational force, which only attracts, is the predominant force between astronomical bodies.

32.3 Coulomb's Law

Although electrical forces balance out for astronomical and everyday objects, at the atomic level this is not always true.

Often two or more atoms, when close together, share electrons.

Bonding results when the attractive force between the electrons of one atom and the positive nucleus of another atom is greater than the repulsive force between the electrons of both atoms. Bonding leads to the formation of molecules.

32.3 Coulomb’s Law

think!

What is the chief significance of the fact that *G* in Newton’s law of gravitation is a small number and *k* in Coulomb’s law is a large number when both are expressed in SI units?

32.3 Coulomb's Law

think!

What is the chief significance of the fact that *G* in Newton's law of gravitation is a small number and *k* in Coulomb's law is a large number when both are expressed in SI units?

Answer:

The small value of *G* indicates that gravity is a weak force; the large value of *k* indicates that the electrical force is enormous in comparison.

32.3 Coulomb's Law

think!

a. If an electron at a certain distance from a charged particle is attracted with a certain force, how will the force compare at twice this distance?

32.3 Coulomb's Law

think!

a. If an electron at a certain distance from a charged particle is attracted with a certain force, how will the force compare at twice this distance?

Answer:

a. In accord with the inverse-square law, at twice the distance the force will be one fourth as much.

32.3 Coulomb's Law

think!

a. If an electron at a certain distance from a charged particle is attracted with a certain force, how will the force compare at twice this distance?

b. Is the charged particle in this case positive or negative?

Answer:

a. In accord with the inverse-square law, at twice the distance the force will be one fourth as much.

32.3 Coulomb's Law

think!

a. If an electron at a certain distance from a charged particle is attracted with a certain force, how will the force compare at twice this distance?

b. Is the charged particle in this case positive or negative?

Answer:

a. In accord with the inverse-square law, at twice the distance the force will be one fourth as much.

b. Since there is a force of attraction, the charges must be opposite in sign, so the charged particle is positive.

32.3 Coulomb's Law

CONCEPT CHECK

What does Coulomb's law state?

32.4 Conductors and Insulators

Electrons move easily in good conductors and poorly in good insulators.

32.4 Conductors and Insulators

Outer electrons of the atoms in a metal are not anchored to the nuclei of particular atoms, but are free to roam in the material.

Materials through which electric charge can flow are called **conductors.**

Metals are good conductors for the motion of electric charges because their electrons are "loose."

32.4 Conductors and Insulators

Electrons in other materials—rubber and glass, for example—are tightly bound and remain with particular atoms.

They are not free to wander about to other atoms in the material.

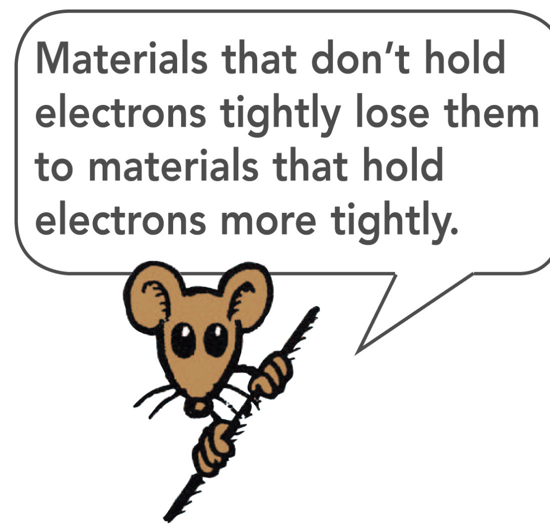
These materials, known as **insulators,** are poor conductors of electricity.

32.4 Conductors and Insulators

A substance is classified as a conductor or an insulator based on how tightly the atoms of the substance hold their electrons.

The conductivity of a metal can be more than a million trillion times greater than the conductivity of an insulator such as glass.

In power lines, charge flows much more easily through hundreds of kilometers of metal wire than through the few centimeters of insulating material that separates the wire from the supporting tower.



32.4 Conductors and Insulators

Semiconductors are materials that can be made to behave sometimes as insulators and sometimes as conductors.

Atoms in a semiconductor hold their electrons until given small energy boosts.

This occurs in photovoltaic cells that convert solar energy into electrical energy.

Thin layers of semiconducting materials sandwiched together make up *transistors*.

32.4 Conductors and Insulators

CONCEPT CHECK

What is the difference between a good conductor and a good insulator?

32.5 Charging by Friction and Contact

Two ways electric charge can be transferred are by friction and by contact.

32.5 Charging by Friction and Contact

We can stroke a cat's fur and hear the crackle of sparks that are produced.

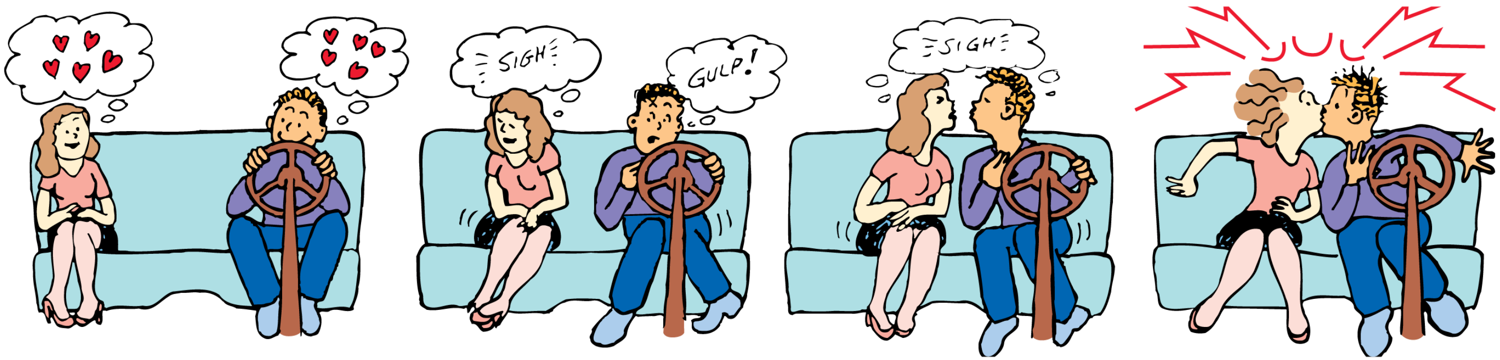
We can comb our hair in front of a mirror in a dark room and see as well as hear the sparks of electricity.

We can scuff our shoes across a rug and feel the tingle as we reach for the doorknob.

Electrons are being transferred by friction when one material rubs against another.

32.5 Charging by Friction and Contact

If you slide across a seat in an automobile, you are in danger of being charged by friction.



32.5 Charging by Friction and Contact

Electrons can also be transferred from one material to another by simply touching.

When a charged rod is placed in contact with a neutral object, some charge will transfer to the neutral object.

This method of charging is called *charging by contact.*

If the object is a good conductor, the charge will spread to all parts of its surface because the like charges repel each other.

32.5 Charging by Friction and Contact

CONCEPT CHECK

What are two ways electric charge can be transferred?

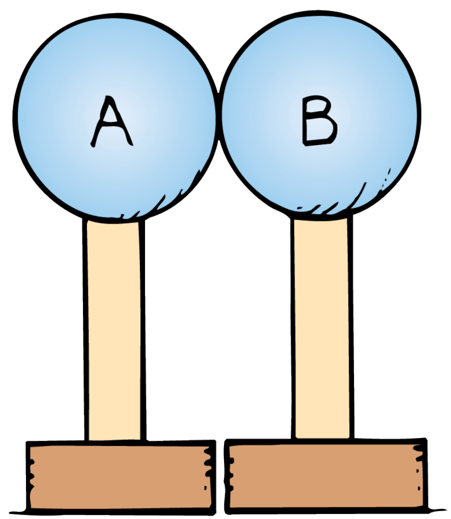
32.6 Charging by Induction

If a charged object is brought *near* a conducting surface, even without physical contact, electrons will move in the conducting surface.

32.6 Charging by Induction

Charging by induction can be illustrated using two insulated metal spheres.

Uncharged insulated metal spheres touching each other, in effect, form a single noncharged conductor.



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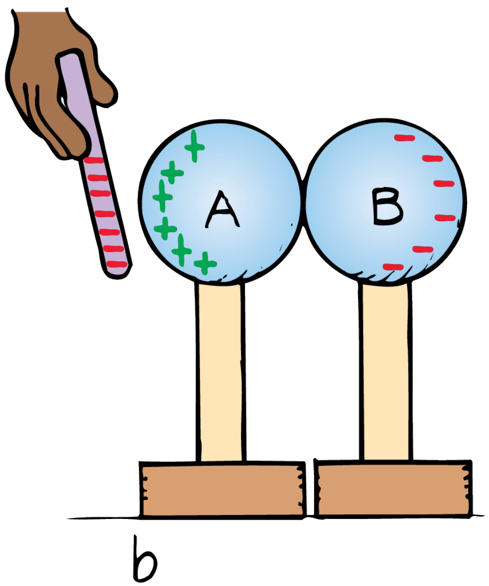
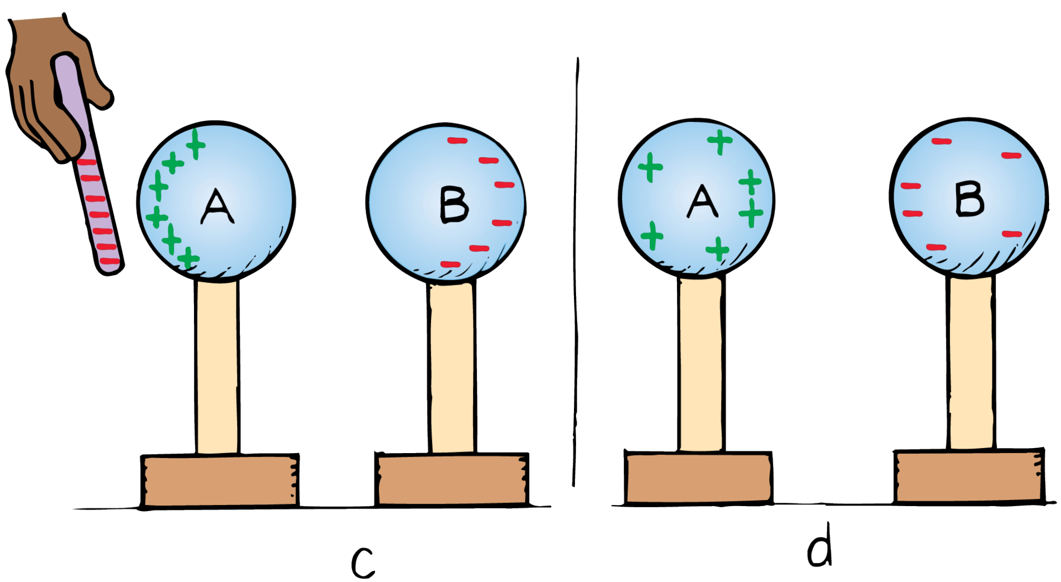
32.6 Charging by Induction

- When a negatively charged rod is held near one sphere, electrons in the metal are repelled by the rod.
- Excess negative charge has moved to the other sphere, leaving the first sphere with an excess positive charge.
- The charge on the spheres has been redistributed, or **induced.**



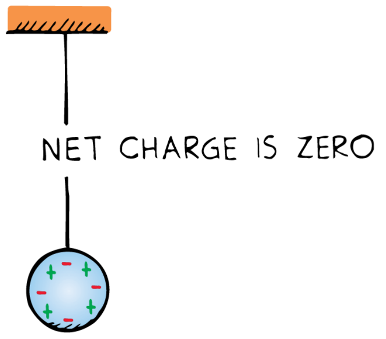
32.6 Charging by Induction

- When the spheres are separated and the rod removed, the spheres are charged equally and oppositely.
- They have been charged by **induction,** which is the charging of an object without direct contact.



32.6 Charging by Induction

Charge induction by grounding can be illustrated using a metal sphere hanging from a nonconducting string.



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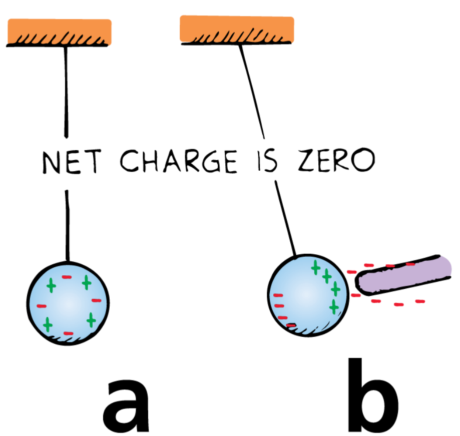
32.6 Charging by Induction

Charge induction by grounding can be illustrated using a metal sphere hanging from a nonconducting string.

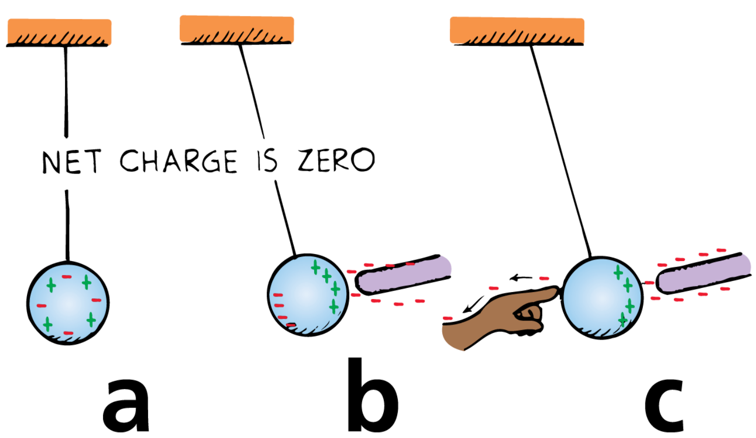
- A charge redistribution is induced by the presence of the charged rod. The net charge on the sphere is still zero.



32.6 Charging by Induction

Charge induction by grounding can be illustrated using a metal sphere hanging from a nonconducting string.

- A charge redistribution is induced by the presence of the charged rod. The net charge on the sphere is still zero.
- Touching the sphere removes electrons by contact and the sphere is left positively charged.



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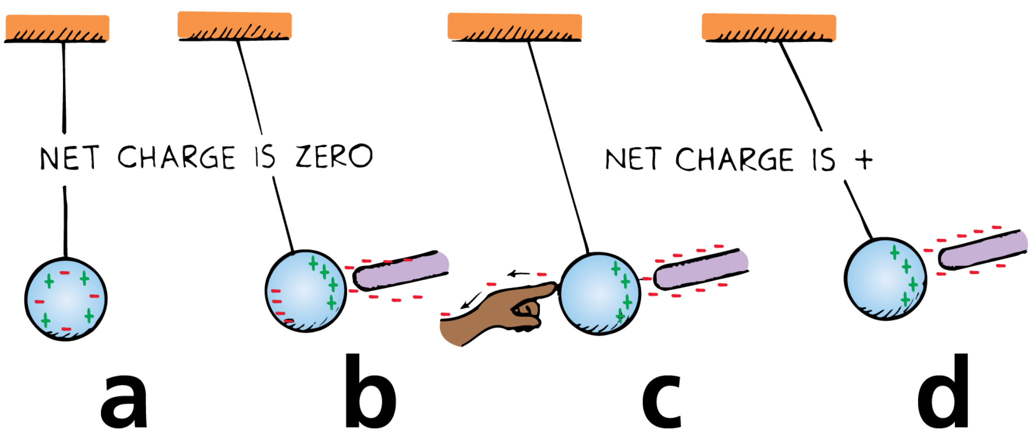
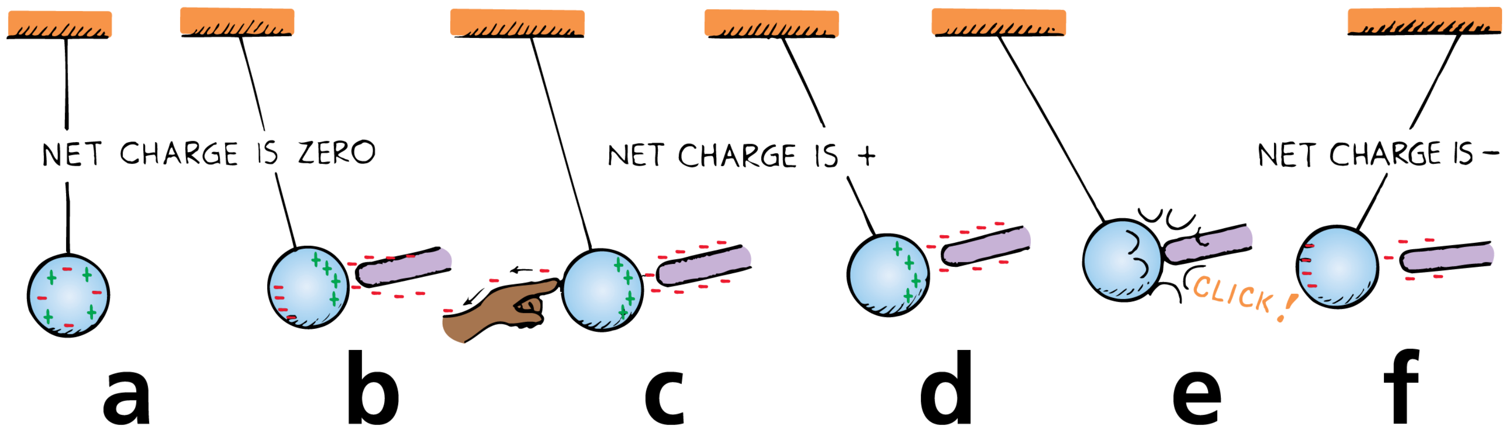
- A charge redistribution is induced by the presence of the charged rod. The net charge on the sphere is still zero.
- Touching the sphere removes electrons by contact and the sphere is left positively charged.
- The positively charged sphere is attracted to a negative rod.



32.6 Charging by Induction

Charge induction by grounding can be illustrated using a metal sphere hanging from a nonconducting string.

- A charge redistribution is induced by the presence of the charged rod. The net charge on the sphere is still zero.
- Touching the sphere removes electrons by contact and the sphere is left positively charged.
- The positively charged sphere is attracted to a negative rod.
- When electrons move onto the sphere from the rod, it becomes negatively charged by contact.



32.6 Charging by Induction

When we touch the metal surface with a finger, charges that repel each other have a conducting path to a practically infinite reservoir for electric charge—the ground.

When we allow charges to move off (or onto) a conductor by touching it, we are **grounding** it.

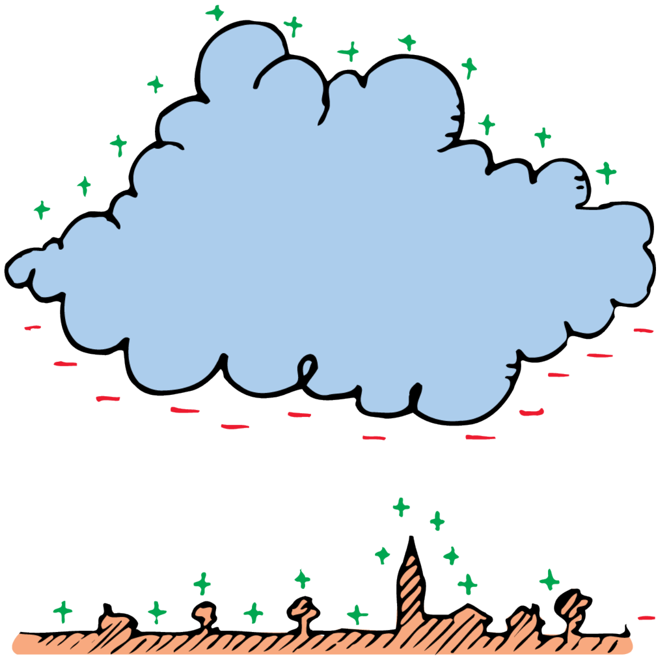
32.6 Charging by Induction

Charging by induction occurs during thunderstorms.

The negatively charged bottoms of clouds induce a positive charge on the surface of Earth below.

Most lightning is an electrical discharge between oppositely charged parts of clouds.

The kind of lightning we are most familiar with is the electrical discharge between clouds and oppositely charged ground below.



32.6 Charging by Induction

If a rod is placed above a building and connected to the ground, the point of the rod collects electrons from the air.

This prevents a buildup of positive charge by induction.

The primary purpose of the lightning rod is to prevent a lightning discharge from occurring.

If lightning does strike, it may be attracted to the rod and short-circuited to the ground, sparing the building.

32.6 Charging by Induction

think!

Why does the negative rod in the two-sphere example have the same charge before and after the spheres are charged, but not when charging takes place in the single-sphere example?

32.6 Charging by Induction

think!

Why does the negative rod in the two-sphere example have the same charge before and after the spheres are charged, but not when charging takes place in the single-sphere example?

Answer:

In the first charging process, no contact was made between the negative rod and either of the spheres. In the second charging process, however, the rod touched the sphere when it was positively charged. A transfer of charge by contact reduced the negative charge on the rod.

32.6 Charging by Induction

CONCEPT CHECK

What happens when a charged object is placed near a conducting surface?

32.7 Charge Polarization

Charge polarization can occur in insulators that are *near* a charged object.

32.7 Charge Polarization

Charging by induction is not restricted to conductors. Charge polarization can occur in insulators that are *near* a charged object.

When a charged rod is brought near an insulator, there are no free electrons to migrate throughout the insulating material. Instead, there is a rearrangement of the positions of charges within the atoms and molecules themselves.

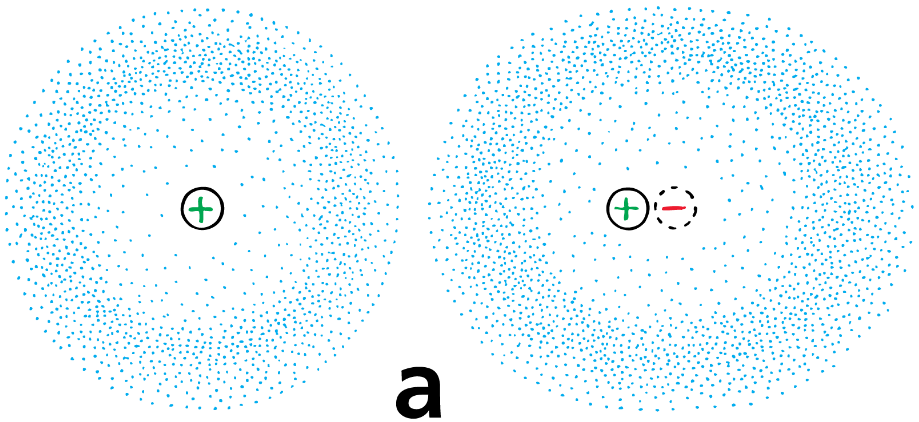
32.7 Charge Polarization

One side of the atom or molecule is induced to be slightly more positive (or negative) than the opposite side.

The atom or molecule is said to be **electrically polarized.**

32.7 Charge Polarization

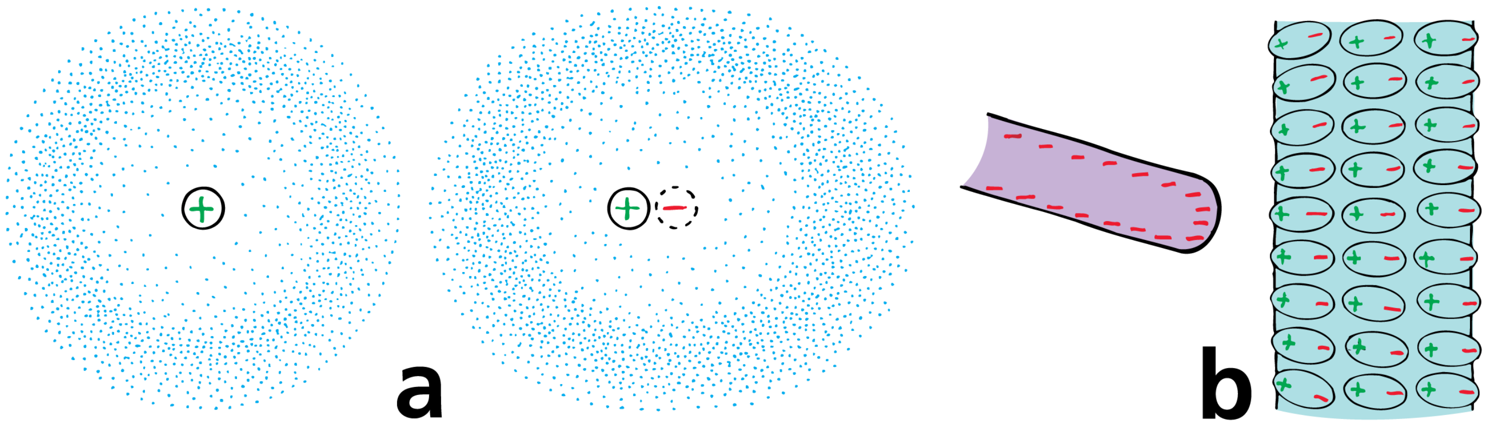
a. When an external negative charge is brought closer from the left, the charges within a neutral atom or molecule rearrange.



32.7 Charge Polarization

a. When an external negative charge is brought closer from the left, the charges within a neutral atom or molecule rearrange.

b. All the atoms or molecules near the surface of the insulator become electrically polarized.



32.7 Charge Polarization

Examples of Charge Polarization

Polarization explains why electrically neutral bits of paper are attracted to a charged object, such as a charged comb. Molecules are polarized in the paper, with the oppositely charged sides of molecules closest to the charged object.

32.7 Charge Polarization

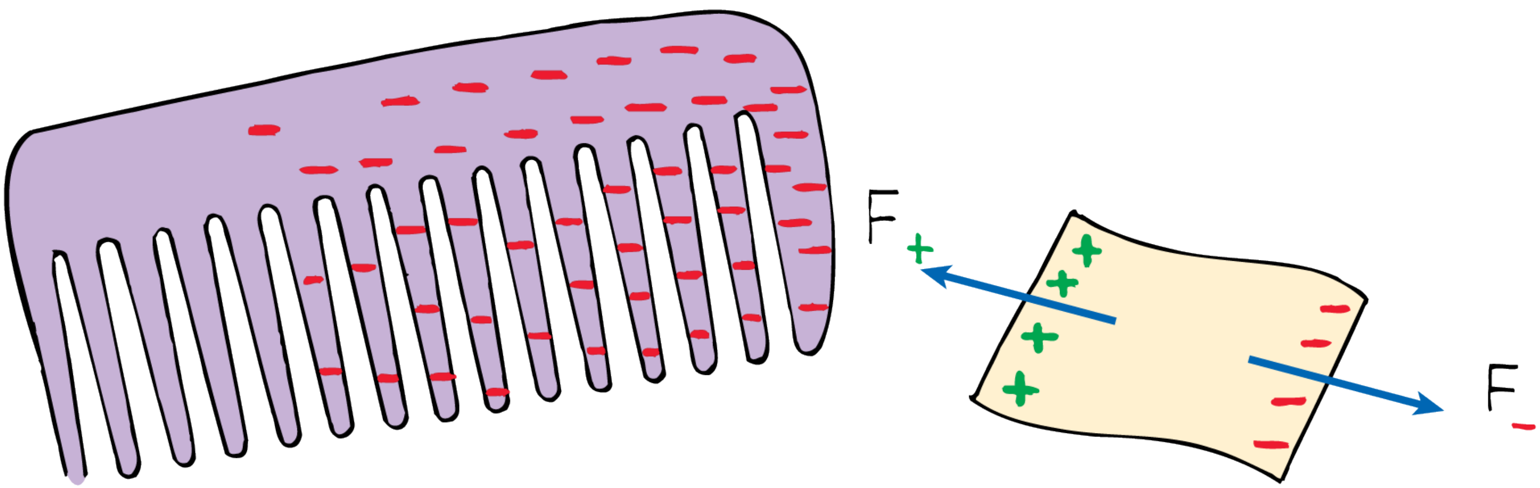
The bits of paper experience a net attraction.

Sometimes they will cling to the charged object and suddenly fly off.

Charging by contact has occurred; the paper bits have acquired the same sign of charge as the charged object and are then repelled.

32.7 Charge Polarization

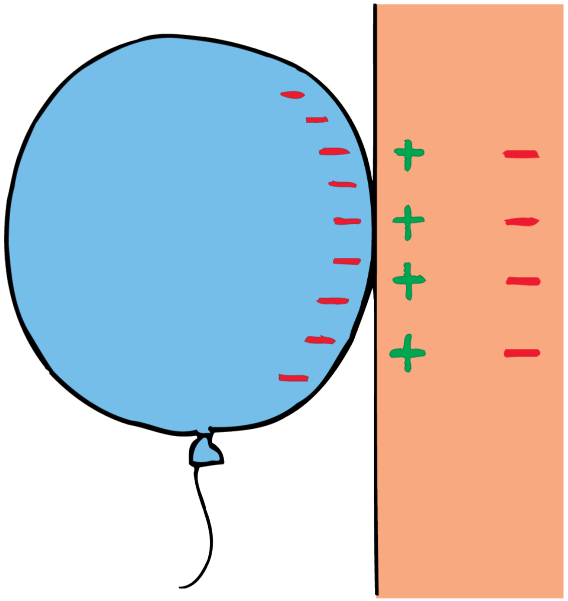
A charged comb attracts an uncharged piece of paper because the force of attraction for the closer charge is greater than the force of repulsion for the farther charge.

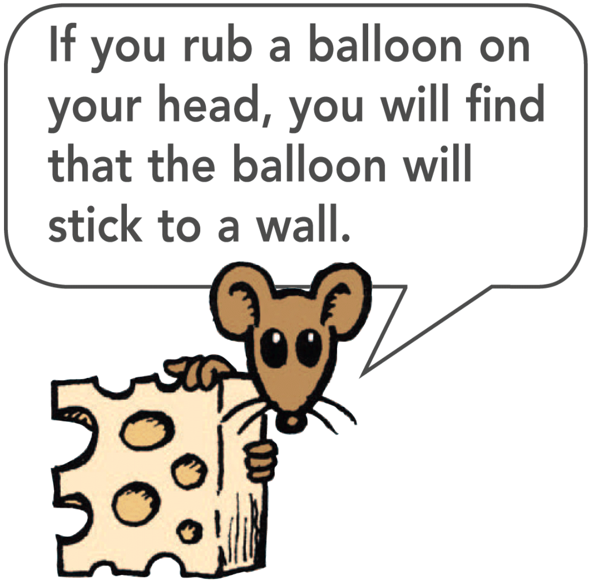


32.7 Charge Polarization

Rub an inflated balloon on your hair and it becomes charged. Place the balloon against the wall and it sticks.

The charge on the balloon induces an opposite surface charge on the wall. The charge on the balloon is slightly closer to the opposite induced charge than to the charge of the same sign.





32.7 Charge Polarization

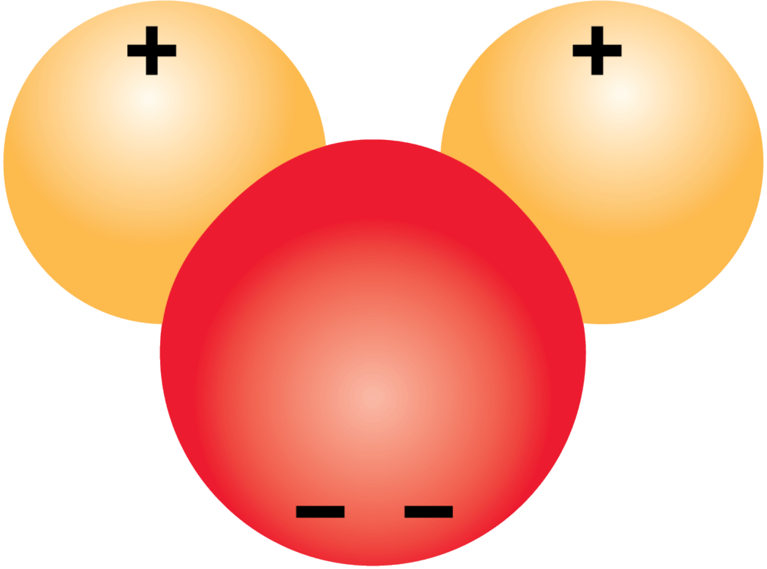
Electric Dipoles

Many molecules—H_2O, for example—are electrically polarized in their normal states.

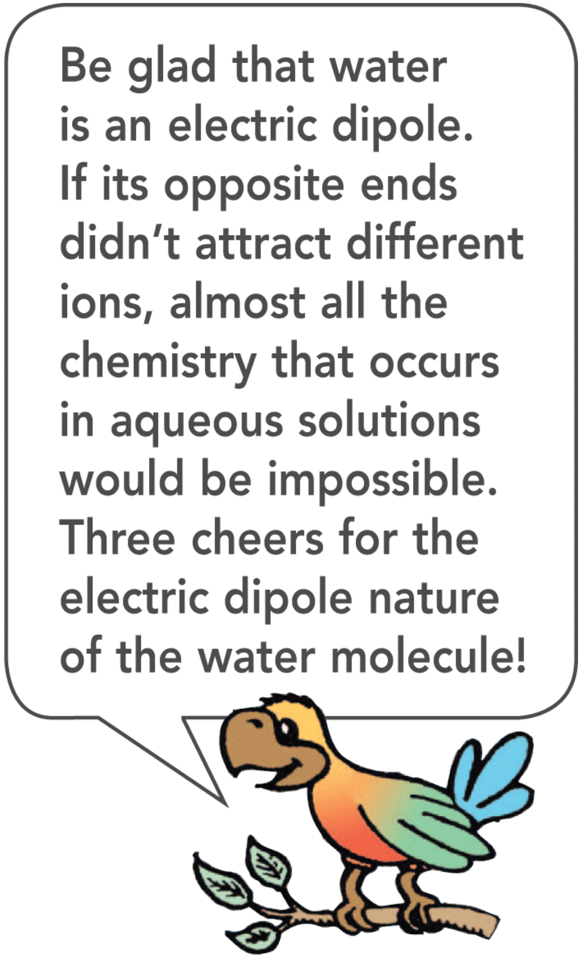
The distribution of electric charge is not perfectly even.

There is a little more negative charge on one side of the molecule than on the other.

Such molecules are said to be *electric dipoles.*



32.7 Charge Polarization



32.7 Charge Polarization

In summary, objects are electrically charged in three ways.

- By friction, when electrons are transferred by friction from one object to another.
- By contact, when electrons are transferred from one object to another by direct contact without rubbing.
- By induction, when electrons are caused to gather or disperse by the presence of nearby charge without physical contact.

32.7 Charge Polarization

If the object is an insulator, on the other hand, then a realignment of charge rather than a migration of charge occurs.

This is charge polarization, in which the surface near the charged object becomes oppositely charged.

32.7 Charge Polarization

CONCEPT CHECK

What happens when an insulator is in the presence of a charged object?

Assessment Questions

1. If a neutral atom has 22 protons in its nucleus, the number of surrounding electrons is
   a. less than 22.
   b. 22.
   c. more than 22.
   d. unknown.

Assessment Questions

1. If a neutral atom has 22 protons in its nucleus, the number of surrounding electrons is
   a. less than 22.
   b. 22.
   c. more than 22.
   d. unknown.

Answer: B

Assessment Questions

2. When we say charge is conserved, we mean that charge can
   a. be saved, like money in a bank.
   b. only be transferred from one place to another.
   c. take equivalent forms.
   d. be created or destroyed, as in nuclear reactions.

Assessment Questions

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   b. only be transferred from one place to another.
   c. take equivalent forms.
   d. be created or destroyed, as in nuclear reactions.

Answer: B

Assessment Questions

3. A difference between Newton's law of gravity and Coulomb's law is that only one of these
   a. is a fundamental physical law.
   b. uses a proportionality constant.
   c. invokes the inverse-square law.
   d. involves repulsive as well as attractive forces.

Assessment Questions

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   a. is a fundamental physical law.
   b. uses a proportionality constant.
   c. invokes the inverse-square law.
   d. involves repulsive as well as attractive forces.

Answer: D

Assessment Questions

4. Which is the predominant carrier of charge in copper wire?
   a. protons
   b. electrons
   c. ions
   d. neutrons

Assessment Questions

4. Which is the predominant carrier of charge in copper wire?
   a. protons
   b. electrons
   c. ions
   d. neutrons

Answer: B

Assessment Questions

5. When you scuff electrons off a rug with your shoes, your shoes are then
   a. negatively charged.
   b. positively charged.
   c. ionic.
   d. electrically neutral.

Assessment Questions

5. When you scuff electrons off a rug with your shoes, your shoes are then
   a. negatively charged.
   b. positively charged.
   c. ionic.
   d. electrically neutral.

Answer: A

Assessment Questions

6. When a cloud that is negatively charged on its bottom and positively charged on its top moves over the ground below, the ground acquires
   a. a negative charge.
   b. a positive charge.
   c. no charge since the cloud is electrically neutral.
   d. an electrically grounded state.

Assessment Questions

6. When a cloud that is negatively charged on its bottom and positively charged on its top moves over the ground below, the ground acquires
   a. a negative charge.
   b. a positive charge.
   c. no charge since the cloud is electrically neutral.
   d. an electrically grounded state.

Answer: B

Assessment Questions

7. When a negatively charged balloon is placed against a non-conducting wall, positive charges in the wall are
   a. attracted to the balloon.
   b. repelled from the balloon.
   c. too bound to negative charges in the wall to have any effect.
   d. neutralized.

Assessment Questions

7. When a negatively charged balloon is placed against a non-conducting wall, positive charges in the wall are
   a. attracted to the balloon.
   b. repelled from the balloon.
   c. too bound to negative charges in the wall to have any effect.
   d. neutralized.

Answer: A