PHY 201

Electricity and Magnetism

Dr. J. Romanos

CHAPTER 21

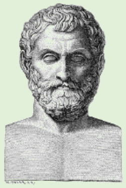
Electric Charge

Introduction

Brief History: Electric Charge

600 BC

Ancient Greek philosopher Thales of Miletus reported the attractive properties of amber when rubbed



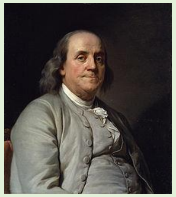
Thales of Miletus

17th Century

1675 AD, Robert Boyle: Electric attraction and repulsion in vacuum

18th Century

1729 AD, Stephen Gray: Materials are classified as conductors and insulators
1733 AD, du Fay: Two distinct types of electricity
1750 AD, Benjamin Franklin: positive and negative label
1770 AD, Coulomb: Inverse Square Law

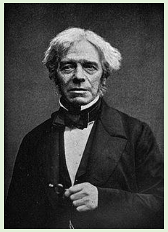


B. Franklin

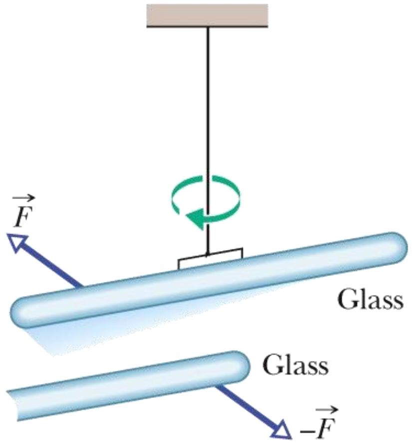
Coulomb

19th Century

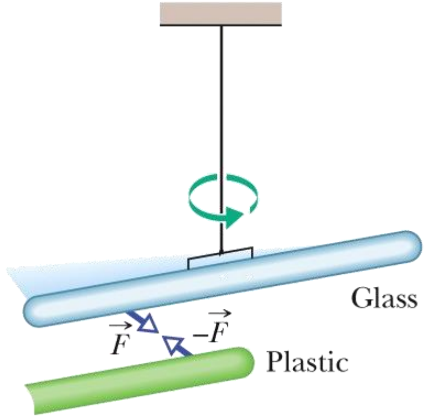
1839 AD, Michael Faraday: Electricity with different polarities
1890 AD J.J. Thompson: Quantization of electric charge



Faraday



(a)



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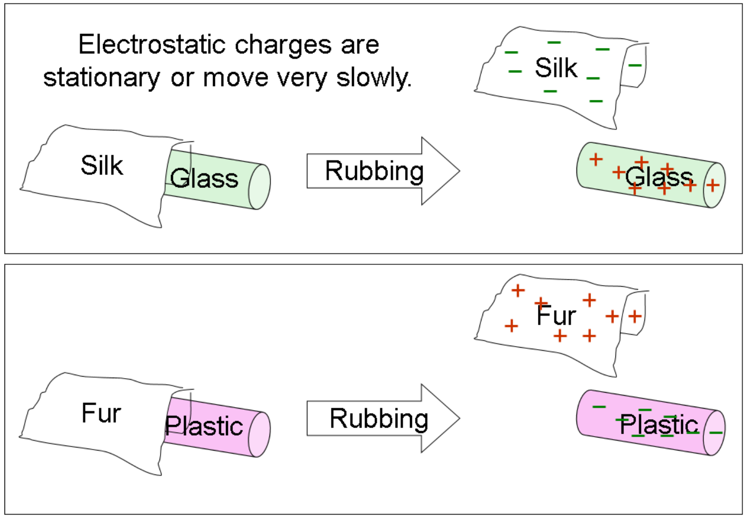
(a) The two glass rods were each rubbed with a silk cloth and one was suspended by thread. When they are close to each other, they repel each other.

(a) The plastic rod was rubbed with fur. When brought close to the glass rod, the rods attract each other.

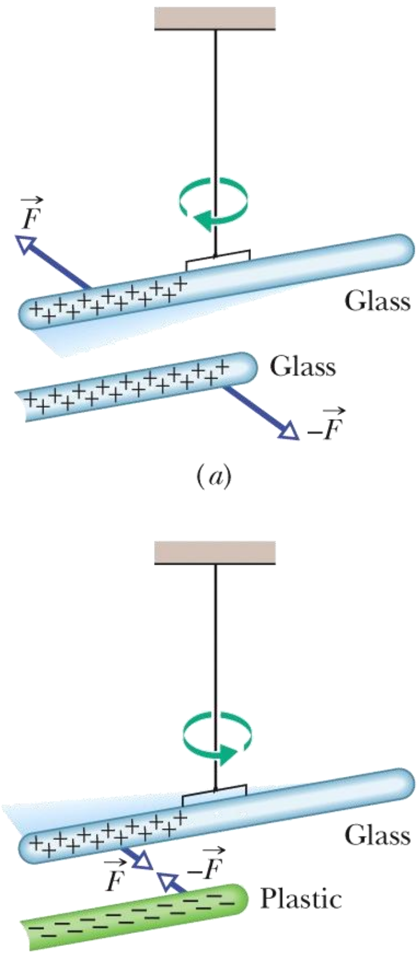
Charging by rubbing



Glass rubbed with silk cloth: glass + and silk -

Plastic rubbed with fur: plastic - and fur +

Electric Charge



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(a) Two charged rods of the same sign repel each other.

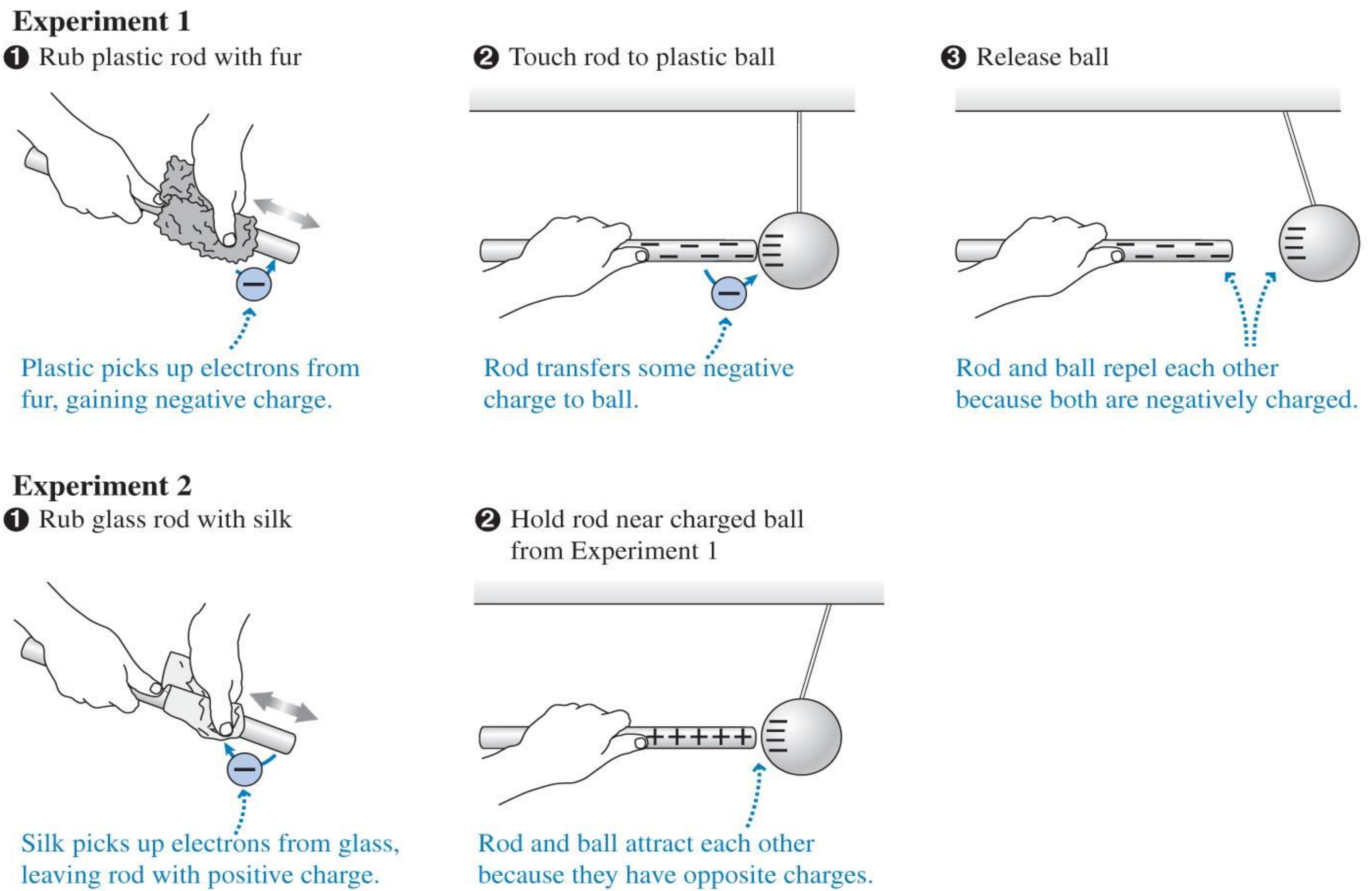
(b) Two charged rods of opposite signs attract each other. Plus signs indicate a positive net charge, and minus signs indicate a negative net charge.

Particles with the same sign of electrical charge repel each other, and particles with opposite signs attract each other.

Charging by:

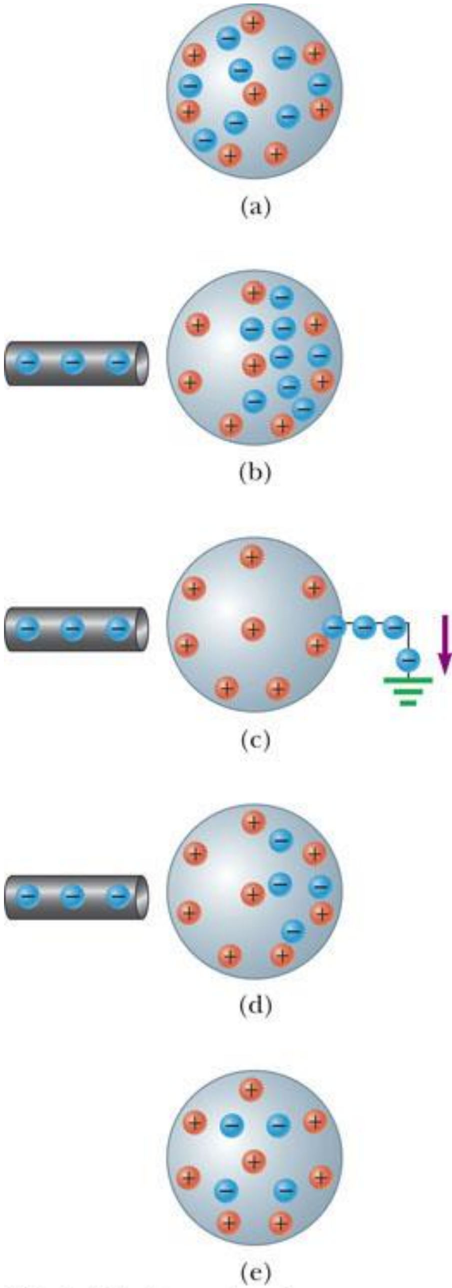
1) Conduction
2) Induction

1) Charging by Conduction (contact)



2) Charging by Induction (no contact)

- When an object is connected to a conducting wire or pipe buried in the earth, it is said to be **grounded**
- A negatively charged rubber rod is brought near a neutral sphere. The charges in the sphere are redistributed: Some of the electrons in the sphere are repelled from the electrons in the rod
- The region of the sphere nearest the negatively charged rod has an excess of positive charge because of the migration of electrons away from this location.
- A grounded conducting wire is connected to the sphere (***Allows some of the electrons to move from the sphere to the ground)***
- The wire to ground is removed, the sphere is left with an excess of induced positive charge
- The positive charge on the sphere is evenly distributed due to the repulsion between the positive charges



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Conductors /Insulators

Materials classified based on their ability to move charge

- **Conductors** are materials in which a significant number of electrons are free to move. Examples include metals.

- The charged particles in nonconductors (**insulators**) are not free to move. There are few (if any) free electrons in a nonconductor. Examples include rubber, plastic, glass.

- **Semiconductors** are materials that are intermediate between conductors and insulators. Examples include silicon and germanium in computer chips.

- **Superconductors** are materials that are perfect conductors, allowing charge to move without any hindrance.

- **Charged Particles.** The properties of conductors and insulators are due to the **structure and electrical nature of atoms**. Atoms consist of positively charged *protons*, negatively charged *electrons*, and electrically neutral *neutrons*. The protons and neutrons are packed tightly together in a central nucleus and do not move.

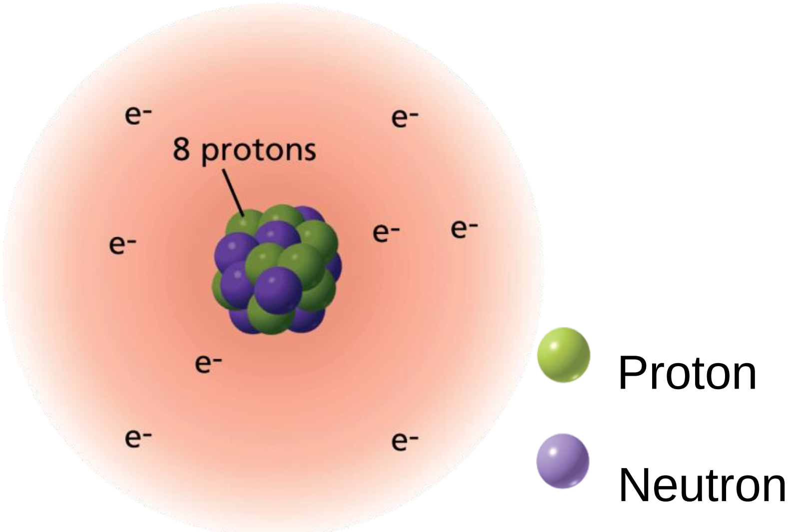

Table 21-1 The Charges of Three Particles

Particle	Symbol	Charge
Electron	e or e^-	$-e$
Proton	p	$+e$
Neutron	n	0

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A neutral atom has equal numbers of protons and electrons.

$${}^{A}_{Z}X$$

Z: Atomic number (number of protons)
N: Number of neutrons
A: Mass number (A = Z + N)
For neutral atoms, Z is also the number of electrons

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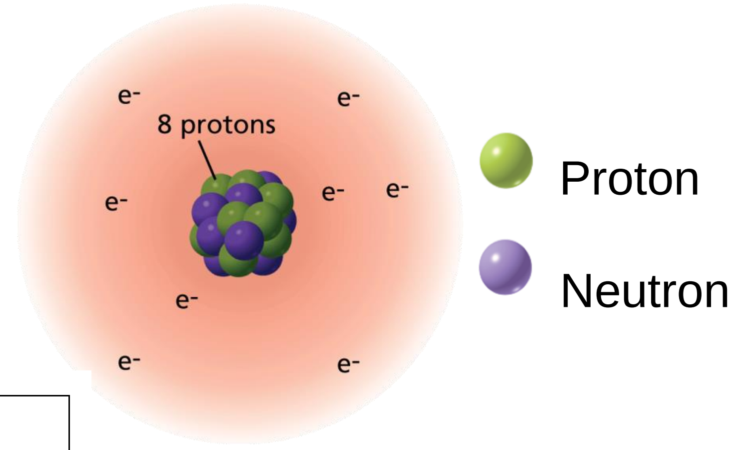
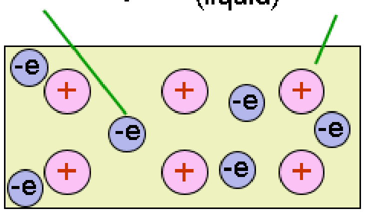
- A neutral atom has equal numbers of protons and electrons
- An atom becomes a **positive ion** when it loses electrons and a **negative ion** when it gains electrons



Electrons can move freely

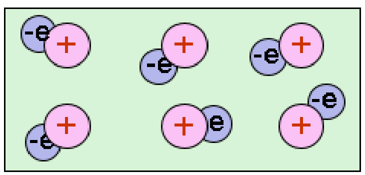
Ions are fixed (solid) or move very slowly (liquid)



Conductors

metals
human body
tap water

Electrons held to ions and cannot move freely



Insulators

glass
plastic
pure water

- For **conductors**, outermost electrons are loosely held by nucleus
- For **insulators**, outermost electrons are tightly held by nucleus

Conduction Electrons

- When atoms of a conductor like copper come together to form the solid, some of their outermost—and so most loosely held—electrons become free to wander about within the solid, leaving behind positively charged atoms (positive ions).
- We call the mobile electrons **conduction electrons**.
- Only conduction electrons can move

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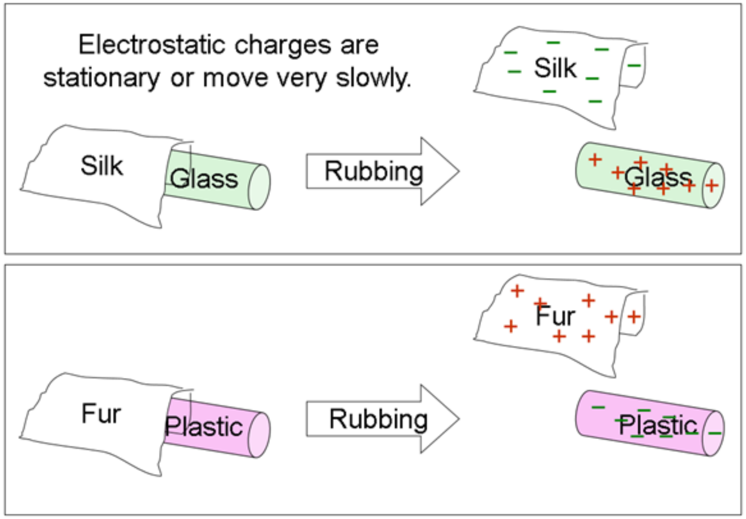
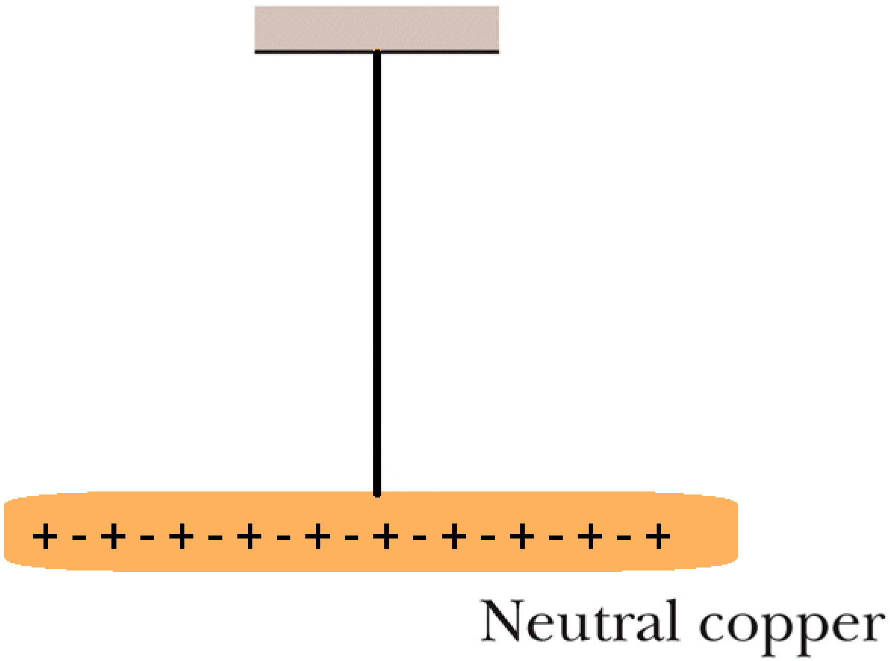
Charged Insulator ?!

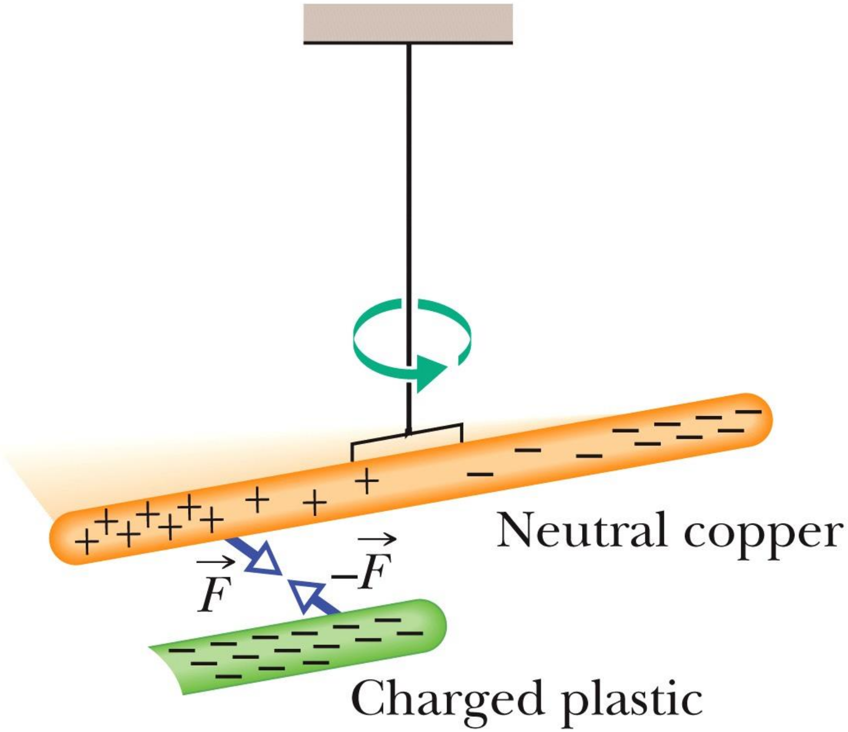
Charging by rubbing



In insulator, such as glass, the atoms' electrons have very little freedom to move around. External forces such as physical rubbing can force some of these electrons to leave their respective atoms and transfer to the atoms of another material, they do not move between atoms within that material very easily.

Conductor: Induced charge

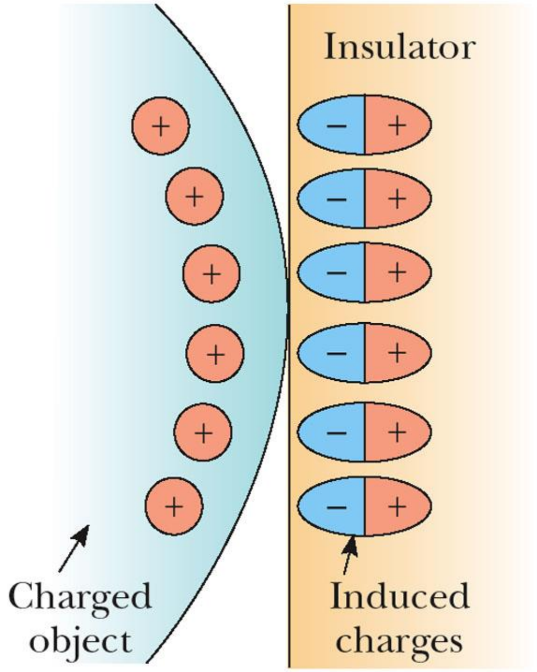




Induced Charge. A neutral copper rod is electrically isolated from its surroundings by being suspended on a non-conducting thread. Either end of the copper rod will be attracted by a charged rod. Here, conduction electrons in the copper rod are repelled to the far end of that rod by the negative charge on the plastic rod. Then that negative charge attracts the remaining positive charge on the near end of the copper rod, rotating the copper rod to bring that near end closer to the plastic rod.

Insulator: Polarization

- The charged object (on the left) induces charge on the surface of the insulator
- A charged comb attracts bits of paper due to polarization of the paper



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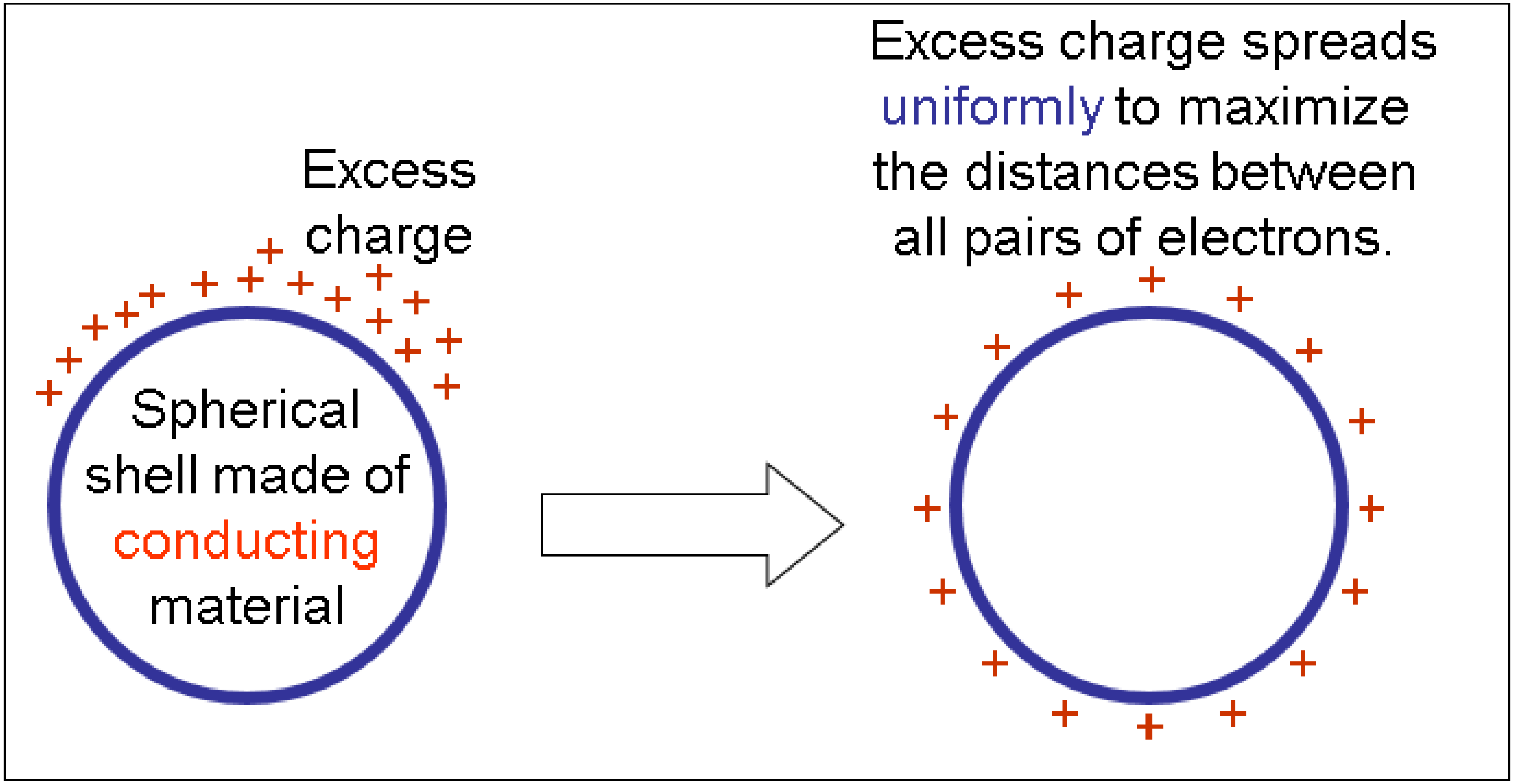

If excess charge is placed on a spherical shell that is made of a conducting material, the excess charge spreads uniformly over the surface.

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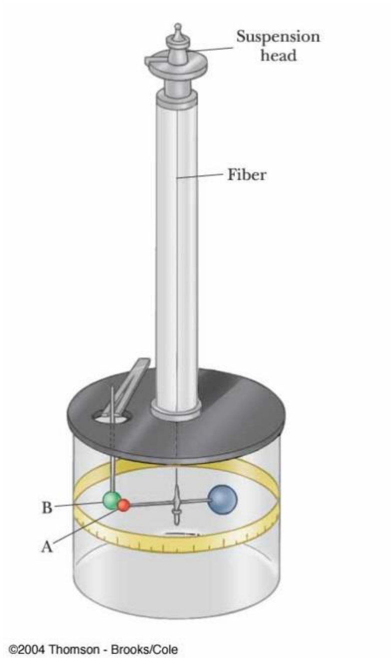
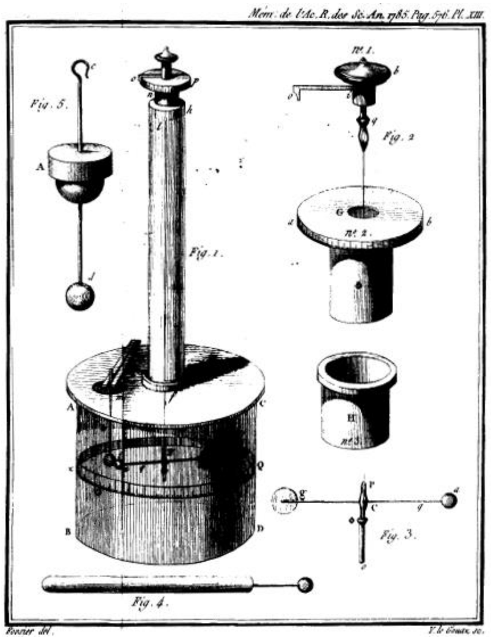
Coulomb’s law

Coulomb's law





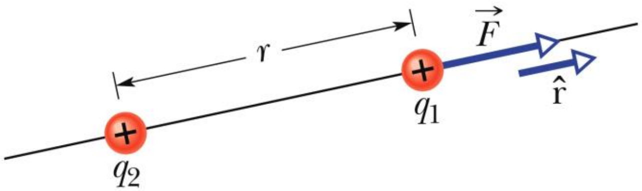
- Charles Coulomb measured the magnitudes of electric forces between two small charged spheres
- He found the force depended on the charges and the distance between them

$$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$$

Coulomb's law

Coulomb's law describes the **electrostatic force** (or electric force) between two charged particles. If the particles have charges q_1 and q_2, are separated by distance r, and are at rest (or moving only slowly) relative to each other, then the magnitude of the force acting on each due to the other is given by

$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1|\,|q_2|}{r^2} \quad \text{(Coulomb's law)},$$



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The electrostatic force on particle 1 can be described in terms of a unit vector ***r*** along an axis through the two particles, radially away from particle 2.

where $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/N.m^2$ is the permittivity constant. The ratio $1/4\pi\varepsilon_0$ is often replaced with the electrostatic constant (or Coulomb constant) $k=8.99\times 10^9\ N.m^2/C^2$. Thus k = $1/4\pi\varepsilon_0$.

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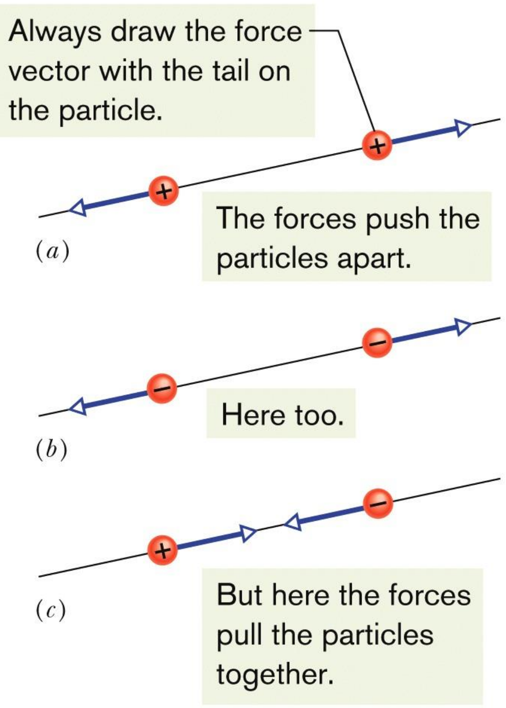
- The electrostatic force vector acting on a charged particle due to a second charged particle is either directly toward the second particle (opposite signs of charge) or directly away from it (same sign of charge).

- If multiple electrostatic forces act on a particle, the net force is the vector sum (not scalar sum) of the individual forces.



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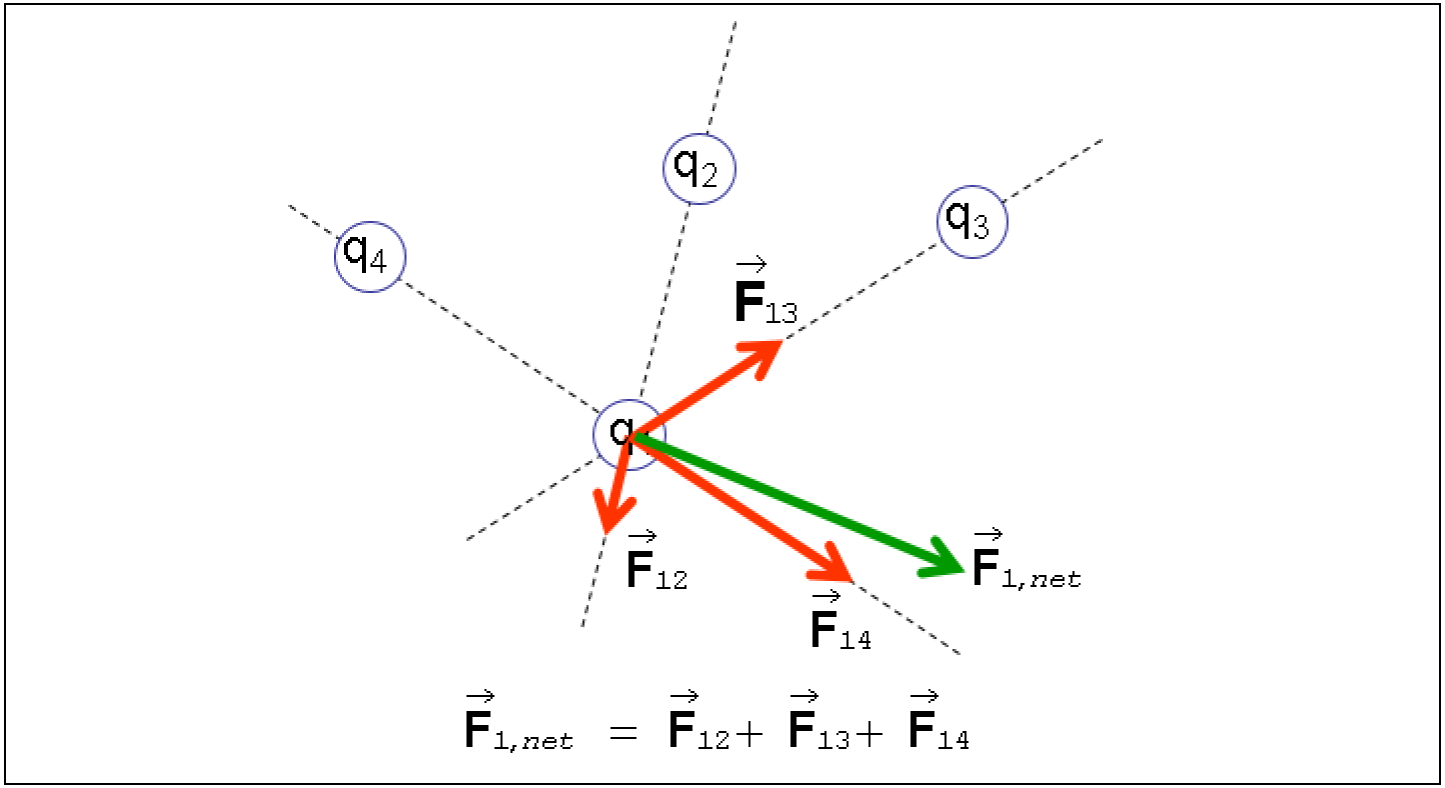
Two charged particles repel each other if they have the same sign of charge, either (a) both positive or (b) both negative. (c) They attract each other if they have opposite signs of charge.

Multiple Forces: If multiple electrostatic forces act on a particle, the net force is the vector sum (not scalar sum) of the individual forces.

$$\vec{F}_{1,\text{net}} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \vec{F}_{15} + \cdots + \vec{F}_{1n},$$



Principle of superposition: the net force acting on any particle is the vector sum of the forces acting on this particle due to individual particles

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Charge is quantized and conserved

Charge is Quantized

- Electric charge is measured in **Coulomb**
- The smallest charge you can find is $e = 1.602 \times 10^{-19}$ C.
- Electric charge is quantized (restricted to certain values). All other charges are multiple of this charge.
- The charge of a particle can be written as ne, where *n* is a positive or negative integer and *e* is the elementary charge. Any positive or negative charge *q* that can be detected can be written as

$$q = ne, \qquad n = \pm 1, \pm 2, \pm 3, \ldots,$$

in which *e*, the elementary charge, has the approximate value

$$e = 1.602 \times 10^{-19} \text{ C}.$$

Table 21-1 The Charges of Three Particles

Particle	Symbol	Charge
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Charge is Quantized

- When a physical quantity such as charge can have only discrete values rather than any value, we say that the quantity is **quantized**.

- It is possible, for example, to find a particle that has no charge at all or a charge of $+10e$ or $-6e$,

- Charge of $3.57e$ is not possible

Charge is Conserved

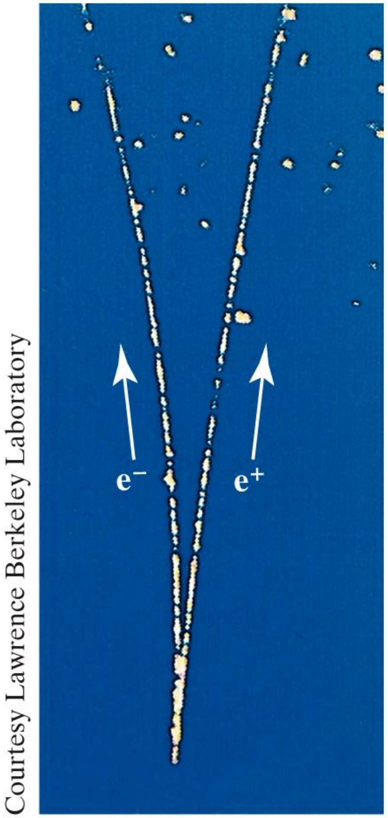
The net electric charge of any isolated system is always conserved.

If two charged particles undergo an annihilation process, they have equal and opposite signs of charge.

$$e^- + e^+ \rightarrow \gamma + \gamma$$

If two charged particles appear as a result of a pair production process, they have equal and opposite signs of charge.

$$\gamma \rightarrow e^- + e^+$$



A photograph of trails of bubbles left in a bubble chamber by an electron and a positron. The pair of particles was produced by a gamma ray that entered the chamber directly from the bottom. Being electrically neutral, the gamma ray did not generate a telltale trail of bubbles along its path, as the electron and positron did.

21 Summary

Electric Charge

- The strength of a particle's electrical interaction with objects around it depends on its electric charge, which can be either positive or negative.

Conductors and Insulators

- Conductors are materials in which a significant number of electrons are free to move. The charged particles in nonconductors (insulators) are not free to move.

Conservation of Charge

- The net electric charge of any isolated system is always conserved.

Coulomb's Law

- The magnitude of the electrical force between two charged particles is proportional to the product of their charges and inversely proportional to the square of their separation distance.
- .

$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1|\,|q_2|}{r^2}$$ **Eq. 21-4**

$$e = 1.602 \times 10^{-19}\,\mathrm{C}.$$ **Eq. 21-12**

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