Chapter 21

Coulomb's Law

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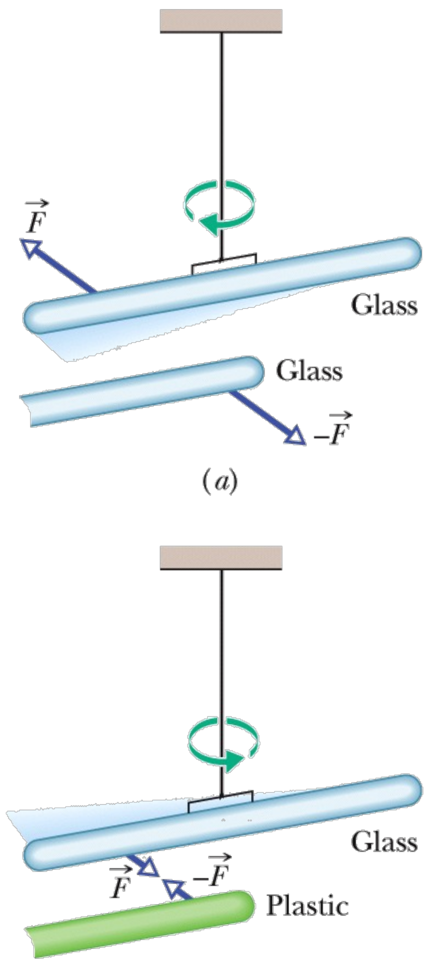
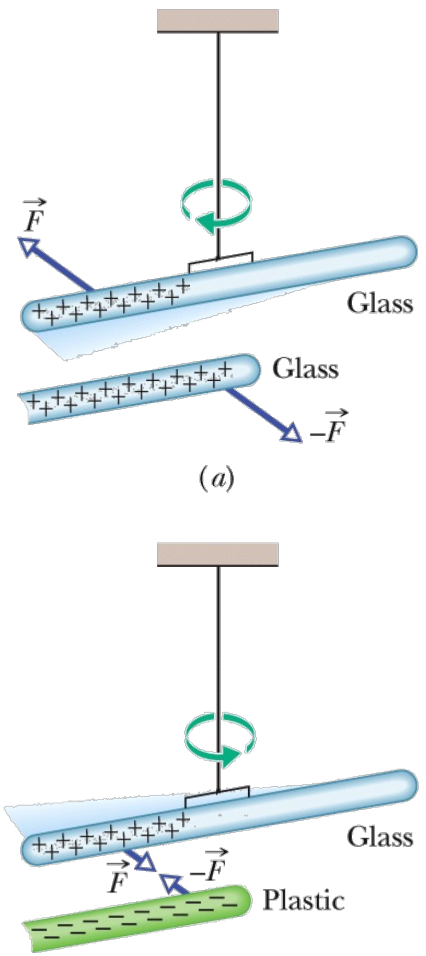


Magic?

(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.

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

21-1 Coulomb's Law



Electric Charge

(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.

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. Examples include rubber, plastic, glass.

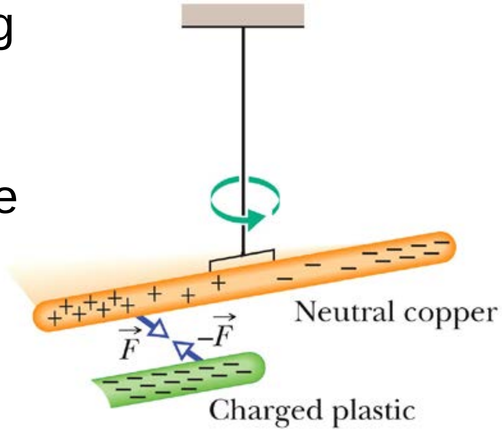
- **Semiconductors** are materials that are intermediate between conductors and insulators; examples include silicon and germanium in computer chips.

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

21-1 Coulomb's Law

- **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.
- 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**. There are few (if any) free electrons in a nonconductor.

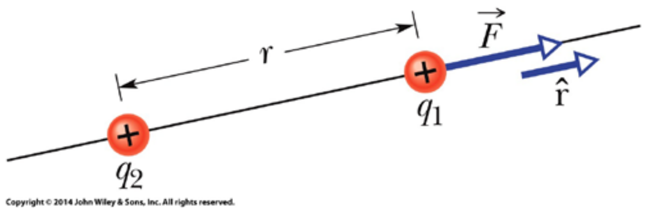
Induced Charge. A neutral copper rod is electrically isolated from its surroundings by being suspended on a non-conducting thread. Either end of the copper rod will be attracted by a charged rod. Here, conduction electrons in the copper rod are repelled to the far end of that rod by the negative charge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



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

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

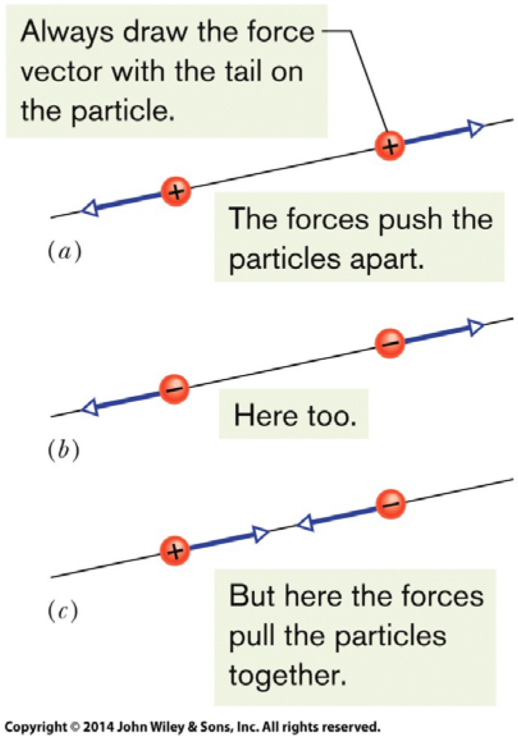


The electrostatic force on particle 1 can be described in terms of a unit vector ***r*** along an axis through the two particles, radially away from particle 2.

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) $k = 8.99\times10^9\ N.m^2/C^2$. Thus $k = 1/4\pi\varepsilon_0$.

Coulomb's Law

- 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.



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.

21-1 Coulomb's Law

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

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

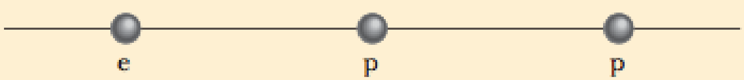
Shell Theories: There are two shell theories for electrostatic force

Shell theory 1. A charged particle outside a shell with charge uniformly distributed on its surface is attracted or repelled as if the shell's charge were concentrated as a particle at its center.

Shell theory 2. A charged particle inside a shell with charge uniformly distributed on its surface has no net force acting on it due to the shell.

Checkpoint 2

The figure shows two protons (symbol p) and one electron (symbol e) on an axis. On the central proton, what is the direction of (a) the force due to the electron, (b) the force due to the other proton, and (c) the net force?



Answer: (a) left towards the electron
(b) left away from the other proton
(c) left

21-2 Charge is Quantized

- Electric charge is quantized (restricted to certain values).

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

21-2 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*, but not a particle with a charge of, say, *3.57e*.

Checkpoint 4

Initially, sphere A has a charge of $-50e$ and sphere B has a charge of $+20e$. The spheres are made of conducting material and are identical in size. If the spheres then touch, what is the resulting charge on sphere A?

Answer: *-15e*

21-3 Charge is Conserved

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

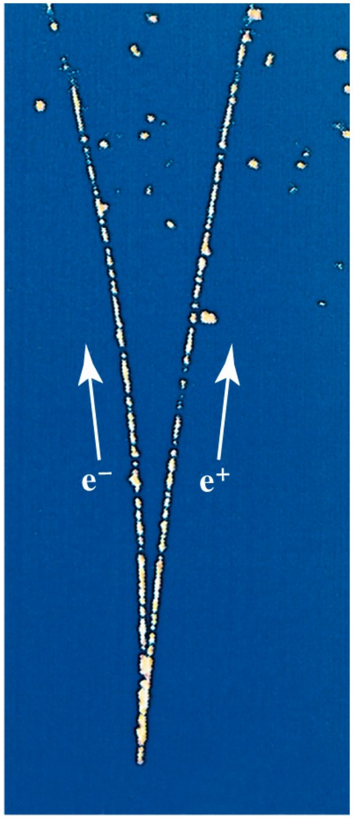
If two charged particles undergo an annihilation process, they have equal and opposite signs of charge.

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

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

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

Courtesy Lawrence Berkeley Laboratory



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

The Elementary Charge

- Electric charge is quantized (restricted to certain values).
- *e* is the elementary charge

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

Eq. 21-12