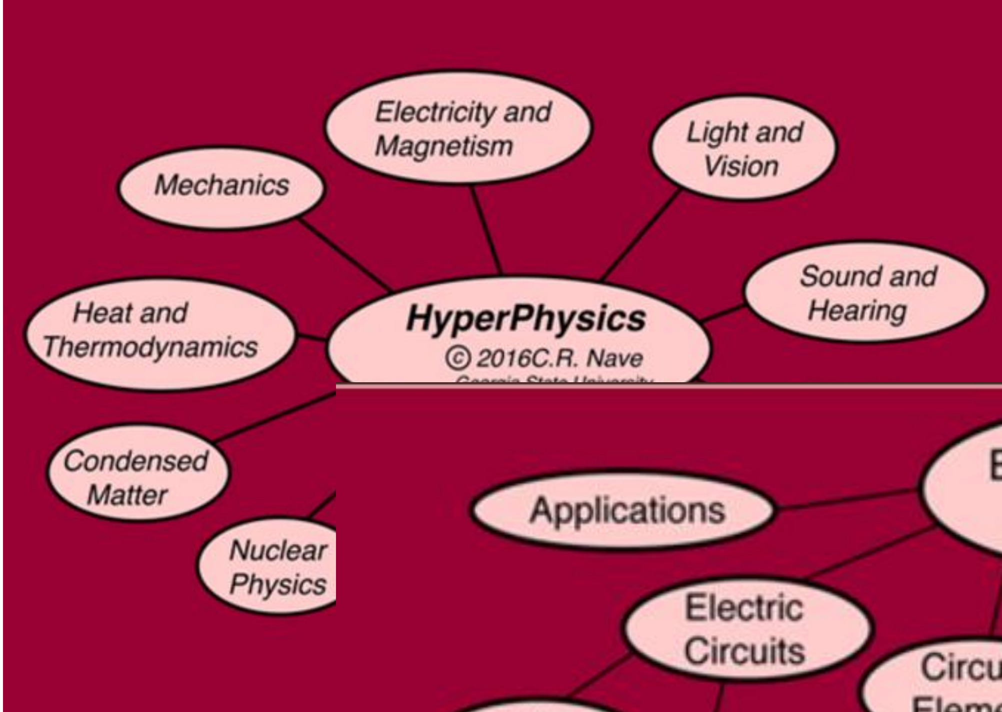
Week	Topic	Content	Text reference [CLO][PLO]
1	Electric Charge	• Electric charge (Section 17.1) • Conductor and insulators (Section 17.2)	College Physics: Chapter 17
2	Electric Charge	• Conservation and quantization of charge (Section 17.3) • Coulomb's Law (Section 17.4)	College Physics: Chapter 17
3 & 4	Electric Field	• Electric Fields and Electric Forces (Section 17.5) • Calculating Electric Fields (Section 17.6) • Electric Field Lines (Section 17.7) • Gauss's Law and Field Calculations (Section 17.8)	College Physics: Chapter 17
5 & 6	Electric Potential	• Electric Potential Energy (Section 18.1) • Potential (Section 18.2) • Equipotential Surfaces (Section 18.3)	College Physics: Chapter 18
7	Capacitance	• Vacuum & Dielectric Capacitors (Sections 18.5 and 18.8) • Capacitors in series and in parallel (Section 18.6)	College Physics: Chapter 18
	MIDTERM		
8	Current, Resistance, and Dielectric Current Circuits	• Current, Resistance & Ohm's Law (sections 19.1 & 2) • Electromotive force and Circuits (section 19.3) • Energy and Power in Electric Circuits (section 19.4)	College Physics: Chapter 19
9		• Resistors in Series and in Parallel (section 19.5) • Kirchhoff's Rules (section 19.6)	
10 & 11	Magnetic Field and Magnetic Forces	• Magnetism (Section 20.1) • Magnetic Field and Magnetic Force (Section 20.2) • Motion of Charged Particles in a Magnetic Field (Section 20.3) • Magnetic force on a current-Carrying Conductor (section 20.5) • Force & Torque on a Current Loop; Direct-Current Motors (section 20.6)	College Physics: Chapter 20
12		• Magnetic Field of a Long, Straight Conductor & forces between Parallel Conductors (sections 20.7-8) • Solenoid Magnetic Field (section 20.9) • Biot-Savart and Ampere's laws (section 20.10)	
13 & 14	Electromagnetic Induction	• Electromagnetic Induction & Faraday's Law (sections 21.1-3) • Lenz's Law (section 21.4) • Motional Electromotive Force (section 21.5)	College Physics: Chapter 21
15	Electromagnetic Induction	• Mutual Inductance and Self-Inductance (section 21.7-8) • Transformers (section 21.9)	College Physics: Chapter 21
16		EXAMS	



HyperPhysics
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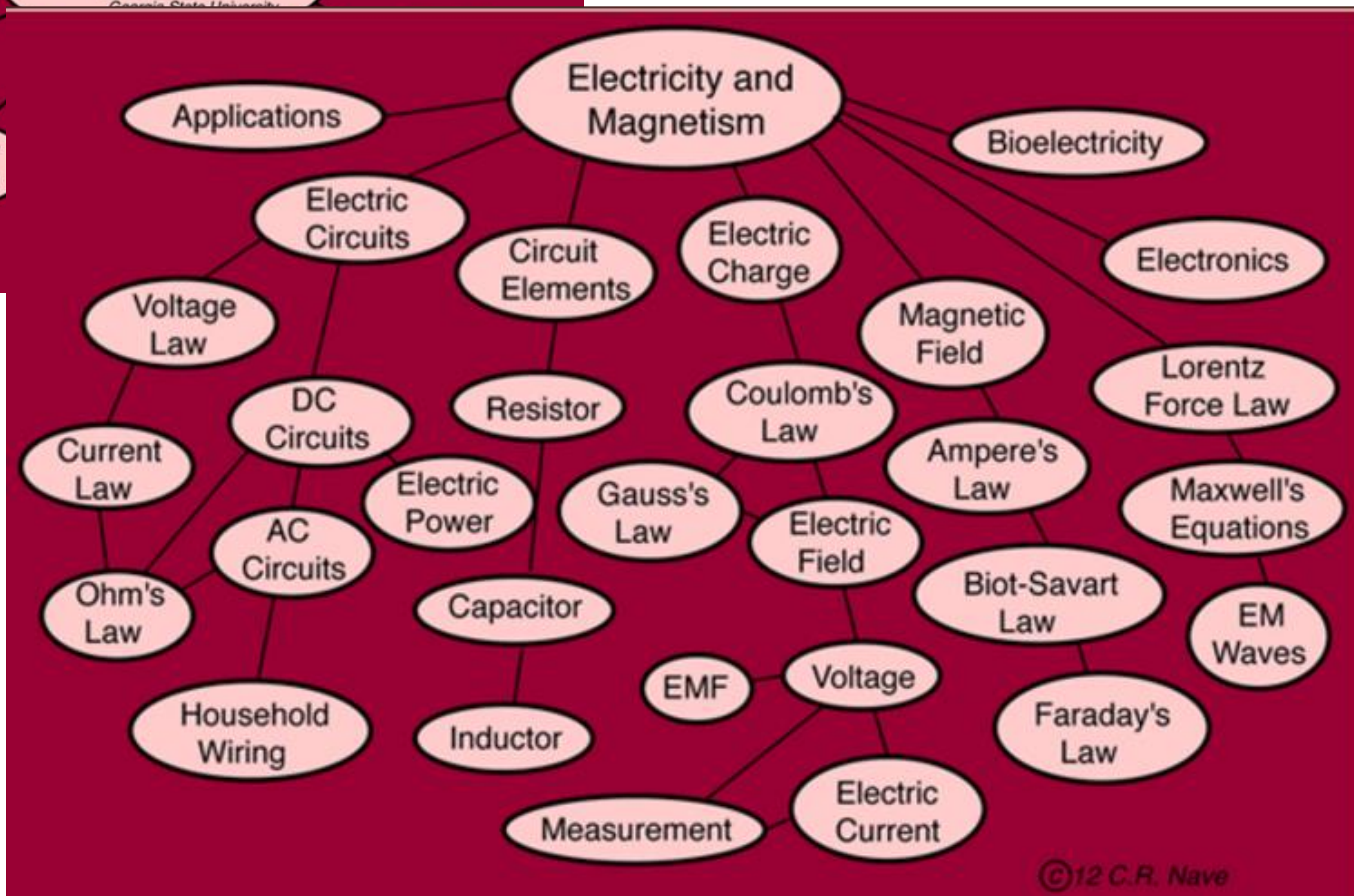
Mechanics
Electricity and Magnetism
Light and Vision
Sound and Hearing
Heat and Thermodynamics
Condensed Matter
Nuclear Physics



Electricity and Magnetism
Applications
Bioelectricity
Electric Circuits
Circuit Elements
Electric Charge
Electronics
Magnetic Field
Voltage Law
Lorentz Force Law
DC Circuits
Resistor
Coulomb's Law
Current Law
Ampere's Law
Maxwell's Equations
Electric Power
Gauss's Law
AC Circuits
Electric Field
Ohm's Law
Biot-Savart Law
Capacitor
EM Waves
EMF
Voltage
Household Wiring
Inductor
Faraday's Law
Electric Current
Measurement
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17 Electric Charge and Electric Field

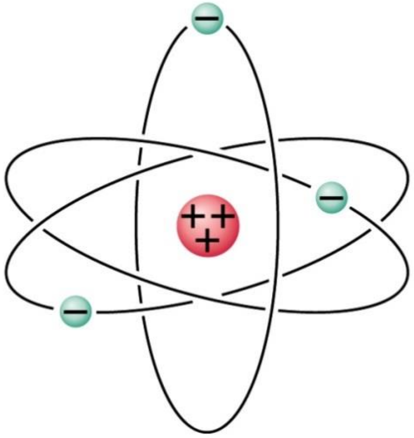
- Materials/substances may be classified according to their capacity to carry or ***conduct*** electric charge:

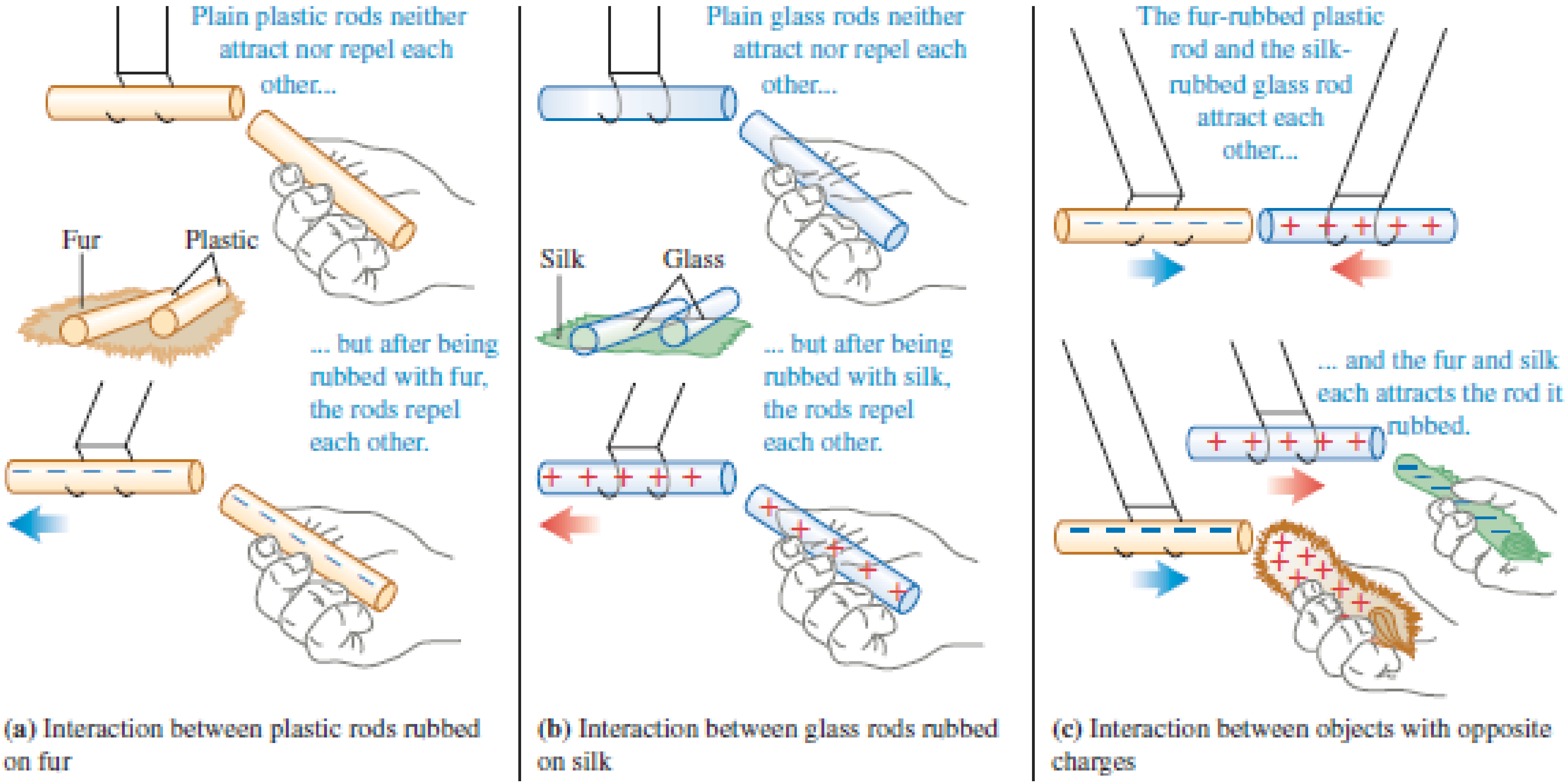
- Conductors are material in which electric charges move freely.
  - Metals are good conductors: Copper, aluminum, and silver.

- Insulator are materials in which electrical charge do not move freely.
  - Most nonmetals are insulator: Glass, Rubber are good insulators.

- Semiconductors are a third class of materials with electrical properties somewhere between those of insulators and conductors.
  - Silicon and germanium are semiconductors used widely in the fabrication of electronic devices.

Objects that exert electric forces are said to have charge. Charge is the source of electrical force. There are two kinds of electrical charges, positive and negative. Same charges (+ and +, or - and -) repel and opposite charges (+ and -) attract each other.





▲ **FIGURE 17.1** Experiments illustrating the nature of electric charge.

Like and unlike charges

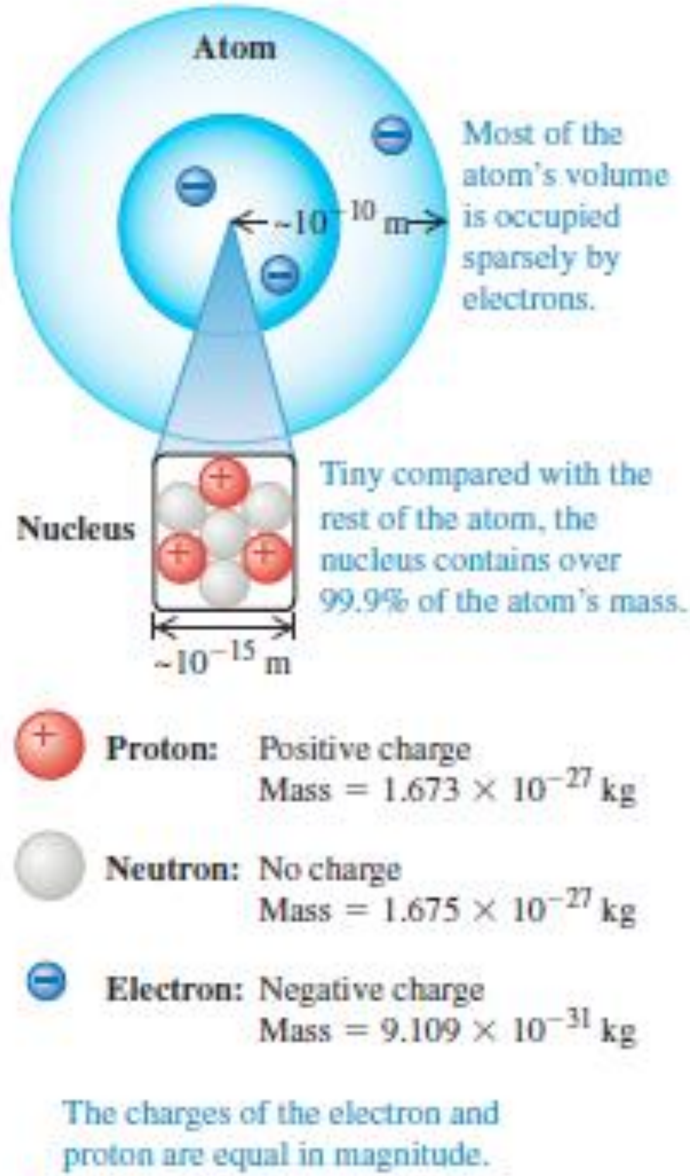
Two positive charges or two negative charges repel each other; a positive and a negative charge attract each other.

In the preceding discussion, the plastic rod and the silk have negative charge; the glass rod and the fur have positive charge.

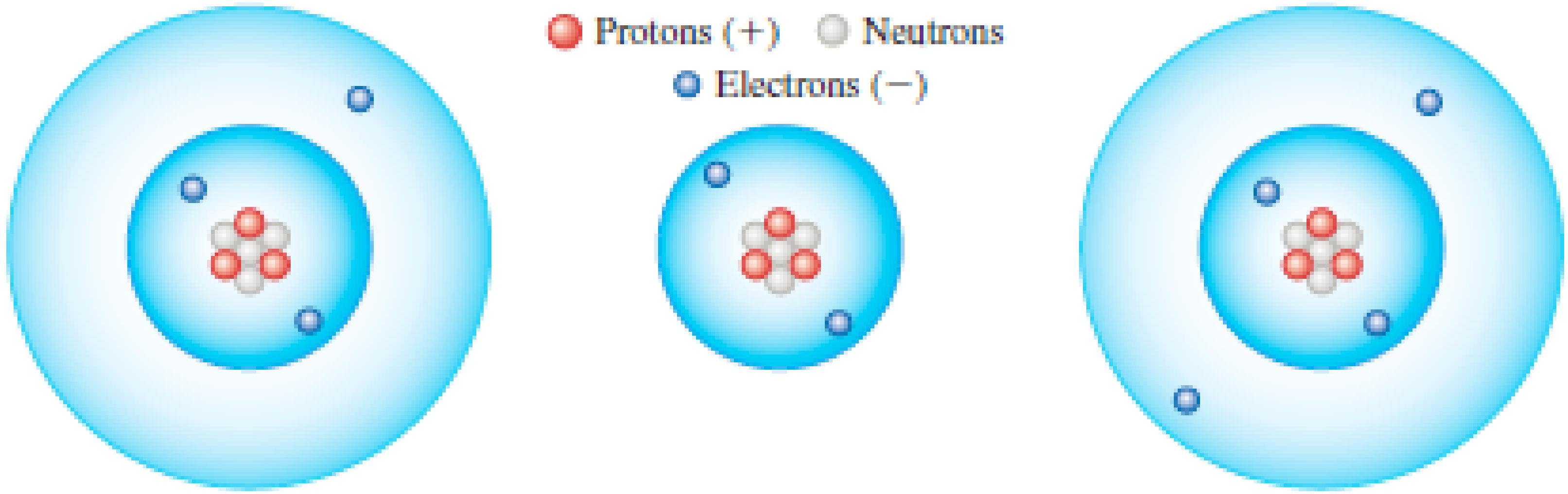
The person in this snapshot was amused to find her hair standing on end.
Luckily, she and her companion left before the area was hit by lightning.

Just before lightning strikes, strong charges build up in the ground and in the clouds overhead. If you're standing on charged ground, the charge will spread onto your body.

Because like charges repel, all your hairs tend to get as far from each other as they can.



▲ **FIGURE 17.2** Schematic depiction of the structure and components of an atom.



(a) Neutral lithium atom (Li):

3 protons (3+)
4 neutrons
3 electrons (3−)

Electrons equal protons:
Zero net charge

(b) Positive lithium ion (Li^+):

3 protons (3+)
4 neutrons
2 electrons (2−)

Fewer electrons than protons:
Positive net charge

(c) Negative lithium ion (Li^-):

3 protons (3+)
4 neutrons
4 electrons (4−)

More electrons than protons:
Negative net charge

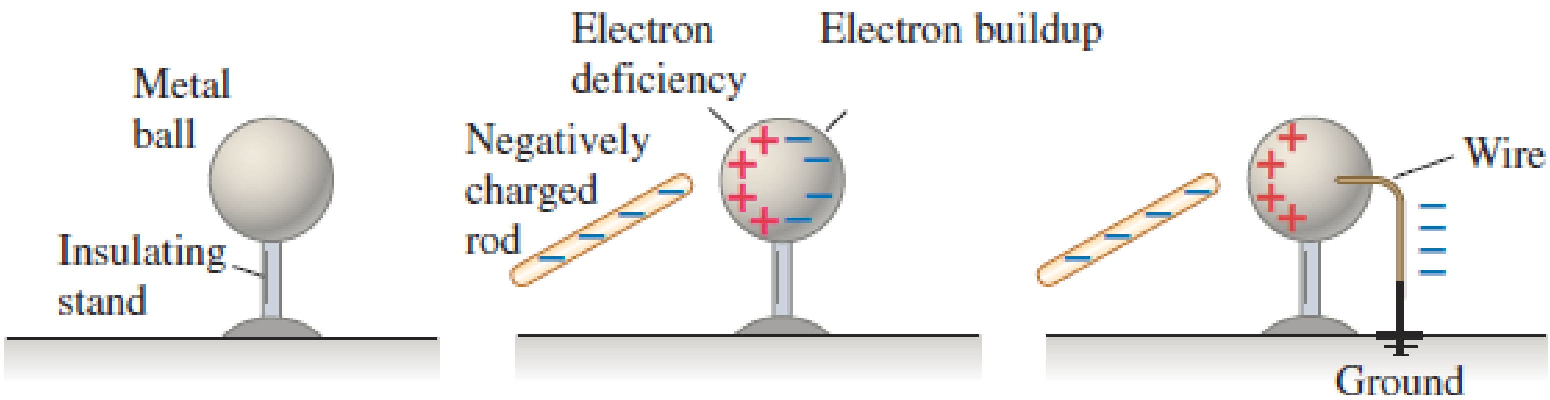
FIGURE 17.3 The neutral lithium (Li) atom and positive and negative lithium ions.

$$\text{Mass of electron} = m_e = 9.1093826(16) \times 10^{-31}\ \text{kg};$$
$$\text{Mass of proton} = m_p = 1.67262171(29) \times 10^{-27}\ \text{kg};$$
$$\text{Mass of neutron} = m_n = 1.67492728(29) \times 10^{-27}\ \text{kg}.$$

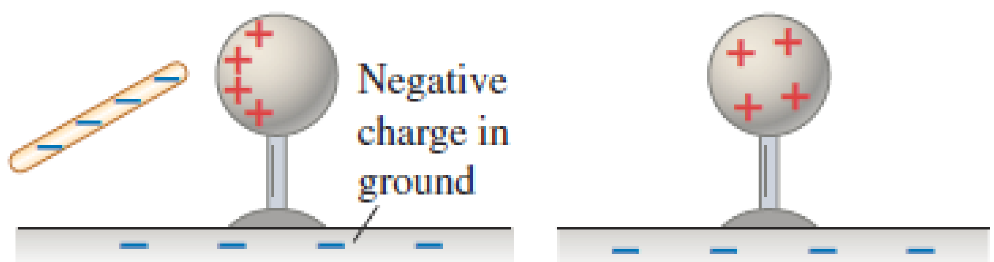
An **ion** is an atom that has lost or gained one or more electrons.

Ordinarily, when an ion is formed, the structure of the nucleus is unchanged. In a solid object such as a carpet or a copper wire, the nuclei of the atoms are not free to move about, so a net charge is due to an excess or deficit of electrons.

Induction

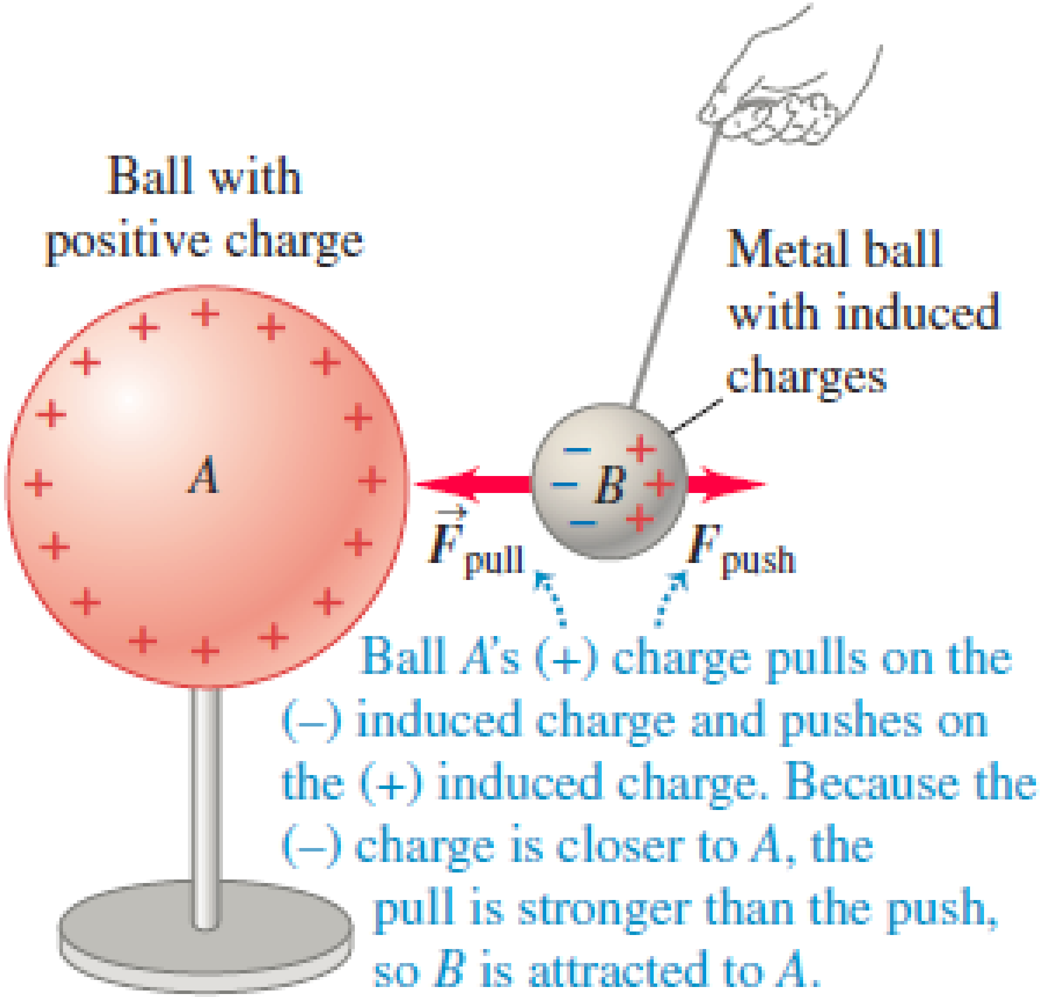


1. Uncharged metal ball
2. Negative charge on rod repels electrons, creating zones of negative and positive **induced charge.**
3. Wire lets electron buildup (induced negative charge) flow into ground.



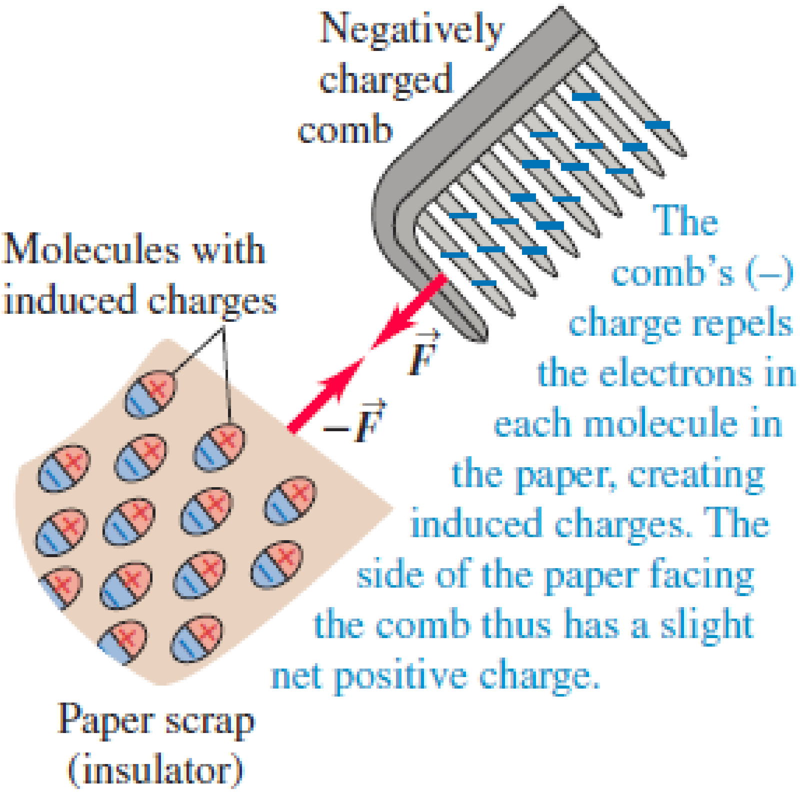
4. Wire removed; ball now has only an electron-deficient region of positive charge.
5. Rod removed; positive charge spreads over ball.

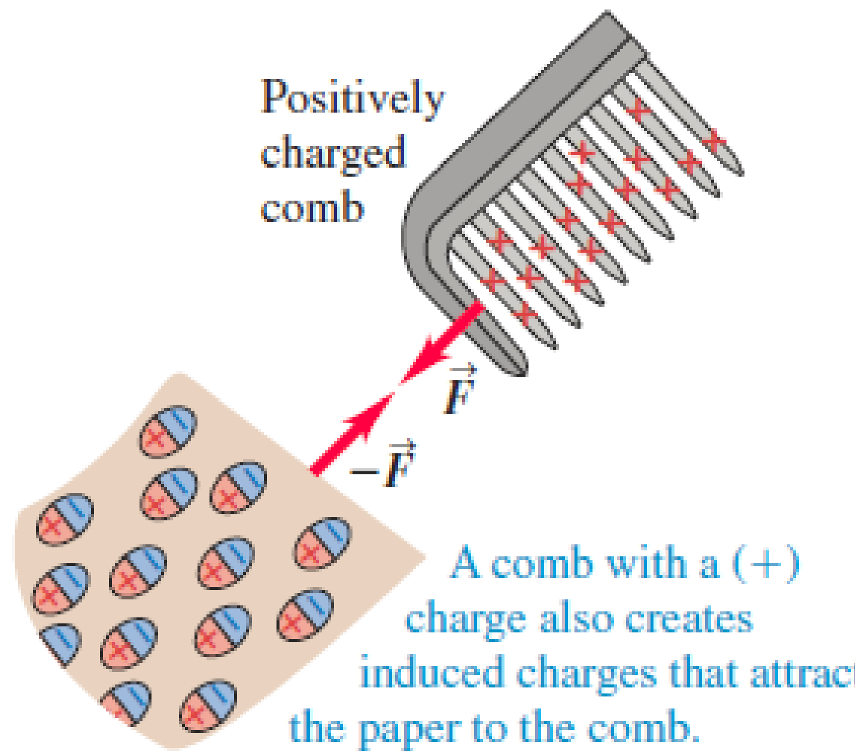
Induced Polarisation



▲ **FIGURE 17.7** The charge on ball *A* induces charges in ball *B*, resulting in a net attractive force between the balls.

A charged plastic comb picks up uncharged bits of paper.



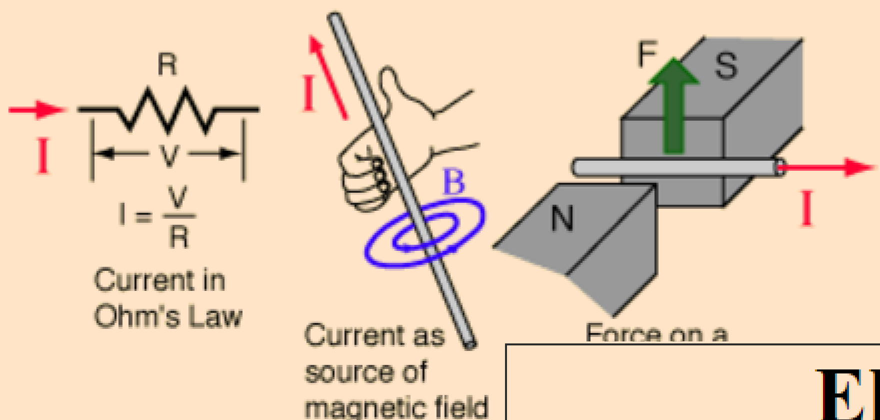


Conservation of charge

The algebraic sum of all the electric charges in any closed system is constant. Charge can be transferred from one object to another, and that is the only way in which an object can acquire a net charge.

Electric Current

Electric current is the rate of charge flow past a given point in an electric circuit, measured in Coulombs/second which is named Amperes. In most DC electric circuits, it can be assumed that the resistance to current flow is a constant so that the current in the circuit is related to voltage and resistance by Ohm's law. The standard abbreviations for the units are 1 A = 1C/s.



Electric Charge

The unit of electric charge is the Coulomb (abbreviated C). Ordinary matter is made up of atoms which have positively charged nuclei and negatively charged electrons surrounding them. Charge is quantized as a multiple of the electron or proton charge:

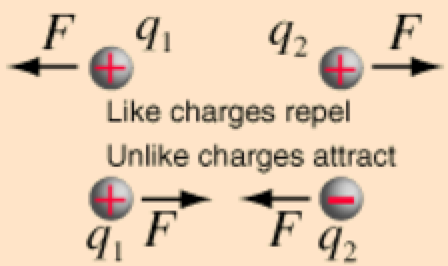
⊕ proton charge $e = 1.602 \times 10^{-19}$ coulombs

⊖ electron charge $-e = -1.602 \times 10^{-19}$ coulombs

Coulomb's Law

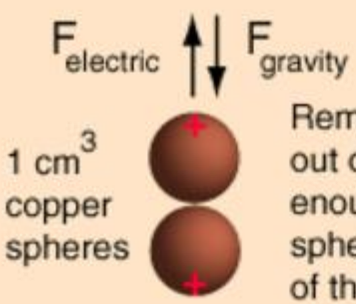
Like charges repel, unlike charges attract.

The electric force acting on a point charge q_1 as a result of the presence of a second point charge q_2 is given by Coulomb's Law:



$$F = \frac{kq_1q_2}{r^2} = \frac{q_1q_2}{4\pi\varepsilon_0 r^2}$$ *Coulomb's Law*

where ε_0 = permittivity of space

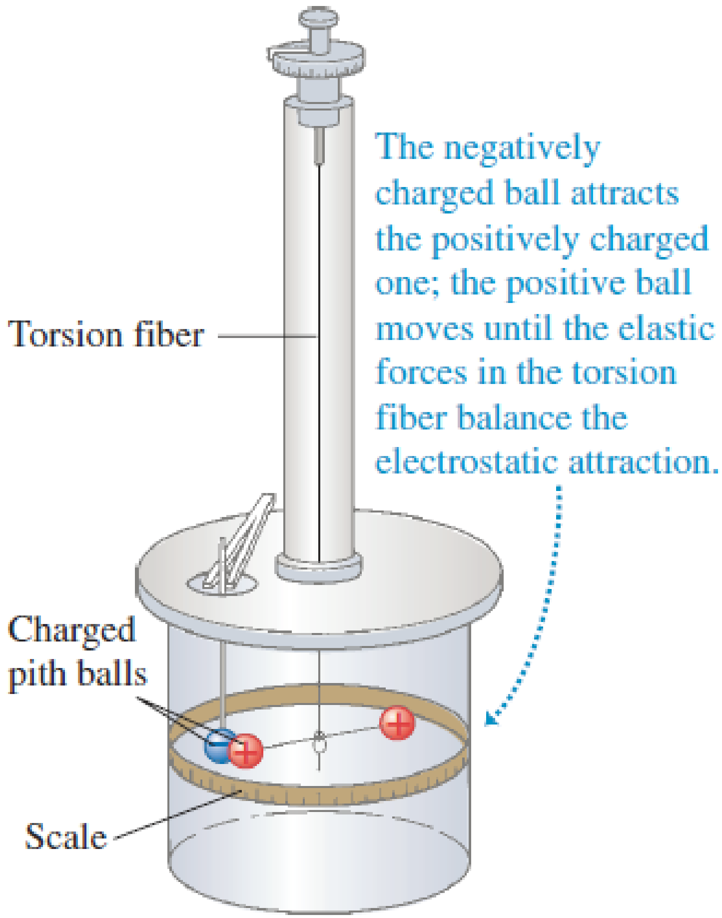


Removal of one valence electron out of 5.7×10^{12} would provide enough net charge to lift the top sphere, overcoming the gravity of the entire Earth.

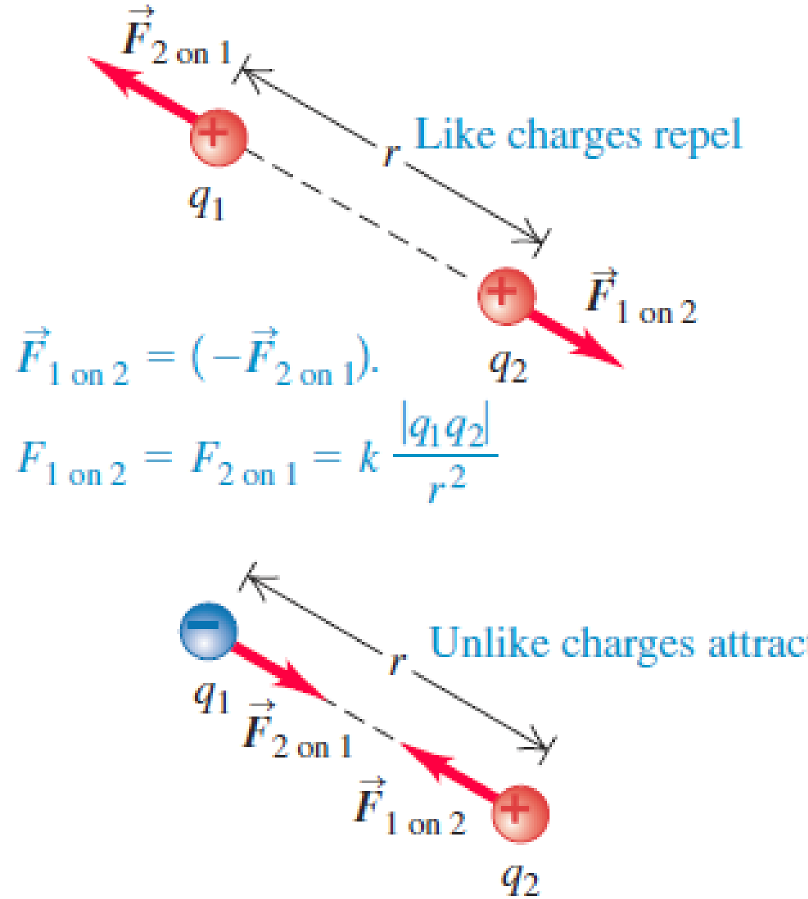
Coulomb's Constant

$$k = \frac{1}{4\pi\varepsilon_0} \approx 9x10^9\, N \cdot m^2/C^2 = \text{Coulomb's constant}$$

The constant of proportionality k appearing in Coulomb's law is often called Coulomb's constant. Note that it can be expressed in terms of another constant, ε_0 = permittivity of space.



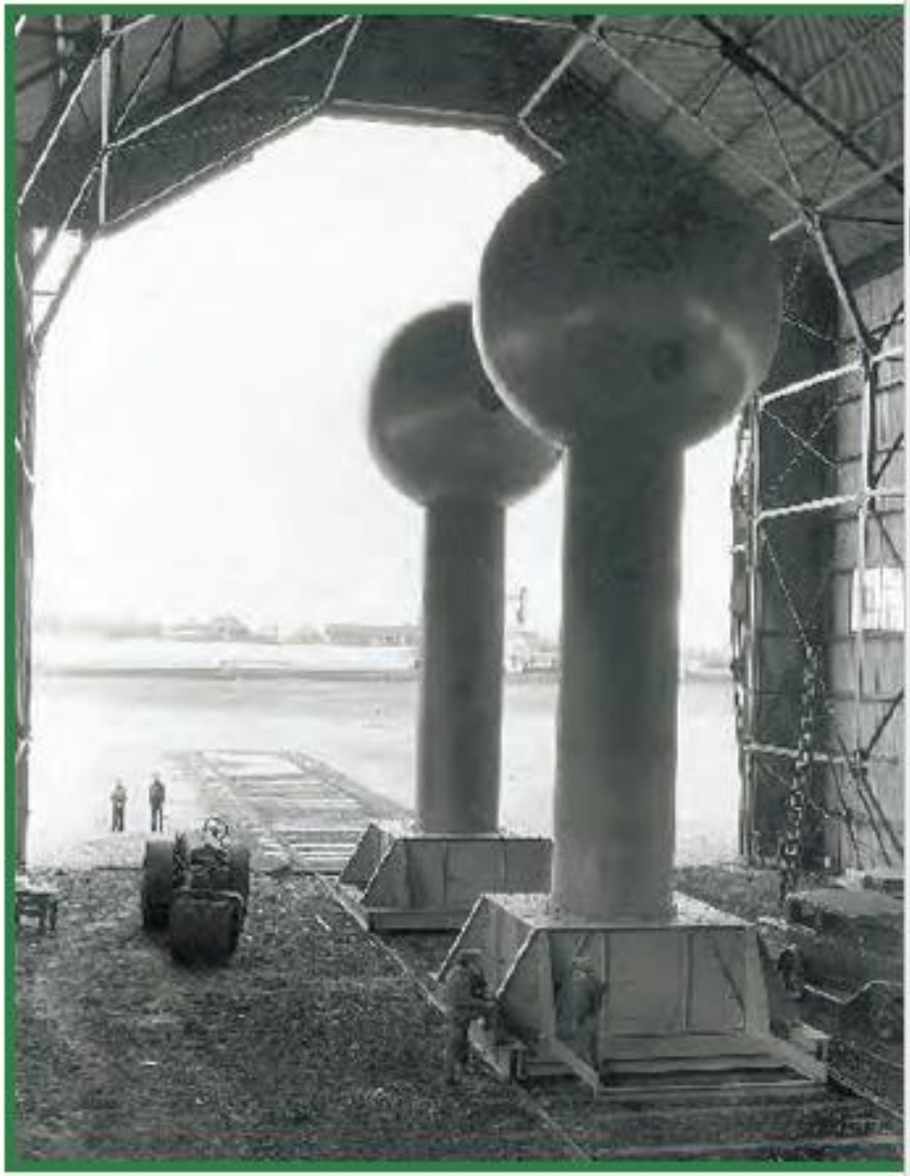
(a) A torsion balance of the type used by Coulomb to measure the electric force



(b) Interaction of like and unlike charges

Schematic depiction of the apparatus Coulomb used to determine the forces between charged objects that can be treated as point charges.

The forces that two charges exert on each other always act along the line joining the charges. The two forces are always equal in magnitude and opposite in direction, even when the charges are not equal. *The forces obey Newton's third law.*



Generators, like the huge Van de Graaff generators shown here, can accumulate either positive or negative charges on the surface of a metal sphere, thus generating immense electric fields.

EXAMPLE 17.2 Gravity in the hydrogen atom

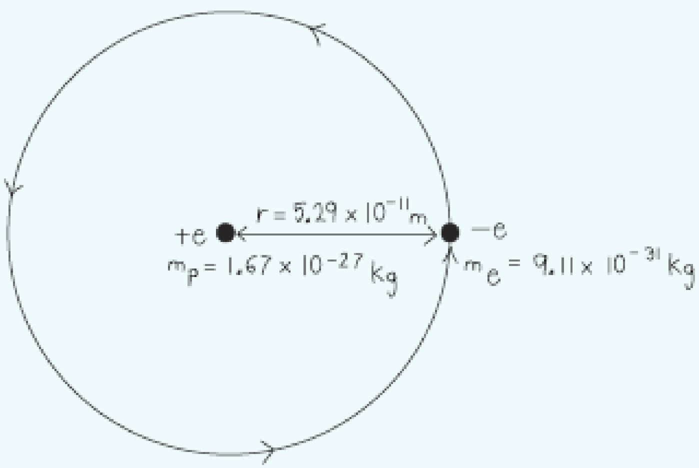
A hydrogen atom consists of one electron and one proton. In an early, simple model of the hydrogen atom called the *Bohr model,* the electron is pictured as moving around the proton in a circular orbit with radius $r = 5.29 \times 10^{-11}$ m. (In Chapter 29, we'll study the Bohr model and also more sophisticated models of atomic structure.) What is the ratio of the magnitude of the electric force between the electron and proton to the magnitude of the gravitational attraction between them? The electron has mass $m_e = 9.11 \times 10^{-31}$ kg, and the proton has mass $m_p = 1.67 \times 10^{-27}$ kg.

SOLUTION

SET UP Figure 17.10 shows our sketch. The distance between the proton and electron is the radius r. Each particle has charge of magnitude e. The electric force is given by Coulomb's law and the gravitational force by Newton's law of gravitation.

SOLVE Coulomb's law gives the magnitude F_e of the electric force between the electron and proton as

$$F_e = k\frac{|q_1 q_2|}{r^2} = k\frac{e^2}{r^2},$$



▲ **FIGURE 17.10** Our sketch for this problem.

where $k = 8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}$. The gravitational force $\vec{F}_g$ has magnitude F_g:

$$F_g = G\frac{m_1 m_2}{r^2} = G\frac{m_e m_p}{r^2},$$

where $G = 6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$. The ratio of the two forces is

$$\frac{F_e}{F_g} = \left(\frac{ke^2}{r^2}\right)\left(\frac{r^2}{Gm_e m_p}\right) = \frac{ke^2}{Gm_e m_p}$$

$$= \left(\frac{8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}}{6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}}\right) \times \frac{(1.60 \times 10^{-19}\ \mathrm{C})^2}{(9.11 \times 10^{-31}\ \mathrm{kg})(1.67 \times 10^{-27}\ \mathrm{kg})},$$

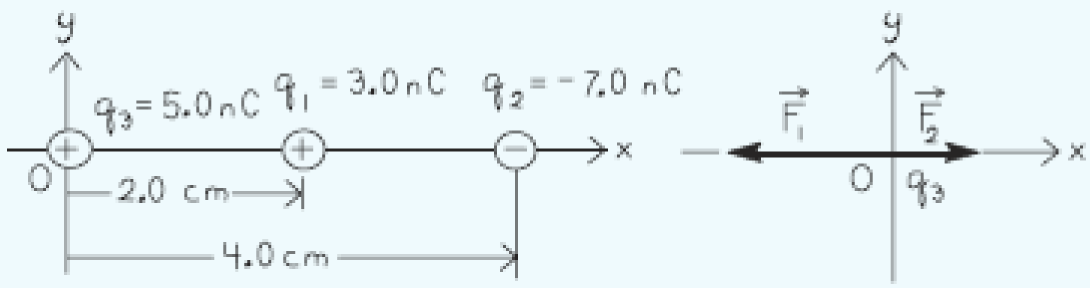
$$\frac{F_e}{F_g} = 2.27 \times 10^{39}.$$

REFLECT In our expression for the ratio, all the units cancel and the ratio is dimensionless. The astonishingly large value of F_e/F_g—about 10^{39}—shows that, in atomic structure, the gravitational force is completely negligible compared with the electrostatic force. The reason gravitational forces dominate in our daily experience

Continued

EXAMPLE 17.3 **Adding forces**

Two point charges are located on the positive x axis of a coordinate system. Charge $q_1 = 3.0\ \text{nC}$ is 2.0 cm from the origin, and charge $q_2 = -7.0\ \text{nC}$ is 4.0 cm from the origin. What is the total force (magnitude and direction) exerted by these two charges on a third point charge $q_3 = 5.0\ \text{nC}$ located at the origin?



(a) Our diagram of the situation (b) Free-body diagram for q_3

+ve direction

$$F_1 = k\frac{|q_1 q_3|}{r_{12}^2}$$
$$= (8.99 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{(3.0 \times 10^{-9}\ \text{C})(5.0 \times 10^{-9}\ \text{C})}{(0.020\ \text{m})^2}$$
$$= 3.37 \times 10^{-4}\ \text{N},$$

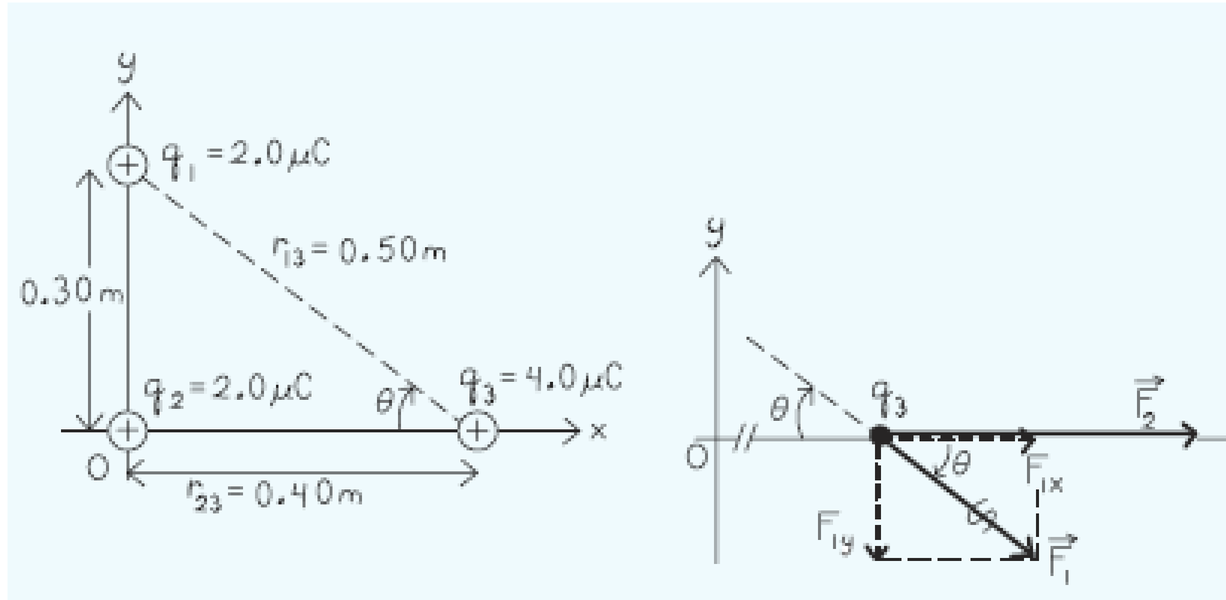
$$F_T = F_2 - F_1$$

$$F_2 = k\frac{|q_2 q_3|}{r_{23}^2}$$
$$= (8.99 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{(7.0 \times 10^{-9}\ \text{C})(5.0 \times 10^{-9}\ \text{C})}{(0.040\ \text{m})^2}$$
$$= 1.97 \times 10^{-4}\ \text{N}.$$

Vector addition of forces

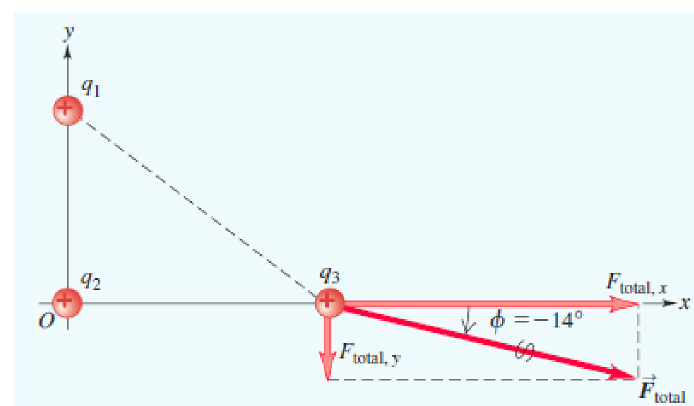
$$F_1 = k\frac{|q_1 q_3|}{r_{13}^2}$$

$$F_2 = k\frac{|q_2 q_3|}{r_{23}^2}$$



(a) Our sketch of the situation (b) Free-body diagram for q_3

- Find x & y components of the forces 1 and 2.
- Add all the x forces to get resultant x
- Add all the y forces to get resultant y
- Combine the x and y components using vector concepts.



17.5 Electric Field and Electric Forces

Definition of electric field

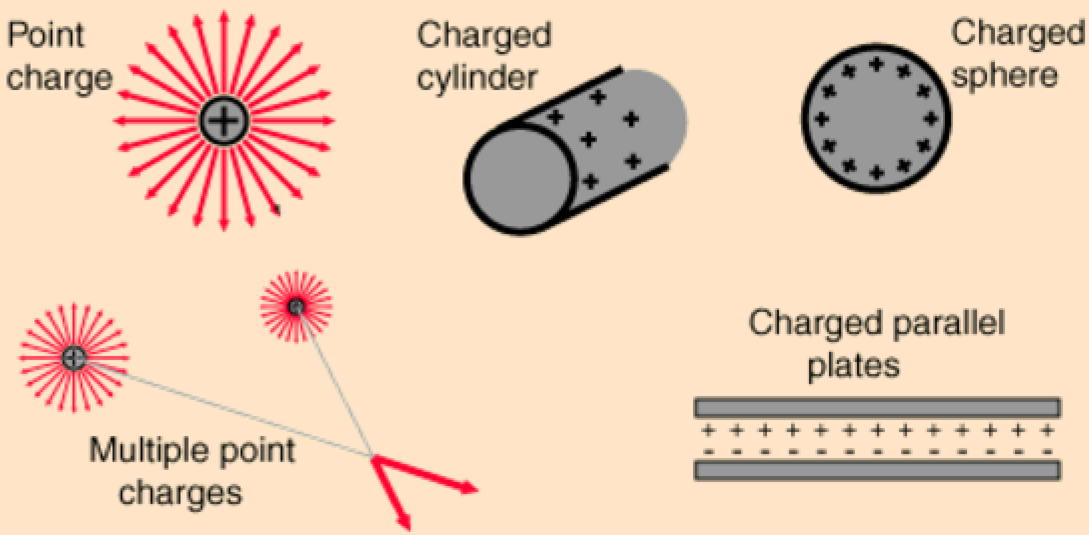
When a charged particle with charge q' at a point P is acted upon by an electric force $\vec{F}'$, the electric field $\vec{E}$ at that point is defined as

$$\vec{E} = \frac{\vec{F}'}{q'}. \tag{17.2}$$

The test charge q' can be either positive or negative. If it is positive, the directions of $\vec{E}$ and $\vec{F}'$ are the same; if it is *negative*, they are opposite (Figure 17.15).

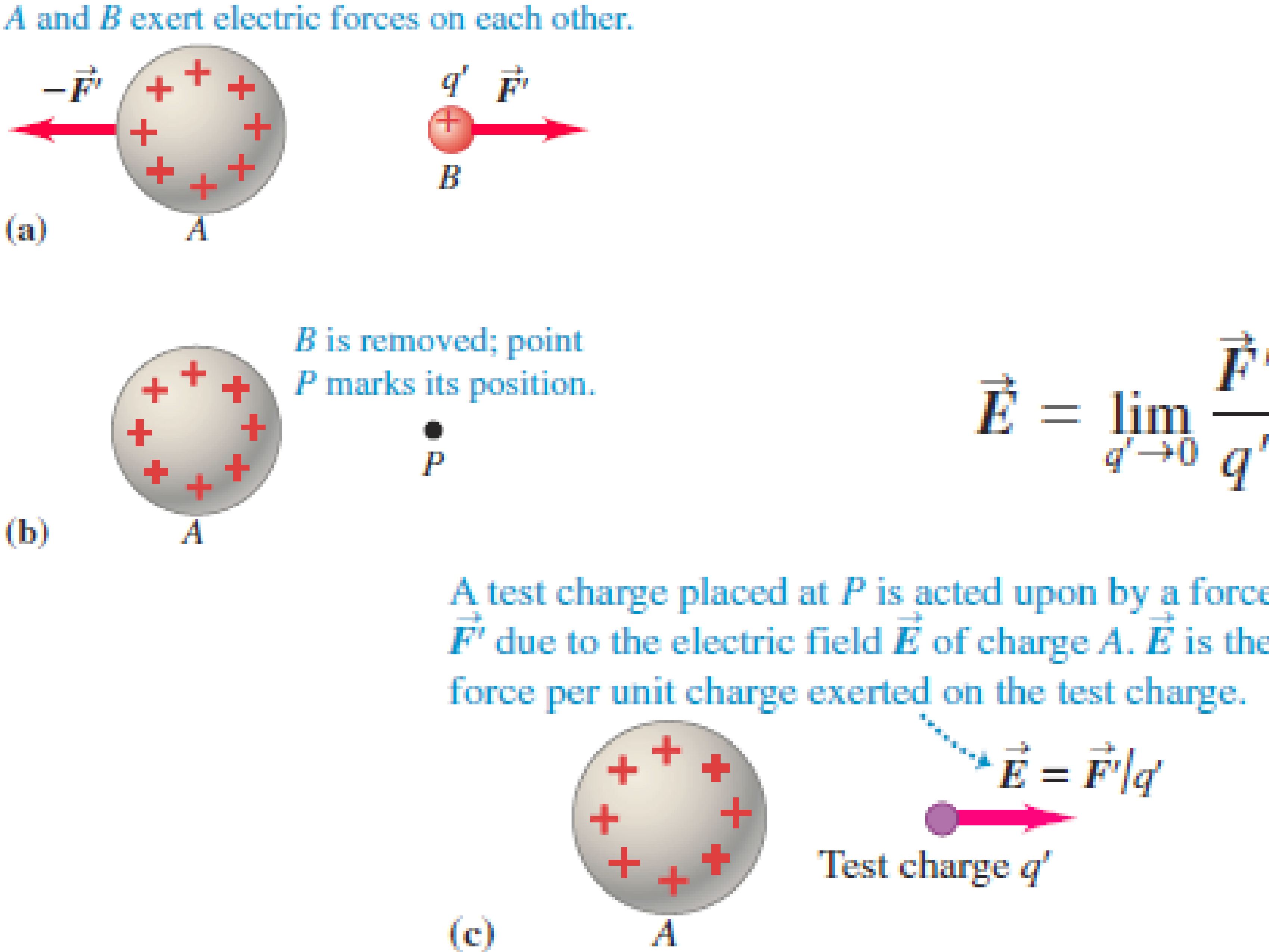
Unit: In SI units, in which the unit of force is the newton and the unit of charge is the coulomb, the unit of electric-field magnitude is 1 newton per coulomb $(1\ \mathrm{N/C})$.

Electric field is defined as the electric force per unit charge. The direction of the field is taken to be the direction of the force it would exert on a positive test charge. The electric field is radially outward from a positive charge and radially in toward a negative point charge.



Click on any of the examples above for more detail.

Electric field in N/C or volts/m. $\vec{E} = \dfrac{\vec{F}}{q}$ electric force in Newtons / charge in Coulombs



$$\vec{E} = \lim_{q' \to 0} \frac{\vec{F}'}{q'}.$$

The force on a positive test charge points in the direction of the electric field.

The force on a negative test charge points opposite to the electric field.

Principle of superposition

The total electric field at any point due to two or more charges is the vector sum of the fields that would be produced at that point by the individual charges.

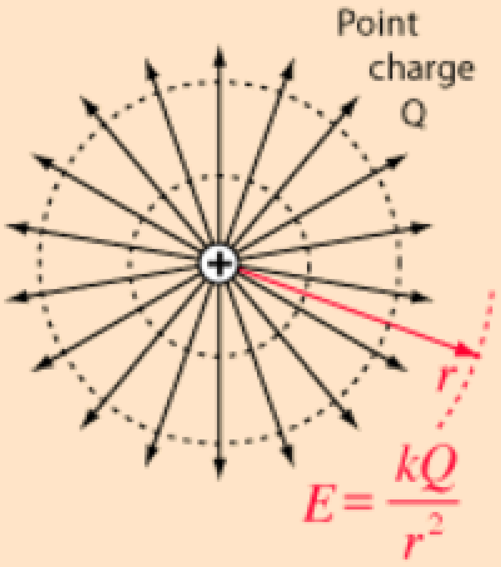
$$\vec{E}_{\text{total}} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \cdots.$$

Electric Field of Point Charge

The electric field of a point charge can be obtained from Coulomb's law:

$F = \frac{kq_1q_2}{r^2}$

$$E = \frac{F}{q} = \frac{kQ_{source}q}{qr^2} = \frac{kQ_{source}}{r^2}$$

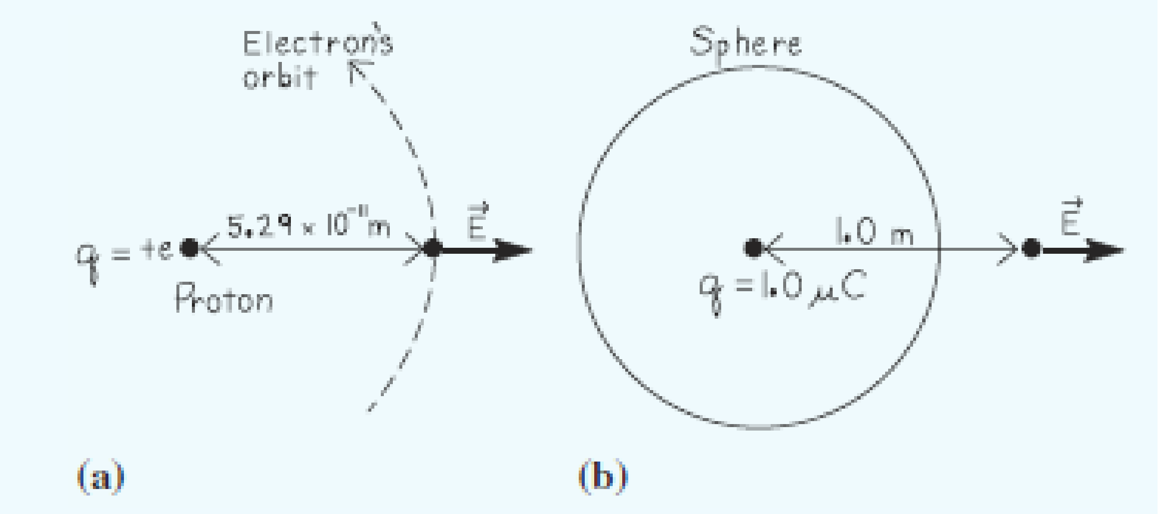


The electric field is radially outward from the point charge in all directions. The circles represent spherical equipotential surfaces.

The electric field from any number of point charges can be obtained from a vector sum of the individual fields. A positive number is taken to be an outward field; the field of a negative charge is toward it.

This electric field expression can also be obtained by applying Gauss' law.

Electric field in a hydrogen atom and Van der Graff (1m from centre)



Acts as single charge at centre

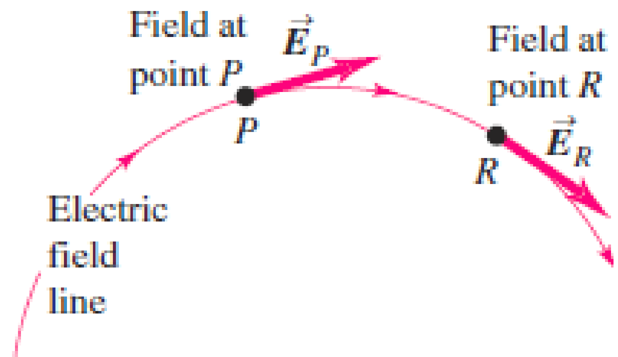
$$E = k\frac{|q|}{r^2}$$
$$= (8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2})\frac{(1.60 \times 10^{-19}\ \mathrm{C})}{(5.29 \times 10^{-11}\ \mathrm{m})^2}$$
$$= 5.14 \times 10^{11}\ \mathrm{N/C}.$$

$$E = k\frac{|q|}{r^2} = (8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2})\frac{(1.0 \times 10^{-6}\ \mathrm{C})}{(1.0\ \mathrm{m})^2}$$
$$= 9.0 \times 10^3\ \mathrm{N/C}.$$

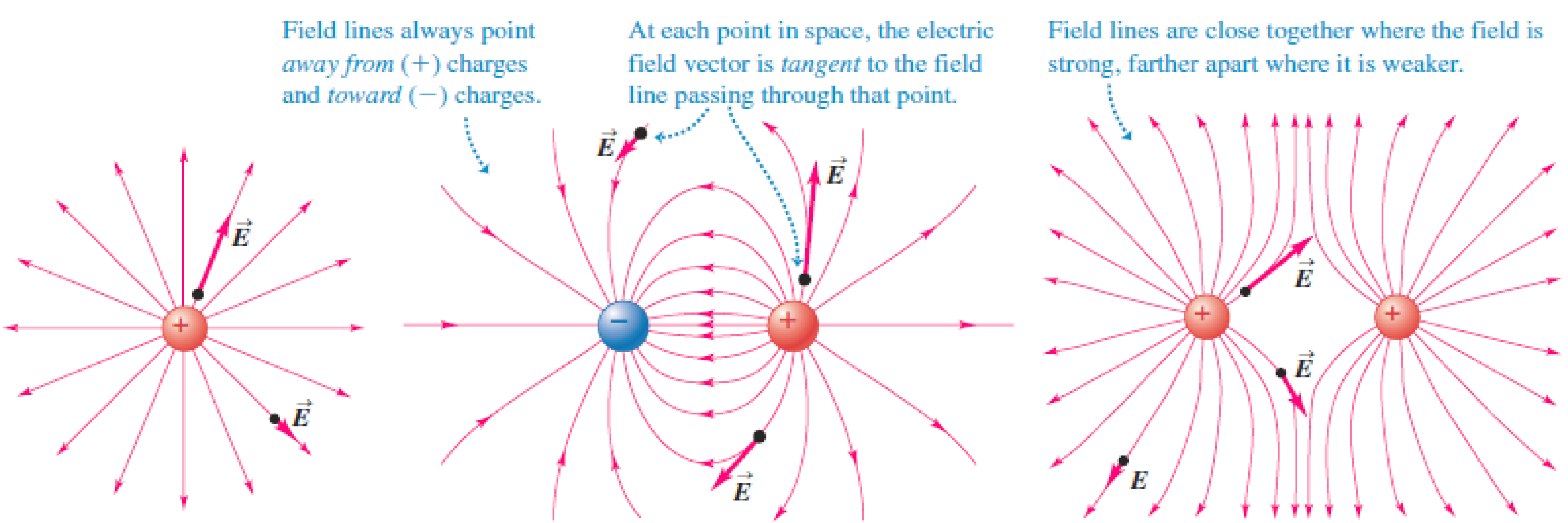
Hydrogen atom is MUCH more

EXAMPLE 17.7 Electric field of an electric dipole

17.7 Electric Field Lines



▲ **FIGURE 17.21** The direction of the electric field at any point is tangent to the field line through that point.

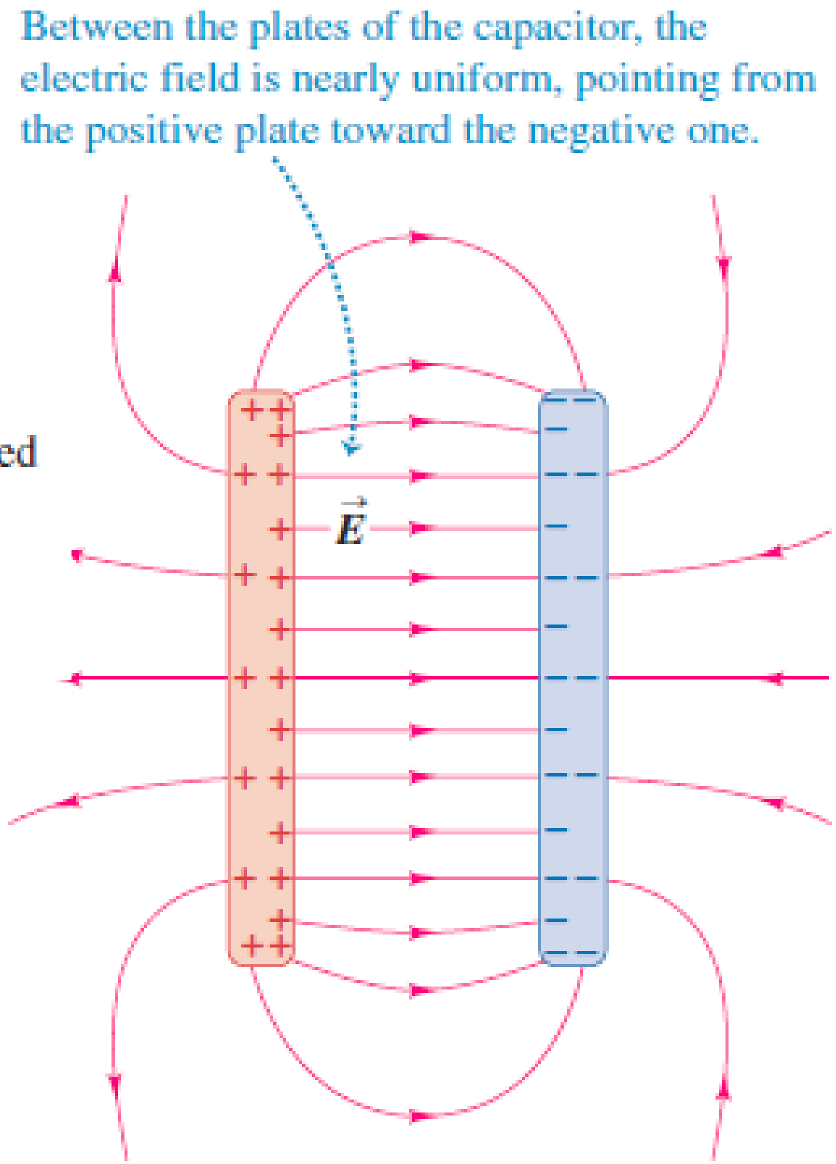


(a) A single positive charge

(b) Two equal and opposite charges (a dipole)

(c) Two equal positive charges

NOTE ► There may be a temptation to think that when a charged particle moves in an electric field, its path always follows a field line. Resist that temptation; the thought is erroneous. The direction of a field line at a given point determines the direction of the particle's *acceleration*, not its velocity. We've seen several examples of motion in which the velocity and acceleration vectors have different directions. ◄



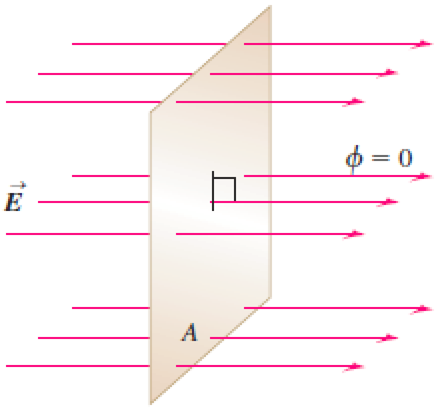
▲ **FIGURE 17.23** The electric field produced by a parallel-plate capacitor (seen in cross section). Between the plates, the field is nearly uniform.

17.8 Gauss's Law and Field Calculations

Rather than adding many point charges as in coulombs law we can image a Gaussian surface where the electric field goes through.
Gauss's law is a relation between the field at *all* the points on the surface and the total charge enclosed within the surface.

First we need to define electric flux.

Electric flux



Electric field $\vec{E}$ is perpendicular to area A; the angle between $\vec{E}$ and a line perpendicular to the surface is zero. The flux is $\Phi_E = EA$.

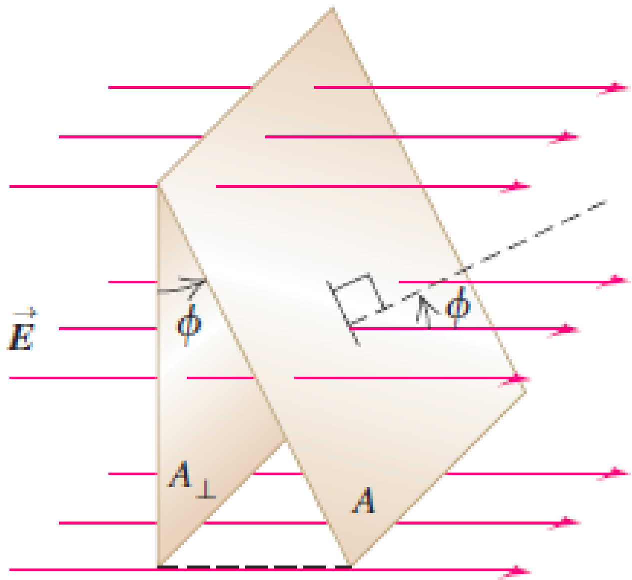
The definition of electric flux involves an area A and the electric field at various points in the area. The area needn't be the surface of a real object; in fact, it will usually be an imaginary area in space. Consider first a small, flat area A perpendicular to a uniform electric field $\vec{E}$ (Figure 17.24a). We denote electric flux by Φ_E; we define the electric flux Φ_E through the area A to be the product of the magnitude E of the electric field and the area A:

$$\Phi_E = EA.$$

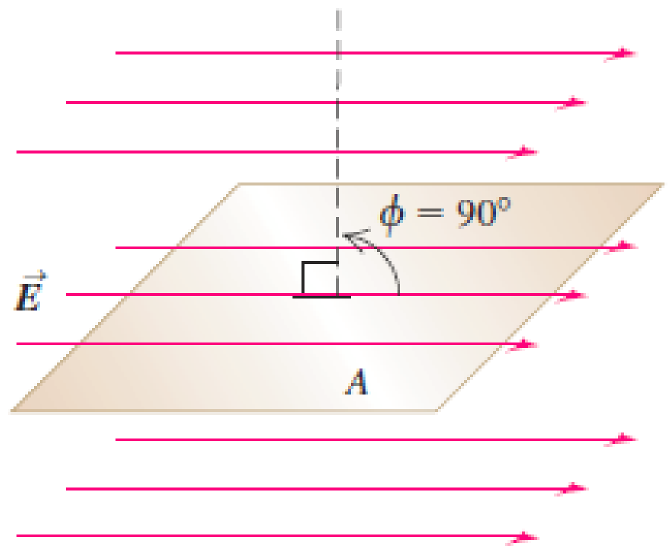
Roughly speaking, we can picture Φ_E in terms of the number of field lines that pass through A. More area means more lines through the area, and a stronger field means more closely spaced lines and therefore more lines per unit area.

$$\Phi_E = E_{\perp} A.$$

$$\Phi_E = EA\cos\phi.$$

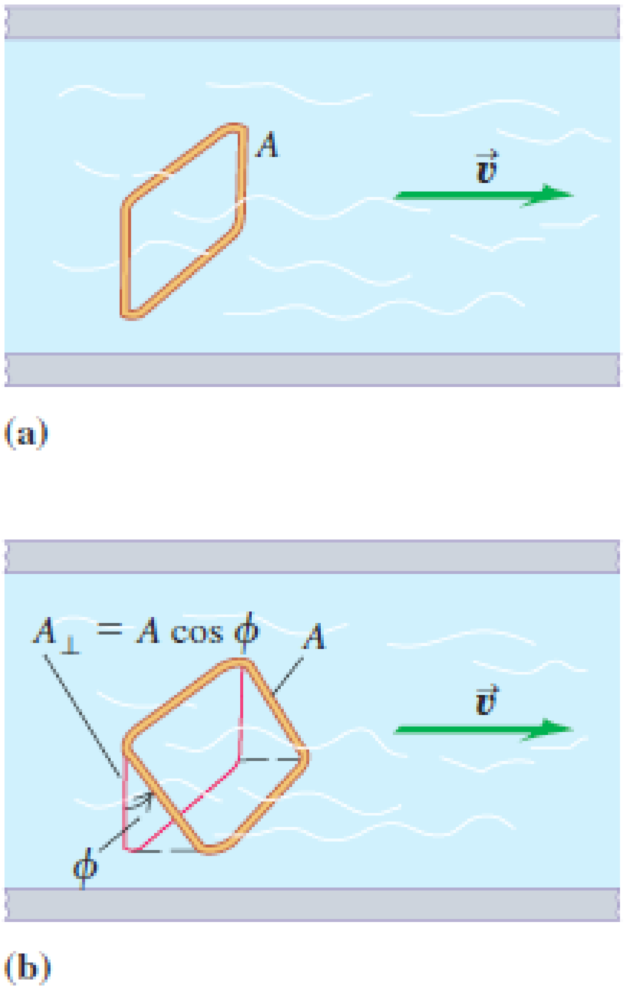


Area A is tilted at an angle ϕ from the perpendicular to $\vec{E}$.
The flux is $\Phi_E = EA\cos\phi$.



Area A is parallel to $\vec{E}$ (tilted at 90° from the perpendicular to $\vec{E}$).
The flux is $\Phi_E = EA\cos 90° = 0$.

This can be compared to water flow.



Gauss's law

The total electric flux Φ_E coming out of any closed surface (that is, a surface enclosing a definite volume) is proportional to the total (net) electric charge Q_{encl} inside the surface, according to the relation

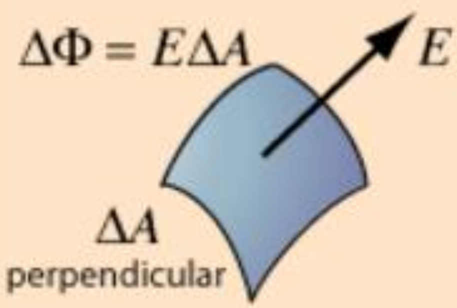
$$\sum E_\perp \, \Delta A = 4\pi k Q_{\text{encl}}. \tag{17.7}$$

The sum on the left side of this equation represents the operations of dividing the enclosing surface into small elements of area ΔA, computing $E_\perp \, \Delta A$ for each one, and adding all these products.

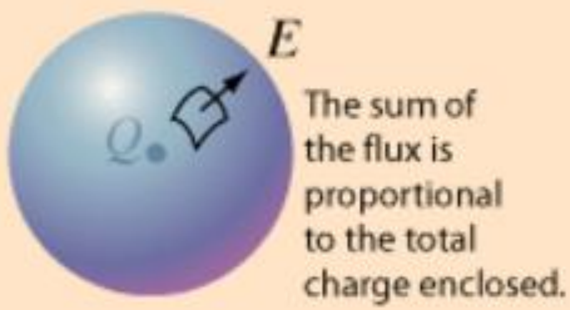
$$\Phi_E = \sum E_\perp \, \Delta A = 4\pi k q. = \frac{Q_{\text{encl}}}{\epsilon_0}.$$

Gauss's Law

The total of the electric flux out of a closed surface is equal to the charge enclosed divided by the permittivity.



$$\Phi_{electric} = \frac{Q}{\varepsilon_0}$$

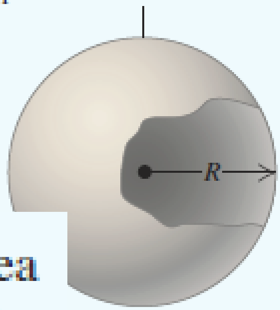


In terms of calculus (just for interest)

Flux $\phi = \int E.\delta A$

Gauss $\phi = \oint E.\delta A = \frac{Q_{enc}}{\varepsilon_o}$

EXAMPLE 17.10 **Field due to a spherical shell of charge**



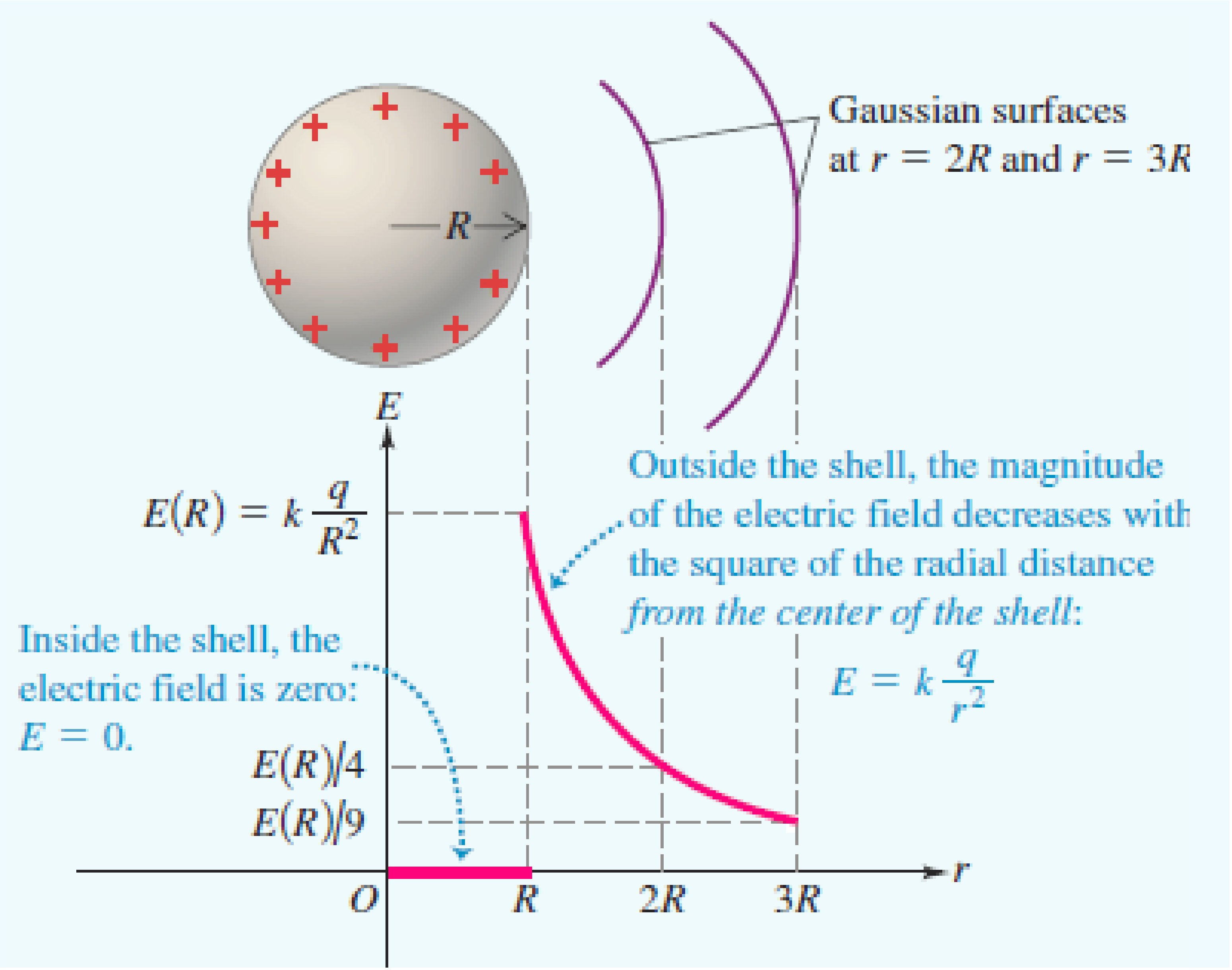
A positive charge q is spread uniformly over a thin spherical shell of radius R (Figure 17.29). Find the electric field at points inside and outside the shell.

Inside the shell $(r < R)$: The Gaussian surface has area $4\pi r^2$. Since, by symmetry, the electric field is uniform over the Gaussian sphere and perpendicular to it at each point, the electric flux is $\Phi_E = EA = E(4\pi r^2)$. The Gaussian surface is inside the shell and encloses none of the charge on the shell, so $Q_{encl} = 0$.

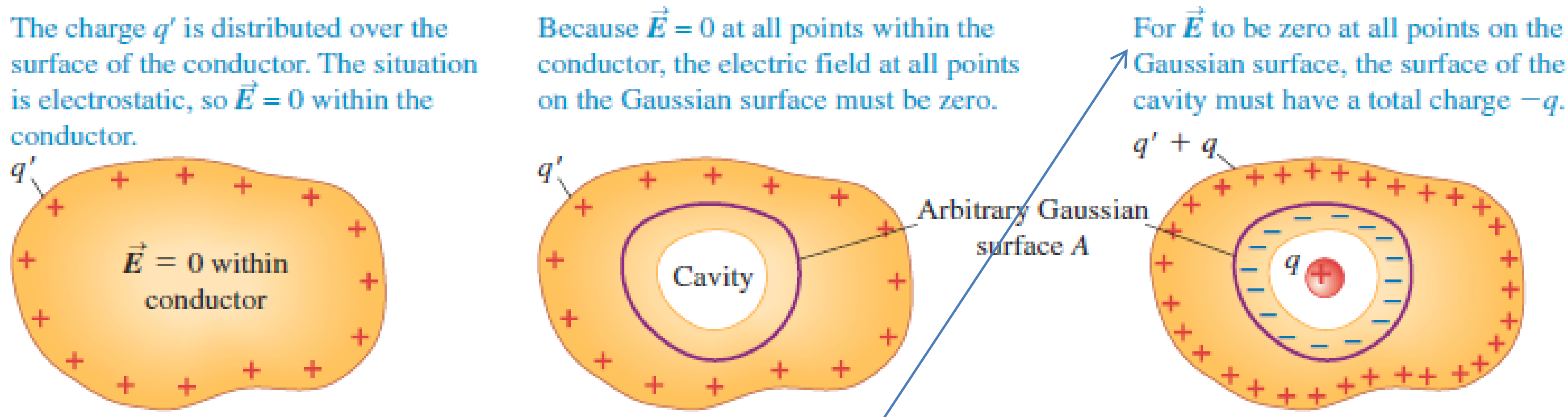
Gauss's law $\Phi_E = Q_{encl}/\epsilon_0$ then says that $\Phi_E = E(4\pi r^2) = 0$, so $E = 0$. The electric field is zero at all points inside the shell.

Outside the shell $(r > R)$: Again, $\Phi_E = E(4\pi r^2)$. But now all of the shell is inside the Gaussian surface, so $Q_{encl} = q$. Gauss's law $\Phi_E = Q_{encl}/\epsilon_0$ then gives $E(4\pi r^2) = q/\epsilon_0$, and it follows that

$$E = \frac{q}{4\pi\epsilon_0 r^2} = k\frac{q}{r^2}.$$



Gaussian surfaces
at r = 2R and r = 3R
R
E
E(R) = k q/R²
Outside the shell, the magnitude
of the electric field decreases with
the square of the radial distance
from the center of the shell:
E = k q/r²
Inside the shell, the
electric field is zero:
E = 0.
E(R)/4
E(R)/9
r
O
R
2R
3R



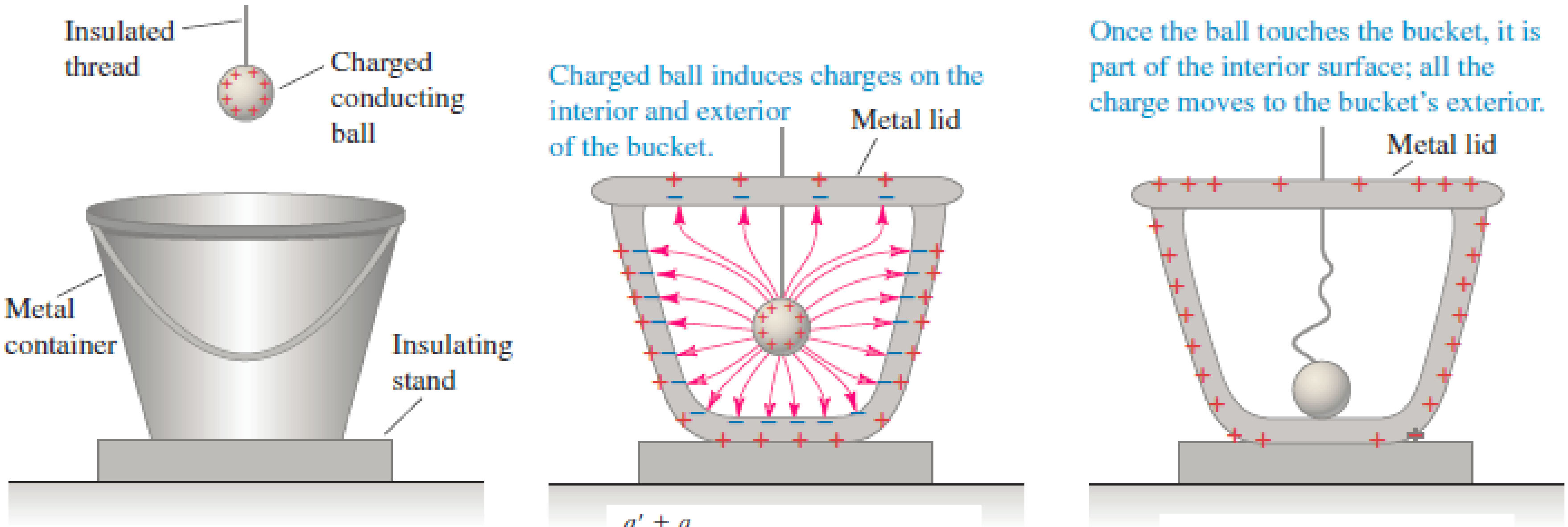
(a) Solid conductor with charge q'

(b) The same conductor with an internal cavity

(c) An isolated charge q is placed in the cavity

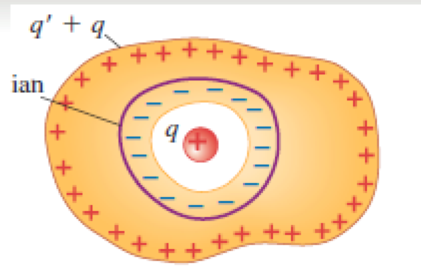
▲ **FIGURE 17.31** The charge on a solid conductor, on a conductor with a cavity, and on a conductor with a cavity that contains a charge.

(because the situation is still electrostatic – no moving charges so no electric field in the conductor must be zero)



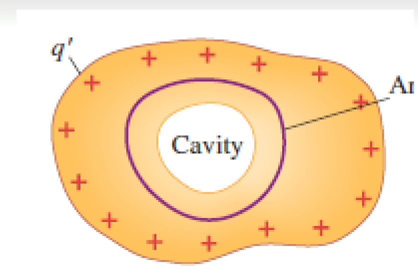
(a)

(b)



(c) An isolated charge q is placed in the cavity

(c)



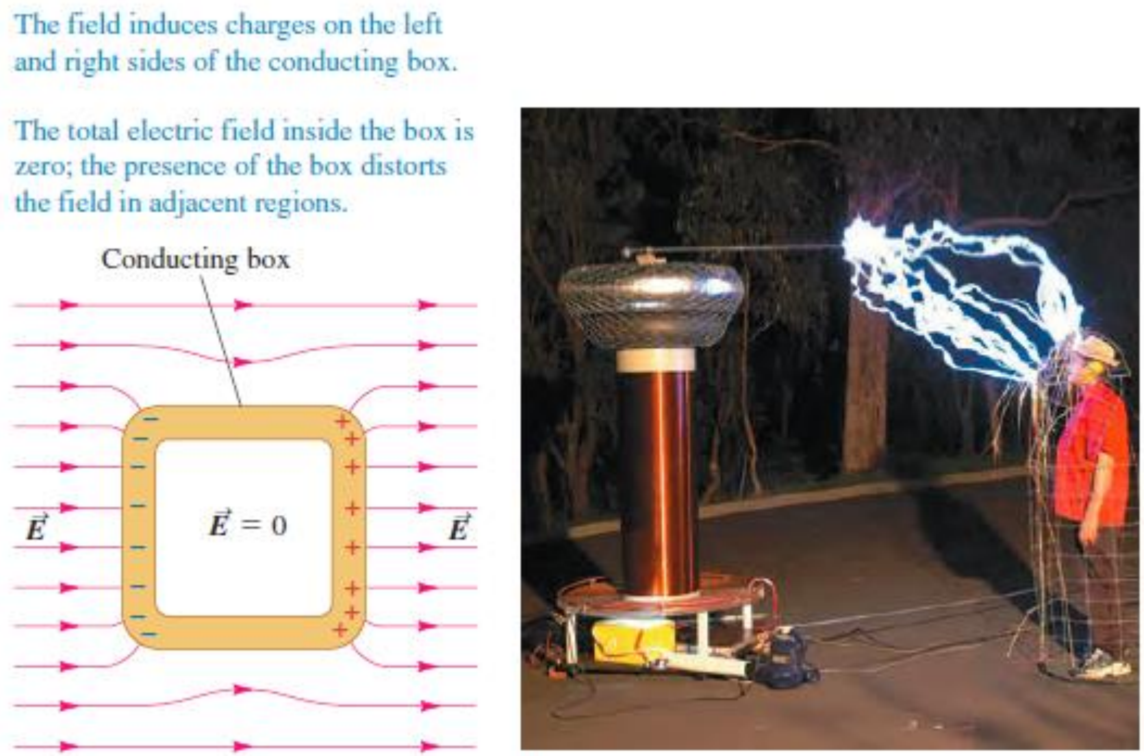
(b) The same conductor with an internal cavity

Faraday Ice Pail

The surface of the ball becomes, in effect, part of the cavity surface. The situation is now the same as Figure 17.31b; if Gauss's law is correct, the net charge on this surface must be zero. Thus, the ball must lose all its charge. Finally, we pull the ball out, to find that it has indeed lost all its charge.

Faraday cage

▲ Application **A Faraday cage when you need one.** If you find yourself in a thunderstorm while driving, *stay in your car*. If it gets hit by lightning, it will act as a Faraday cage and keep you safe.



(a) (b)

▲ **FIGURE 17.34** (a) The effect of putting a conducting box (an electrostatic shield) in a uniform electric field. (b) The conducting cage keeps the operator of this exhibit perfectly safe.

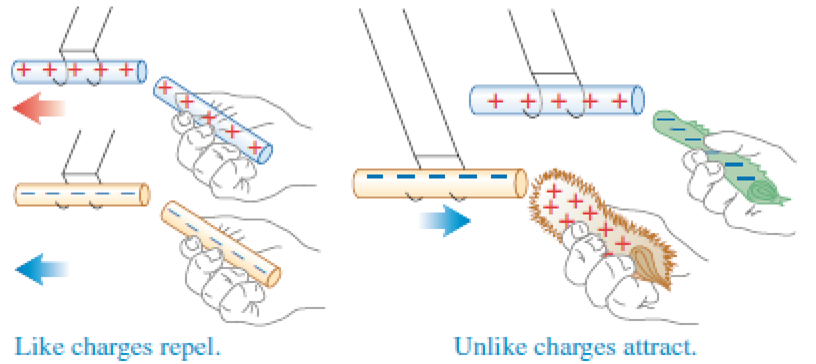
SUMMARY

Electric Charge; Conductors and Insulators

(Sections 17.1–17.3) The fundamental entity in electrostatics is electric charge. There are two kinds of charge: positive and negative. Like charges repel each other; unlike charges attract. **Conductors** are materials that permit electric charge to move within them. **Insulators** permit charge to move much less readily. Most metals are good conductors; most nonmetals are insulators.

All ordinary matter is made of atoms consisting of protons, neutrons, and electrons. The protons and neutrons form the nucleus of the atom; the electrons surround the nucleus at distances much greater than its size. Electrical interactions are chiefly responsible for the structure of atoms, molecules, and solids.

Electric charge is conserved: It can be transferred between objects, but isolated charges cannot be created or destroyed. Electric charge is quantized: Every amount of observable charge is an integer multiple of the charge of an electron or proton.

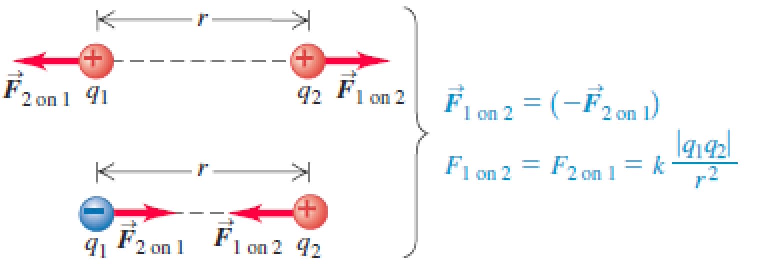


Coulomb's Law

(Section 17.4) Coulomb's law is the basic law of interaction for point electric charges. For point charges q_1 and q_2 separated by a distance r, the magnitude F of the force each charge exerts on the other is

$$F = k\frac{|q_1 q_2|}{r^2}. \tag{17.1}$$

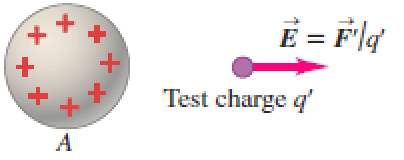
The force on each charge acts along the line joining the two charges. It is repulsive if q_1 and q_2 have the same sign, attractive if they have opposite signs. The forces form an action–reaction pair and obey Newton's third law.



Electric Field and Electric Forces

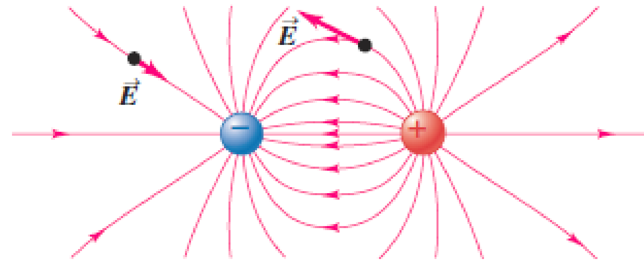
(Sections 17.5 and 17.6) Electric field, a vector quantity, is the force per unit charge exerted on a test charge at any point, provided that the test charge is small enough that it does not disturb the charges that cause the field. The principle of superposition states that the electric field due to any combination of charges is the vector sum of the fields caused by the individual charges. From Coulomb's law, the magnitude of the electric field produced by a point charge is

$$E = k\frac{|q|}{r^2}. \tag{17.4}$$



Electric Field Lines

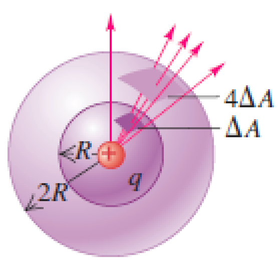
(Section 17.7) **Field lines** provide a graphical representation of electric fields. A field line at any point in space is tangent to the direction of $\vec{E}$ at that point, and the number of lines per unit area (perpendicular to their direction) is proportional to the magnitude of $\vec{E}$ at the point. Field lines point away from positive charges and toward negative charges.



Gauss's Law

(Section 17.8) For a uniform electric field with component $E_\perp$ perpendicular to area A, the **electric flux** through the area is $\Phi_E = E_\perp A$ (Equation 17.6). **Gauss's law** states that the total electric flux Φ_E out of any closed surface (that is, a surface enclosing a definite volume) is proportional to the total electric charge Q_{encl} inside the surface, according to the relation

$$\sum E_\perp \Delta A = 4\pi k Q_{encl}. \tag{17.7}$$



Charges on Conductors

(Section 17.9) In a static configuration with no net motion of charge, the electric field is always zero within a conductor. The charge on a solid conductor is located entirely on its outer surface. If there is a cavity containing a charge $+q$ within the conductor, the surface of the cavity has a total induced charge $-q$.