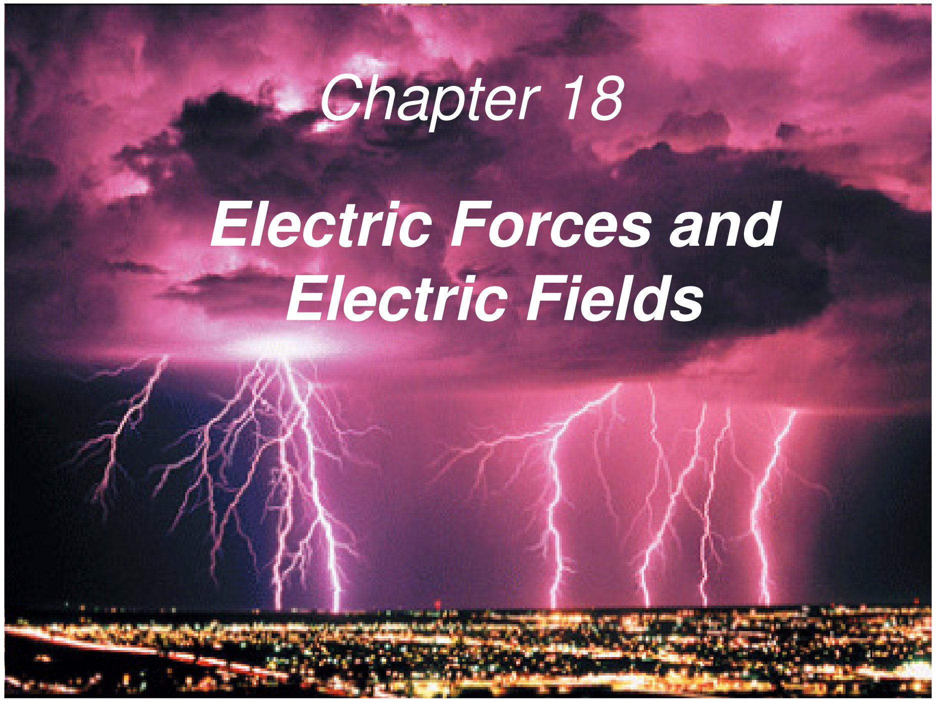
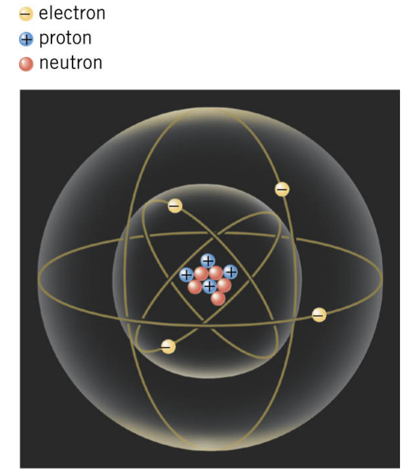


18.1 ***The Origin of Electricity***

The electrical nature of matter is inherent in atomic structure.



$$m_p = 1.673 \times 10^{-27}\,\text{kg}$$

$$m_n = 1.675 \times 10^{-27}\,\text{kg}$$

$$m_e = 9.11 \times 10^{-31}\,\text{kg}$$

$$e = 1.60 \times 10^{-19}\,\text{C}$$

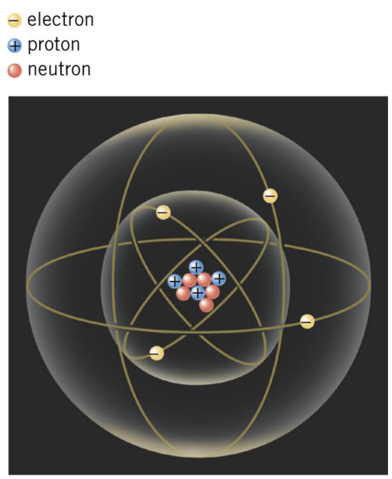
coulombs

18.1 ***The Origin of Electricity***

In nature, atoms are normally found with equal numbers of protons and electrons, so they are electrically neutral.

By adding or removing electrons from matter it will acquire a net electric charge with magnitude equal to *e* times the number of electrons added or removed, *N*.

$$q = Ne$$



18.1 ***The Origin of Electricity***

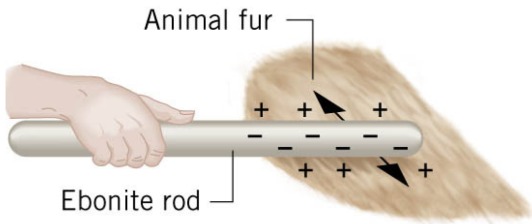
Example 1 **A Lot of Electrons**

How many electrons are there in one coulomb of negative charge?

$$q = Ne$$

$$N = \frac{q}{e} = \frac{1.00\,\text{C}}{1.60 \times 10^{-19}\,\text{C}} = 6.25 \times 10^{18}$$

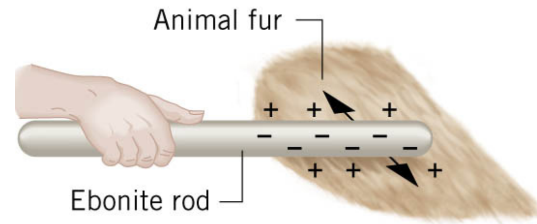
18.2 *Charged Objects and the Electric Force*



It is possible to transfer electric charge from one object to another.

The body that loses electrons has an excess of positive charge, while the body that gains electrons has an excess of negative charge.

18.2 *Charged Objects and the Electric Force*

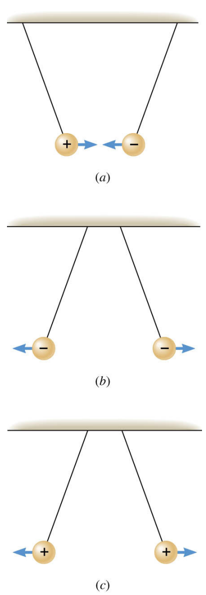


LAW OF CONSERVATION OF ELECTRIC CHARGE

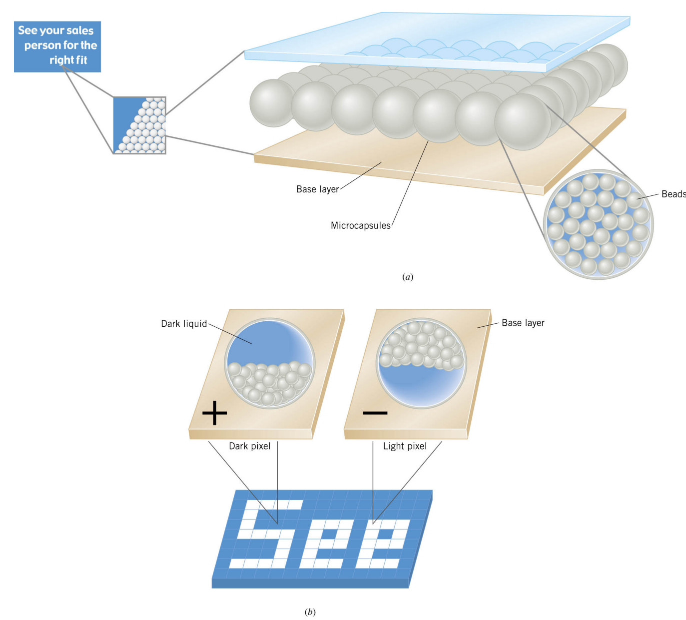
During any process, the net electric charge of an isolated system remains constant (is conserved).

18.2 *Charged Objects and the Electric Force*

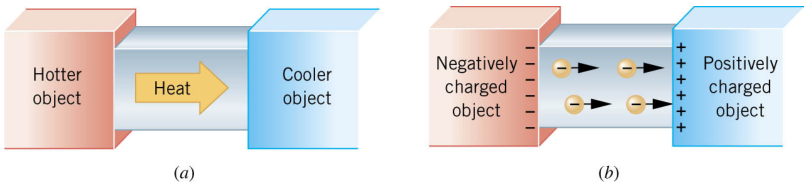
Like charges repel and unlike charges attract each other.



18.2 *Charged Objects and the Electric Force*



18.3 Conductors and Insulators

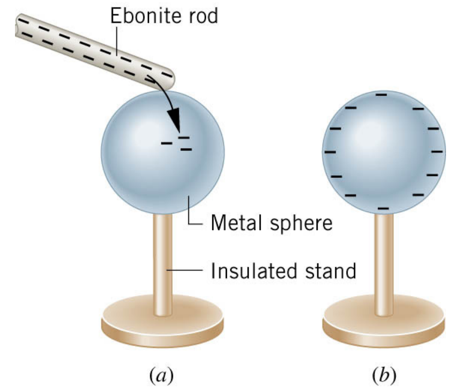


Not only can electric charge exist *on an object,* but it can also move *through and object*.

Substances that readily conduct electric charge are called ***electrical conductors***.

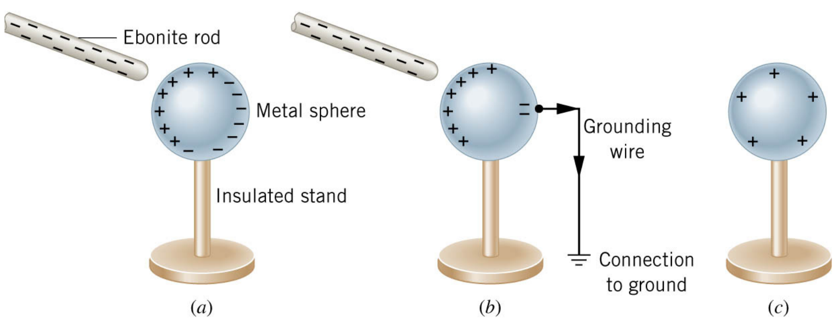
Materials that conduct electric charge poorly are called ***electrical insulators.***

18.4 Charging by Contact and by Induction



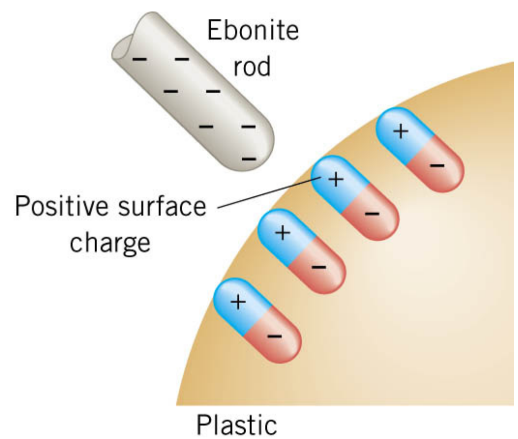
Charging by contact.

18.4 Charging by Contact and by Induction

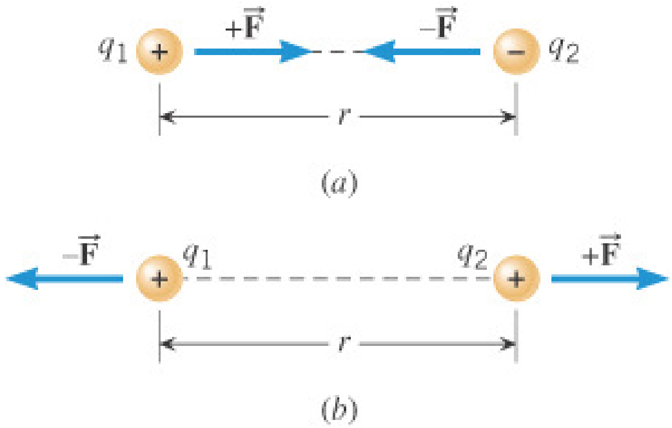


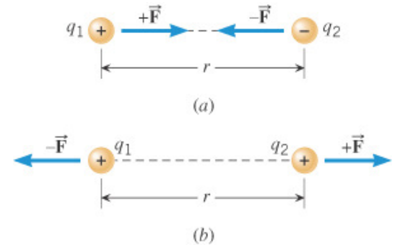
Charging by induction.

18.4 Charging by Contact and by Induction



The negatively charged rod induces a slight positive surface charge on the plastic.





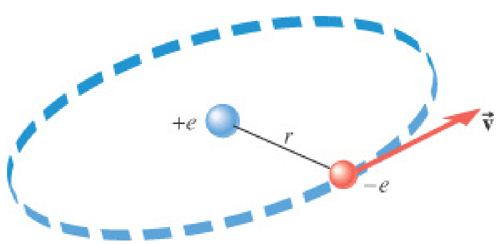
COULOMB'S LAW

The magnitude of the electrostatic force exerted by one point charge on another point charge is directly proportional to the magnitude of the charges and inversely proportional to the square of the distance between them.

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

$$\varepsilon_o = 8.85\times10^{-12}\ \mathrm{C^2/(N\cdot m^2)}$$

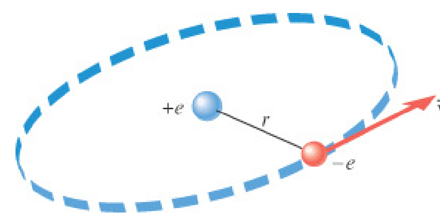
$$k = 1/(4\pi\varepsilon_o) = 8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}$$



Example 3 **A Model of the Hydrogen Atom**

In the Bohr model of the hydrogen atom, the electron is in orbit about the nuclear proton at a radius of 5.29×10^{-11}m. Determine the speed of the electron, assuming the orbit to be circular.

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



$$F = k\frac{|q_1||q_2|}{r^2} = \frac{(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2})(1.60\times10^{-19}\ \mathrm{C})^2}{(5.29\times10^{-11}\ \mathrm{m})^2} = 8.22\times10^{-8}\ \mathrm{N}$$

$$F = ma_c = mv^2/r$$

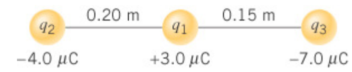
$$\Rightarrow \quad v = \sqrt{Fr/m} = \sqrt{\frac{(8.22\times10^{-8}\ \mathrm{N})(5.29\times10^{-11}\ \mathrm{m})}{9.11\times10^{-31}\ \mathrm{kg}}} = 2.18\times10^{6}\ \mathrm{m/s}$$

Example 4 Three Charges on a Line

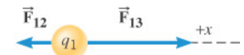
Determine the magnitude and direction of the net force on q_1.

(a)

(b) Free-body diagram for q_1



(a)

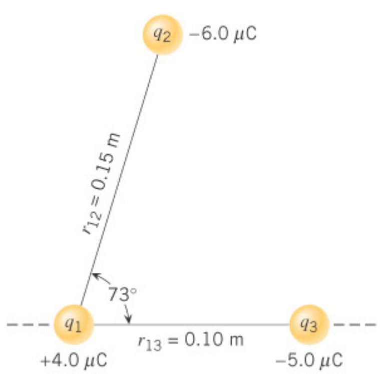


(b) Free-body diagram for q_1

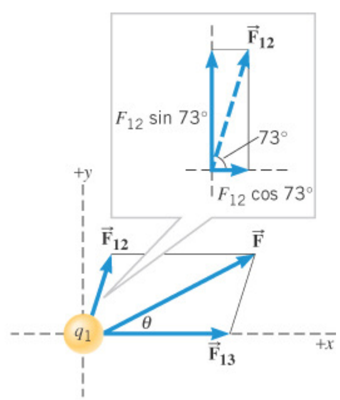
$$F_{12} = k\frac{|q_1||q_2|}{r^2} = \frac{(8.99\times10^9\ \mathrm{N\cdot m^2/C^2})(3.0\times10^{-6}\,\mathrm{C})(4.0\times10^{-6}\,\mathrm{C})}{(0.20\,\mathrm{m})^2} = 2.7\,\mathrm{N}$$

$$F_{13} = k\frac{|q_1||q_3|}{r^2} = \frac{(8.99\times10^9\ \mathrm{N\cdot m^2/C^2})(3.0\times10^{-6}\,\mathrm{C})(7.0\times10^{-6}\,\mathrm{C})}{(0.15\,\mathrm{m})^2} = 8.4\,\mathrm{N}$$

$$\vec{\mathbf{F}} = \vec{\mathbf{F}}_{12} + \vec{\mathbf{F}}_{13} = -2.7\,\mathrm{N} + 8.4\,\mathrm{N} = +5.7\,\mathrm{N}$$



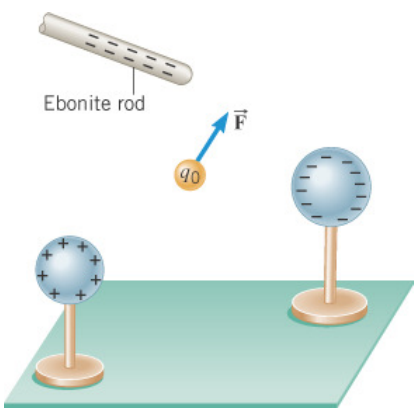
(a)



(b) Free-body diagram for q_1

The positive charge experiences a force which is the vector sum of the forces exerted by the charges on the rod and the two spheres.

This ***test charge*** should have a small magnitude so it doesn't affect the other charge.

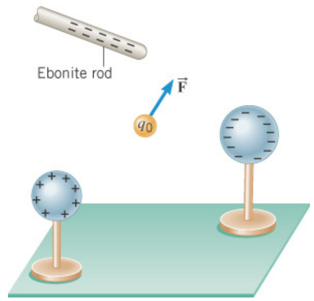


***Example 6* A Test Charge**

The positive test charge has a magnitude of 3.0×10^{-8}C and experiences a force of 6.0×10^{-8}N.

(a) Find the *force per coulomb* that the test charge experiences.

(b) Predict the force that a charge of $+12 \times 10^{-8}$C would experience if it replaced the test charge.



(a) $$\frac{F}{q_o} = \frac{6.0\times10^{-8}\,\text{N}}{3.0\times10^{-8}\,\text{C}} = 2.0\,\text{N/C}$$

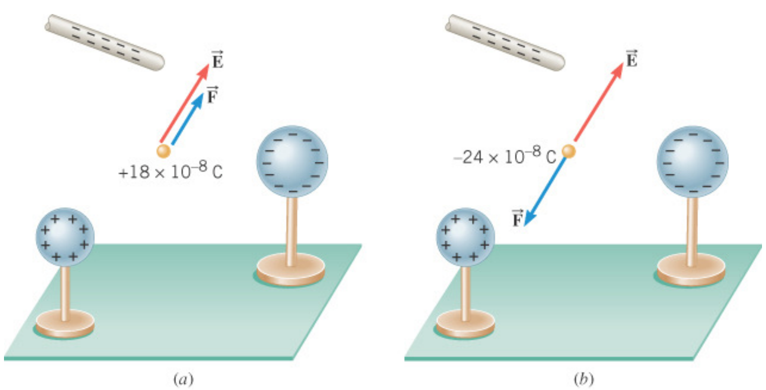
(b) $$F = (2.0\,\text{N/C})(12.0\times10^{-8}\,\text{C}) = 24\times10^{-8}\,\text{N}$$

DEFINITION OF ELECRIC FIELD

The electric field that exists at a point is the electrostatic force experienced by a small test charge placed at that point divided by the charge itself:

$$\vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}}{q_o}$$

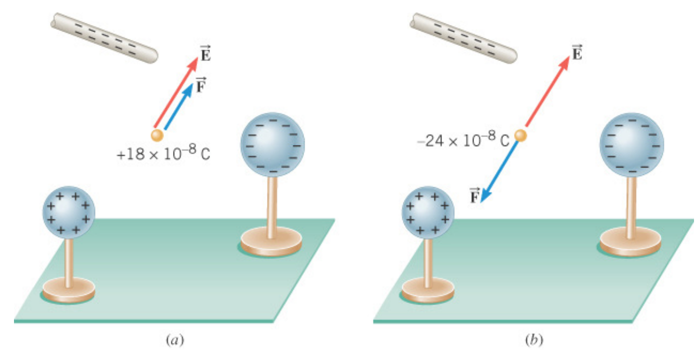
SI Units of Electric Field: newton per coulomb (N/C)

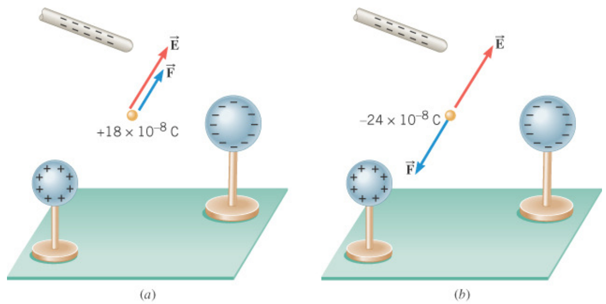


It is the surrounding charges that create the electric field at a given point.

***Example 7* An Electric Field Leads to a Force**

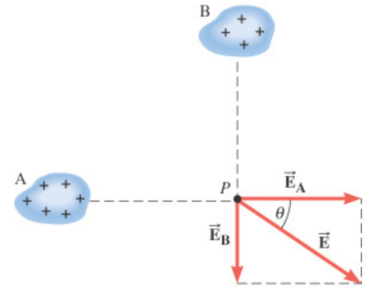
The charges on the two metal spheres and the ebonite rod create an electric field at the spot indicated. The field has a magnitude of 2.0 N/C. Determine the force on the charges in (a) and (b)





(a) $F = |q_o|E = (2.0\,\text{N/C})(18.0\times10^{-8}\,\text{C}) = 36\times10^{-8}\,\text{N}$

(b) $F = |q_o|E = (2.0\,\text{N/C})(24.0\times10^{-8}\,\text{C}) = 48\times10^{-8}\,\text{N}$

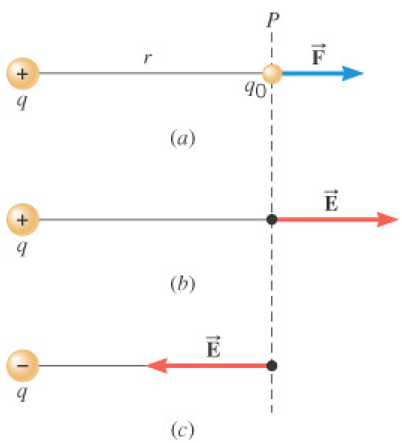


Electric fields from different sources add as vectors.

Example 10 **The Electric Field of a Point Charge**

The isolated point charge of q=+15μC is in a vacuum. The test charge is 0.20m to the right and has a charge q_o=+15μC.

Determine the electric field at point P.

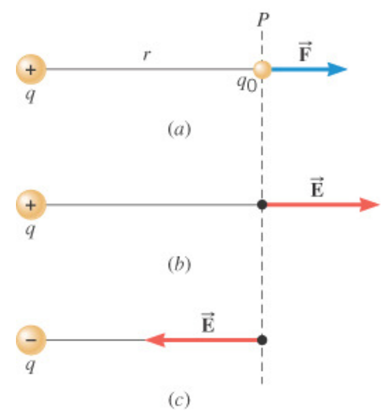


$$\vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}}{q_o}$$

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

$$F = k\frac{|q||q_o|}{r^2}$$
$$= \frac{(8.99\times10^{9}\,\text{N}\cdot\text{m}^2/\text{C}^2)(0.80\times10^{-6}\,\text{C})(15\times10^{-6}\,\text{C})}{(0.20\,\text{m})^2} = 2.7\,\text{N}$$

$$E = \frac{F}{|q_o|} = \frac{2.7\,\text{N}}{0.80\times10^{-6}\,\text{C}} = 3.4\times10^{6}\,\text{N/C}$$



$$E = \frac{F}{|q_o|} = k\frac{|q||q_o|}{r^2}\frac{1}{|q_o|}$$

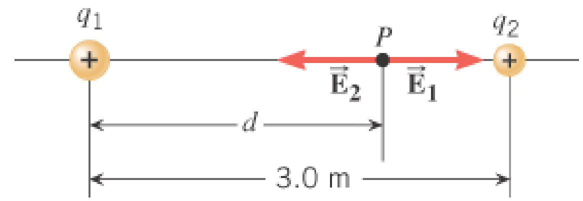
The electric field does not depend on the test charge.

Point charge q:

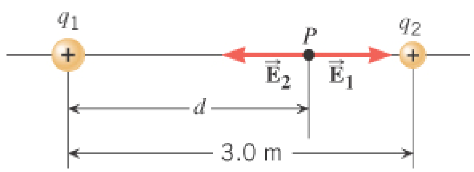
$$E = k\frac{|q|}{r^2}$$

Example 11 **The Electric Fields from Separate Charges May Cancel**

Two positive point charges, q_1=+16μC and q_2=+4.0μC are separated in a vacuum by a distance of 3.0m. Find the spot on the line between the charges where the net electric field is zero.



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



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

$$E_1 = E_2$$

$$k\frac{(16\times10^{-6}\,\mathrm{C})}{d^2} = k\frac{(4.0\times10^{-6}\,\mathrm{C})}{(3.0\mathrm{m}-d)^2}$$

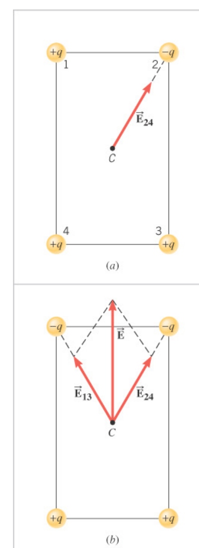
$$2.0(3.0\mathrm{m}-d)^2 = d^2$$

$$d = +2.0\,\mathrm{m}$$

Conceptual Example 12 **Symmetry and the Electric Field**

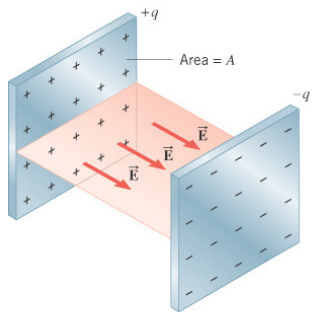
Point charges are fixes to the corners of a rectangle in two different ways. The charges have the same magnitudes but different signs.

Consider the net electric field at the center of the rectangle in each case. Which field is stronger?



18.6 The Electric Field

THE PARALLEL PLATE CAPACITOR



Parallel plate capacitor

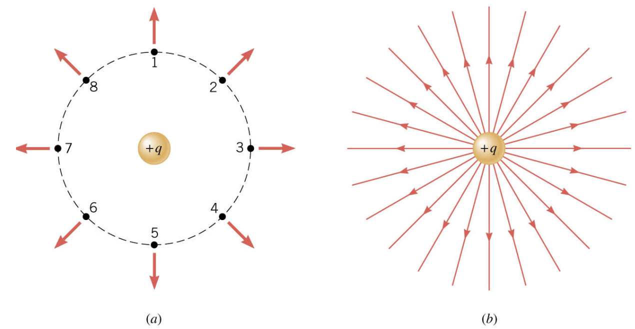
charge density

$$E = \frac{q}{\varepsilon_o A} = \frac{\sigma}{\varepsilon_o}$$

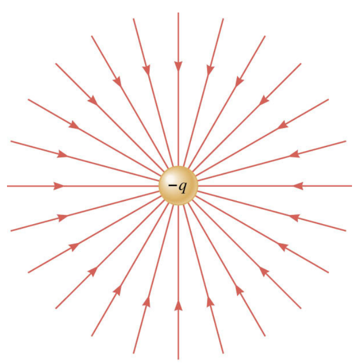
$$\varepsilon_o = 8.85 \times 10^{-12}\ \mathrm{C^2/(N \cdot m^2)}$$

18.7 Electric Field Lines

Electric field lines or ***lines of force*** provide a map of the electric field in the space surrounding electric charges.



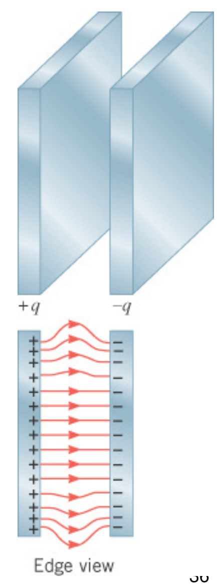
18.7 Electric Field Lines



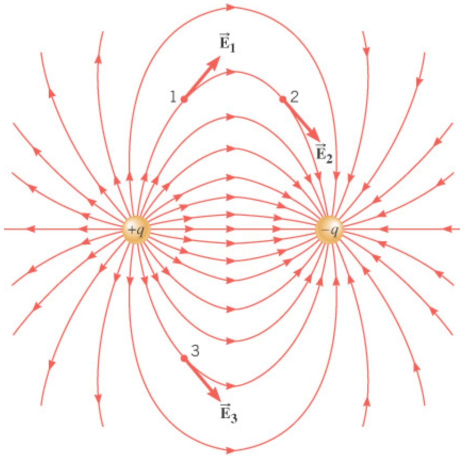
Electric field lines are always directed away from positive charges and toward negative charges.

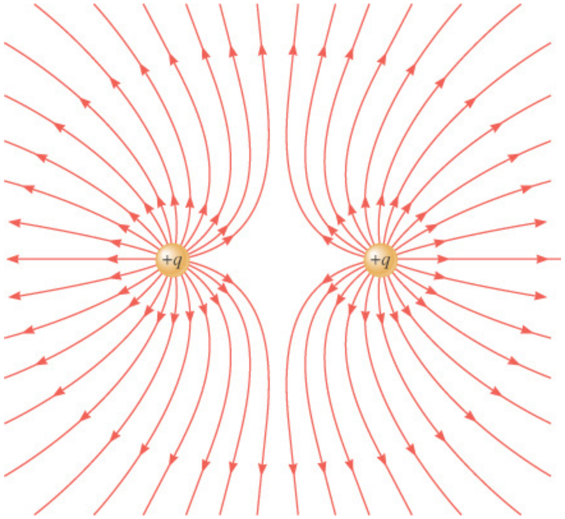
18.7 Electric Field Lines

Electric field lines always begin on a positive charge and end on a negative charge and do not stop in midspace.



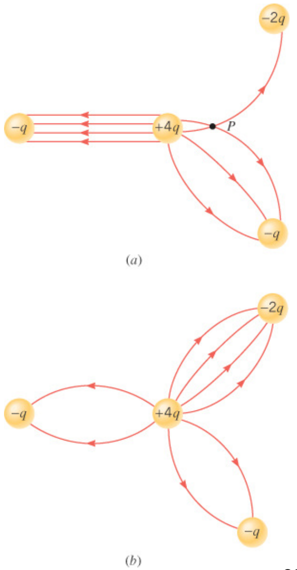
The number of lines leaving a positive charge or entering a negative charge is proportional to the magnitude of the charge.





Conceptual Example 13 **Drawing Electric Field Lines**

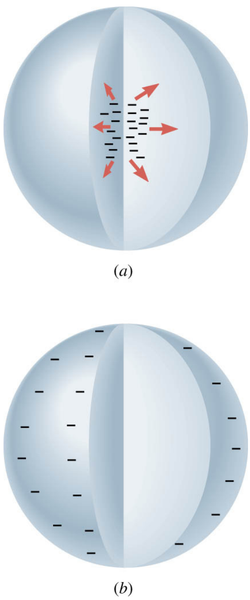
There are three things wrong with part (a) of the drawing. What are they?



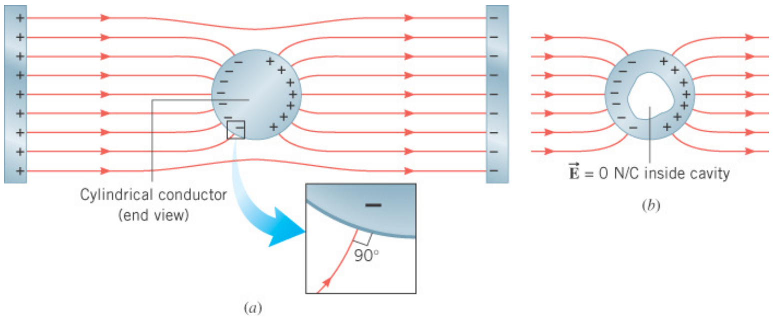
At equilibrium under electrostatic conditions, any excess charge resides on the surface of a conductor.

At equilibrium under electrostatic conditions, the electric field is zero at any point within a conducting material.

The conductor shields any charge within it from electric fields created outside the condictor.



18.8 The Electric Field Inside a Conductor: Shielding



The electric field just outside the surface of a conductor is perpendicular to the surface at equilibrium under electrostatic conditions.

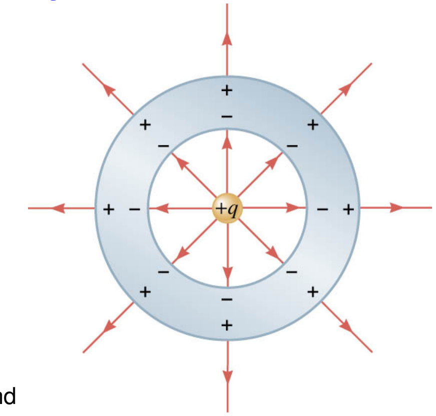
18.8 The Electric Field Inside a Conductor: Shielding

Conceptual Example 14 A Conductor in an Electric Field

A charge is suspended at the center of a hollow, electrically neutral, spherical conductor. Show that this charge induces

(a) a charge of –q on the interior surface and

(b) a charge of +q on the exterior surface of the conductor.



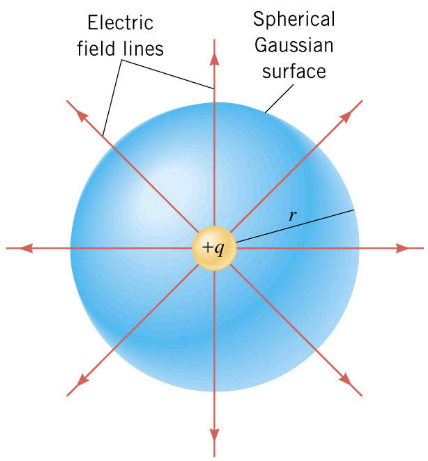
18.9 Gauss' Law

$$E = kq/r^2 = q/\left(4\pi\varepsilon_o r^2\right)$$

$$E = q/\left(A\varepsilon_o\right)$$

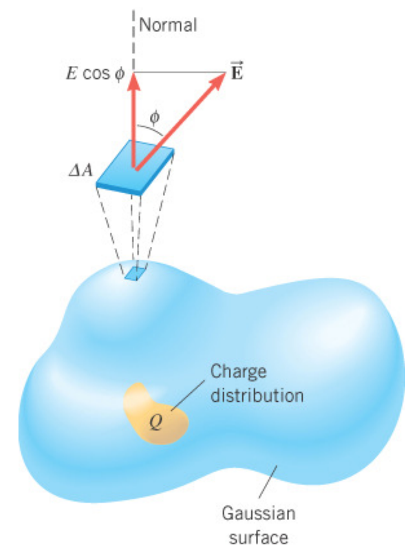
$$\underbrace{EA}_{} = \frac{q}{\varepsilon_o}$$

Electric flux, $\Phi_E = EA$



18.9 Gauss' Law

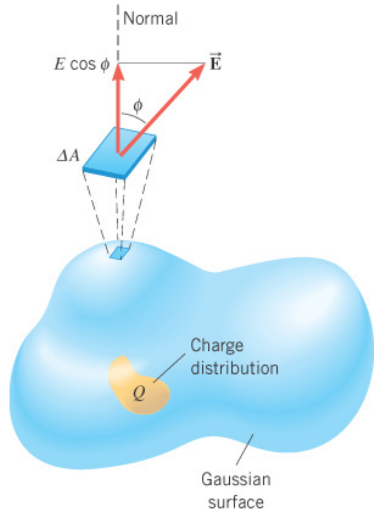
$$\Phi_E = \sum (E\cos\phi)\Delta A$$



GAUSS' LAW

The electric flux through a Gaussian surface is equal to the net charge enclosed in that surface divided by the permittivity of free space:

$$\sum (E\cos\phi)\Delta A = \frac{Q}{\varepsilon_o}$$

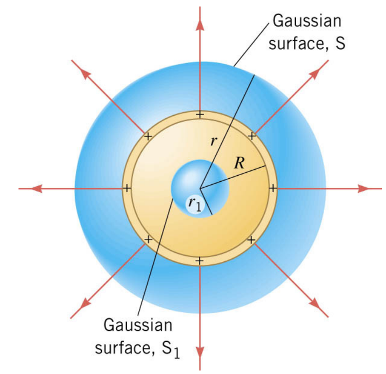


SI Units of Electric Flux: N·m²/C

Example 15 **The Electric Field of a Charged Thin Spherical Shell**

A positive charge is spread uniformly over the shell. Find the magnitude of the electric field at any point (a) outside the shell and (b) inside the shell.

$$\sum (E\cos\phi)\Delta A = \frac{Q}{\varepsilon_o}$$

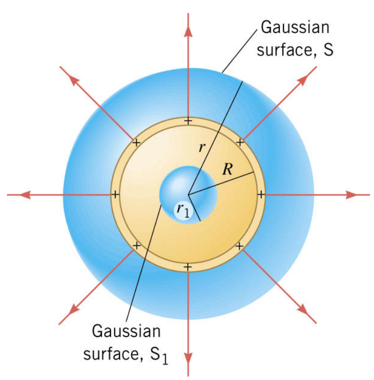


$$\Phi_E = \sum (E\cos\phi)\Delta A = \sum (E\cos 0)\Delta A$$

$$= E\sum \Delta A = E\left(4\pi r^2\right)$$

⇩

$$E\left(4\pi r^2\right) = \frac{Q}{\varepsilon_o}$$



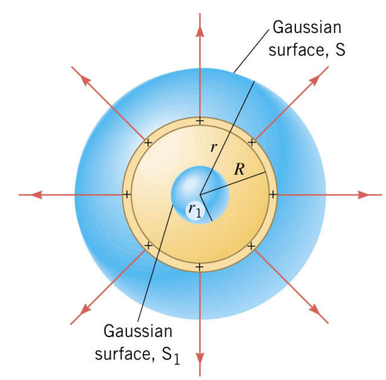
$$E\left(4\pi r^2\right) = \frac{Q}{\varepsilon_o}$$

(a) Outside the shell, the Gaussian surface encloses all of the charge.

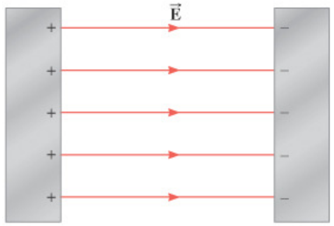
$$E = \frac{q}{4\pi r^2 \varepsilon_o}$$

(b) Inside the shell, the Gaussian surface encloses no charge.

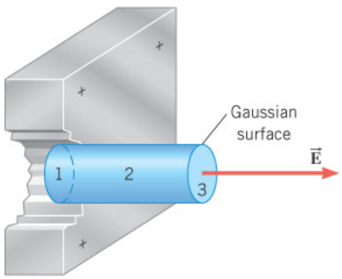
$$E = 0$$



18.9 Gauss' Law

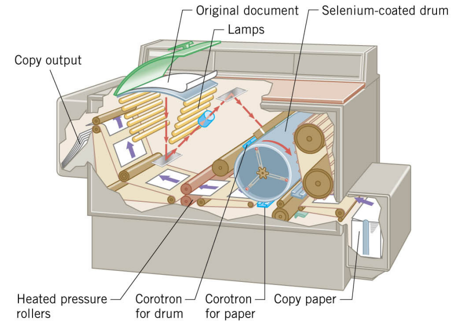


(a)

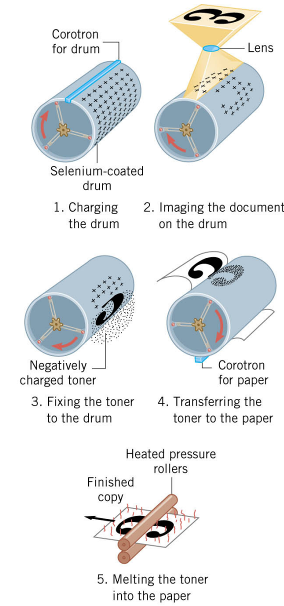


(b)

18.10 Copiers and Computer Printers

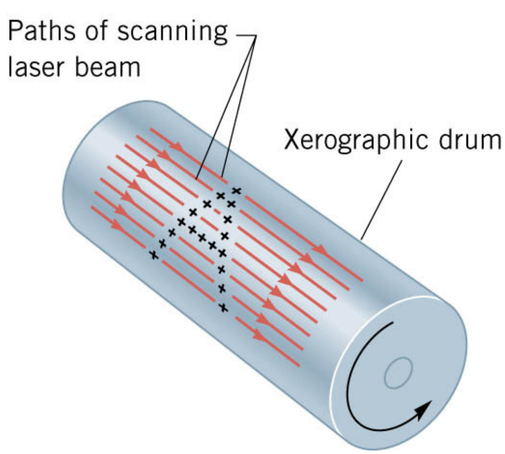


(a)



(b)

18.10 Copiers and Computer Printers



18.10 Copiers and Computer Printers