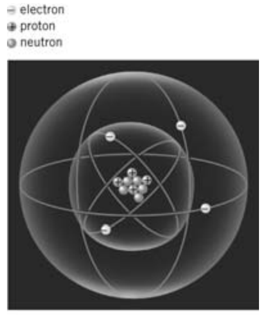
Chapter 18

Electric Fields and Electric Forces

18.1 The Origin of Electricity

The electrical nature of matter is inherent in atomic structure.



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

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

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

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

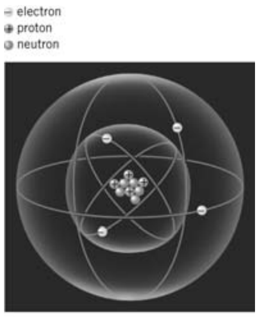
coulombs

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

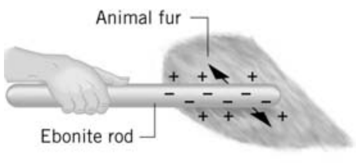
Example 1 **A Lot of Electrons**

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

$$q = Ne$$

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

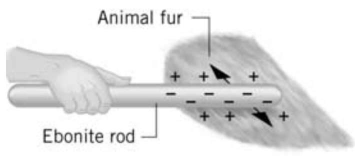
18.2 Charged Objects and the Electric Force



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.

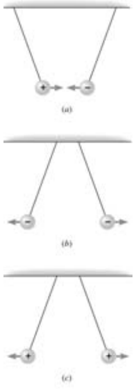
18.2 Charged Objects and the Electric Force



LAW OF CONSERVATION OF ELECTRIC CHARGE

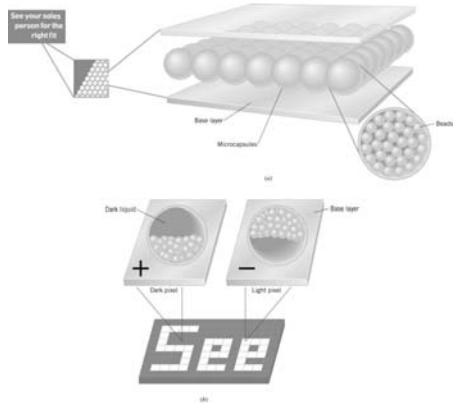
During any process, the net electric charge of an isolated system remains constant (is conserved).

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



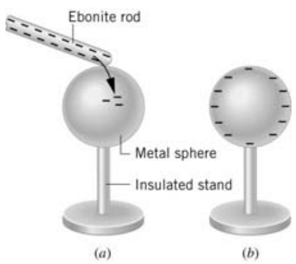
18.3 Conductors and Insulators

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***.

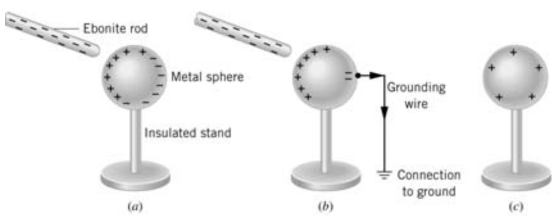
Materials that conduct electric charge poorly are called ***electrical insulators.***

18.4 Charging by Contact and by Induction



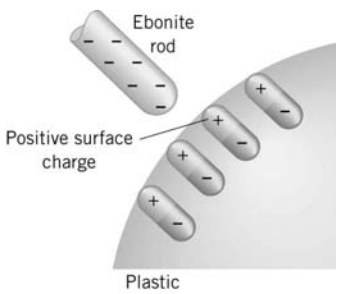
Charging by contact.

18.4 Charging by Contact and by Induction



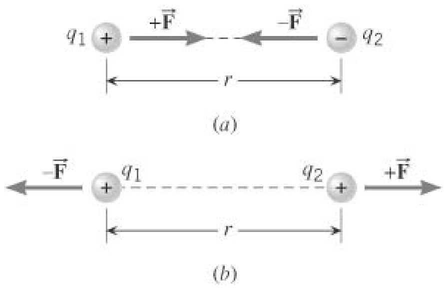
Charging by induction.

18.4 Charging by Contact and by Induction

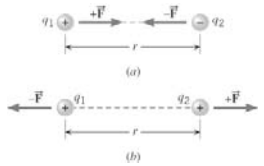


The negatively charged rod induces a slight positive surface charge on the plastic.

18.5 Coulomb's Law



18.5 Coulomb's Law



COULOMB'S LAW

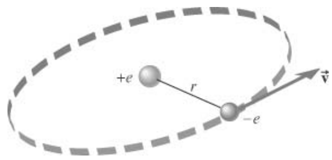
The magnitude of the electrostatic force exerted by one point charge on another point charge is directly proportional to the magnitude of the charges and inversely proportional to the square of the distance between them.

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

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

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

18.5 Coulomb's Law

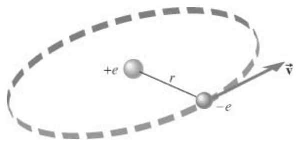


Example 3 **A Model of the Hydrogen Atom**

In the Bohr model of the hydrogen atom, the electron is in orbit about the nuclear proton at a radius of 5.29x10^{-11}m. Determine the speed of the electron, assuming the orbit to be circular.

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

18.5 Coulomb's Law



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

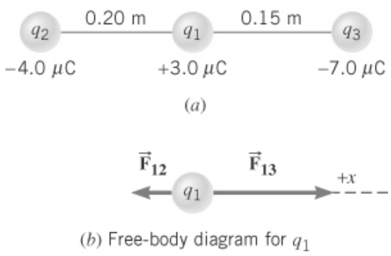
$$F = ma_c = mv^2/r$$

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

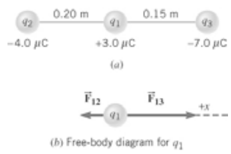
18.5 Coulomb's Law

Example 4 **Three Charges on a Line**

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



18.5 Coulomb's Law

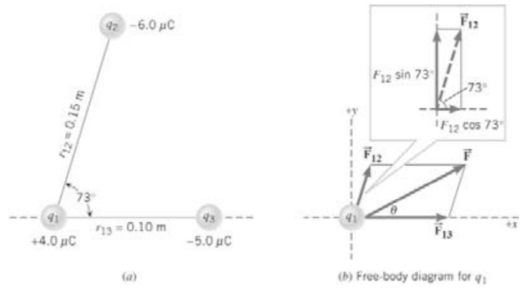


$$F_{12} = k\frac{|q_1||q_2|}{r^2} = \frac{(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2})(3.0\times10^{-6}\ \mathrm{C})(4.0\times10^{-6}\ \mathrm{C})}{(0.20\mathrm{m})^2} = 2.7\mathrm{N}$$

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

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

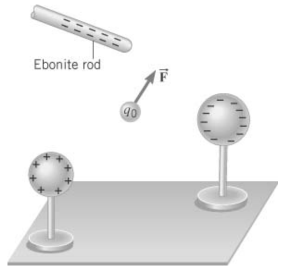
18.5 Coulomb's Law



18.6 The Electric Field

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.



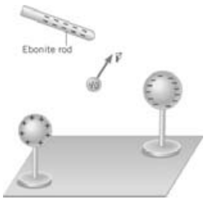
18.6 The Electric Field

Example 6 **A Test Charge**

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

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

(b) Predict the force that a charge of $+12\text{x}10^{-8}$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) $$F = (2.0\,\text{N/C})(12.0\times10^{-8}\,\text{C}) = 24\times10^{-8}\,\text{N}$$

18.6 The Electric Field

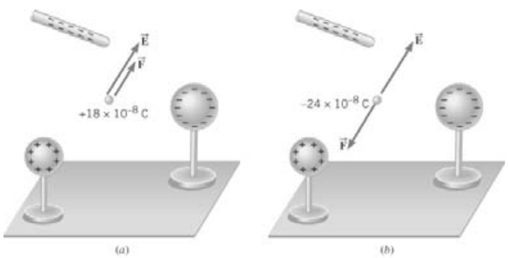
DEFINITION OF ELECRIC FIELD

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)

18.6 The Electric Field

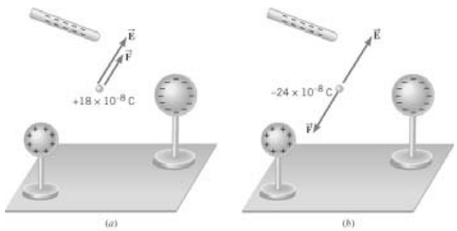


It is the surrounding charges that create the electric field at a given point.

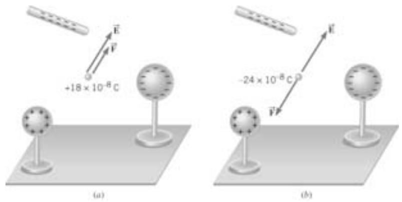
18.6 The Electric Field

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)



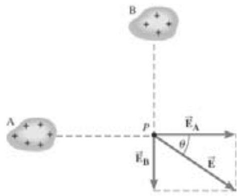
18.6 The Electric Field



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

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

18.6 The Electric Field



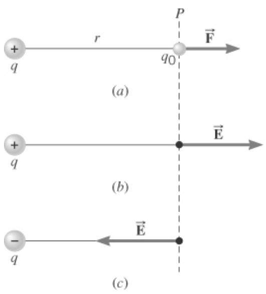
Electric fields from different sources add as vectors.

18.6 The Electric Field

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.



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

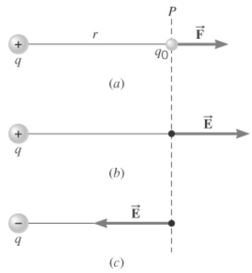
$$F = k\frac{|q_1||q_2|}{r^2}$$

18.6 The Electric Field

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

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

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



18.6 The Electric Field

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

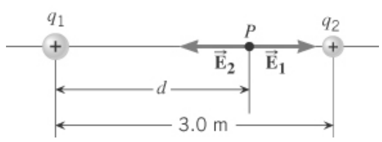
The electric field does not depend on the test charge.

Point charge q: $E = k\dfrac{|q|}{r^2}$

18.6 The Electric Field

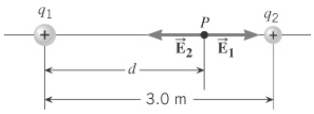
Example 11 **The Electric Fields from Separate Charges May Cancel**

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.



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

18.6 The Electric Field



$$E = k\frac{|q|}{r^2} \qquad E_1 = E_2$$

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

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

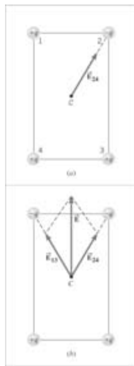
$$d = +2.0\,\mathrm{m}$$

18.6 The Electric Field

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

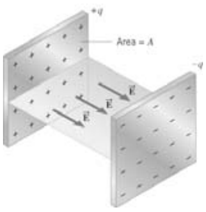
Point charges are fixes to the corners of a rectangle in two different ways. The charges have the same magnitudes but different signs.

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



charge density

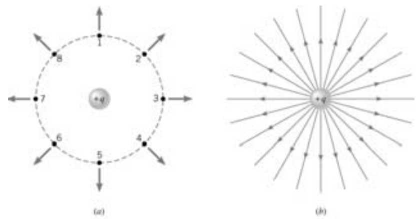
Parallel plate capacitor

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

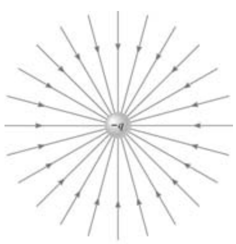
$$\varepsilon_o = 8.85\times10^{-12}\,\mathrm{C}^2/\left(\mathrm{N}\cdot\mathrm{m}^2\right)$$

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.



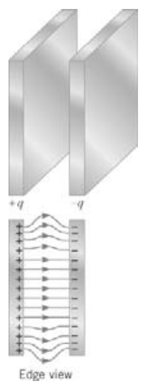
18.7 Electric Field Lines



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

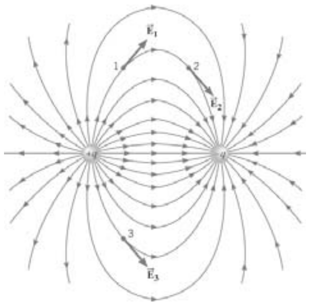
18.7 Electric Field Lines

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

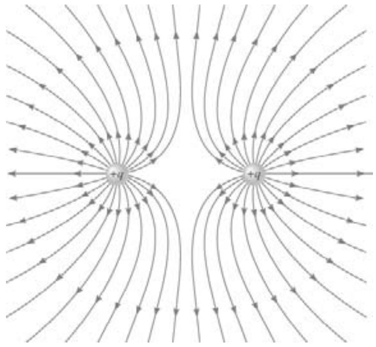


18.7 Electric Field Lines

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



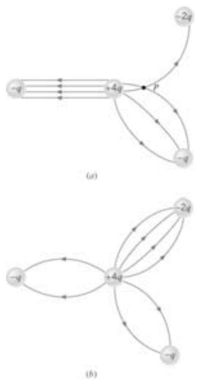
18.7 Electric Field Lines



18.7 Electric Field Lines

Conceptual Example 13 **Drawing Electric Field Lines**

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

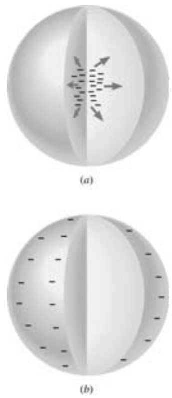


18.8 The Electric Field Inside a Conductor: Shielding

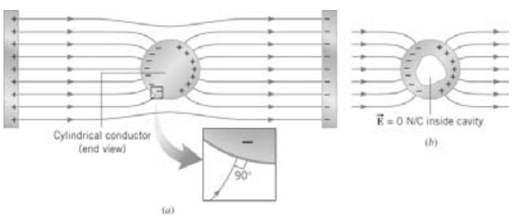
At equilibrium under electrostatic conditions, any excess charge resides on the surface of a conductor.

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.

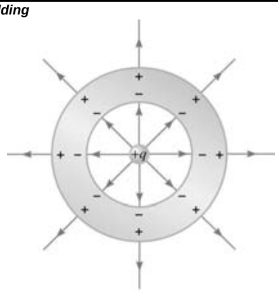
18.8 The Electric Field Inside a Conductor: Shielding

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.



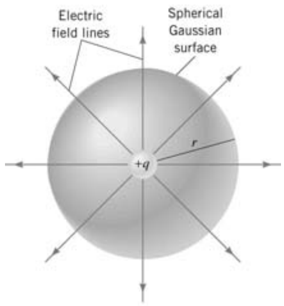
18.9 Gauss' Law

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

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

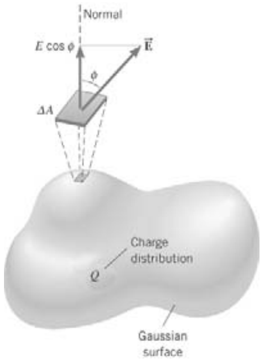
$$\underbrace{EA} = \frac{q}{\varepsilon_o}$$

Electric flux, $\Phi_E = EA$



18.9 Gauss' Law

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

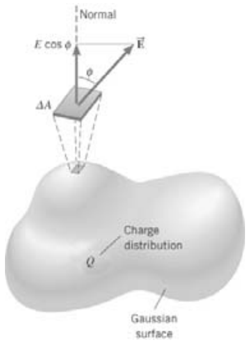


18.9 Gauss' Law

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:

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



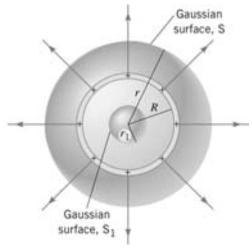
SI Units of Electric Flux: N·m^2/C

18.9 Gauss' Law

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.

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



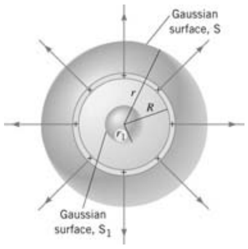
18.9 Gauss' Law

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

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

⇩

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



18.9 Gauss' Law

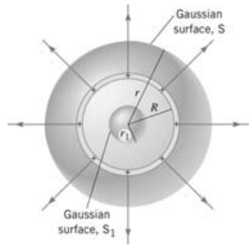
$$E\left(4\pi r^2\right) = \frac{Q}{\varepsilon_o}$$

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

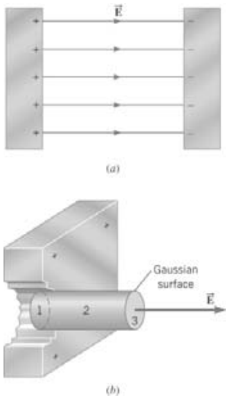
$$E = \frac{q}{4\pi r^2 \varepsilon_o}$$

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

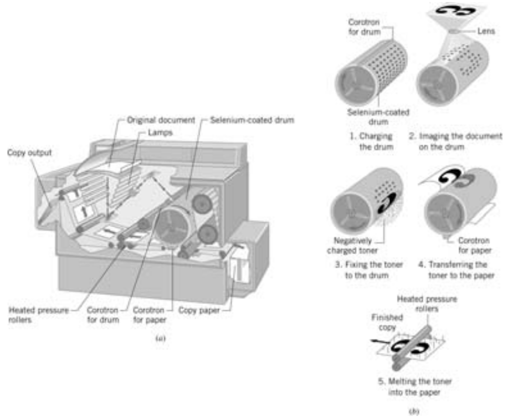
$$E = 0$$



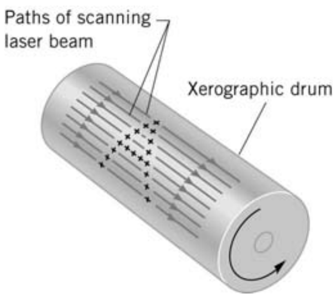
18.9 Gauss' Law



18.10 Copiers and Computer Printers



18.10 Copiers and Computer Printers



18.10 Copiers and Computer Printers