24.4 Conductors in electrostatic equilibrium:

- A good electrical conductor contains charges (electrons) that are not bound to any atom and therefore are free to move about within the material.

➢ **When there is no net motion of charge within a conductor, the conductor is in electrostatic equilibrium, which has the following properties:**

1. The electric field is zero everywhere inside the conductor (E=0).

2. If an isolated conductor carries a charge, the charge resides on its surface.

3. The electric field just outside a charged conductor is perpendicular to the surface of the conductor and has a magnitude σ/ε_0, where σ is the surface charge density at that point.

4. On an irregularly shaped conductor, the surface charge density is greatest at locations where the radius of curvature of the surface is smallest.

1. The electric field is zero everywhere inside the conductor.

A conducting slab in an external electric field E.

The charges induced on the two surfaces of the slab produce an electric field (E') that opposes the external field (E), giving a resultant field of zero inside the slab. The time it takes a good conductor to reach equilibrium is of the order of 10^{-16} s, which for most purposes can be considered instantaneous.

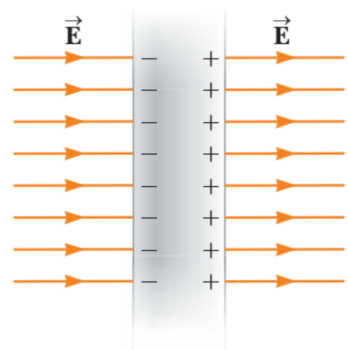


Figure 24.17 A conducting slab in an external electric field $\vec{E}$. The charges induced on the two surfaces of the slab produce an electric field that opposes the external field, giving a resultant field of zero inside the slab.

We can argue that the electric field inside the conductor must be zero under the assumption that we have electrostatic equilibrium. If the field were not zero, free charges in the conductor would accelerate under the action of the field. This motion of electrons, however, would mean that the conductor is not in electrostatic equilibrium. Thus, the existence of electrostatic equilibrium is consistent only with a zero field in the conductor.

2. If an isolated conductor carries a charge, the charge resides on its surface.

We can use Gauss's law to verify the second property of a conductor in electrostatic equilibrium.

The electric field everywhere inside the conductor is zero when it is in electrostatic equilibrium. Therefore, the electric field must be zero at every point on the Gaussian surface.

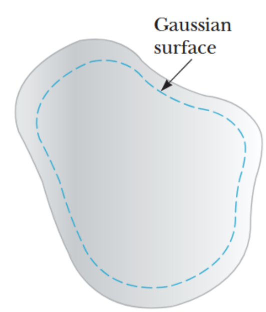


Figure 24.18 A conductor of arbitrary shape. The broken line represents a gaussian surface that can be just inside the conductor's surface.

Thus, the net flux through this Gaussian surface is zero. From this result and Gauss's law, we conclude that the net charge inside the Gaussian surface is zero.

Because there can be no net charge inside the Gaussian surface (which is arbitrarily close to the conductor's surface), any net charge on the conductor must reside on its surface.

3. The electric field just outside a charged conductor is perpendicular to the surface of the conductor and has a magnitude σ/ε_0, where is the surface charge density at that point.

$$\emptyset = \oint E_n dA = E_n A = \frac{q_{in}}{\varepsilon_0} = \frac{\sigma A}{\varepsilon_0}$$

$$E_n = \frac{\sigma}{\varepsilon_0}$$

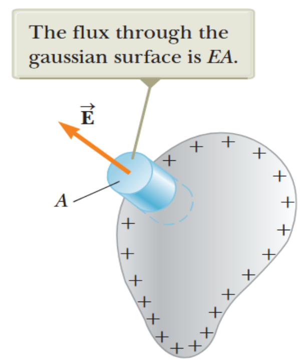
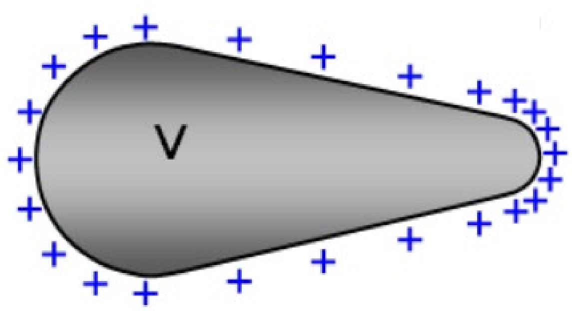


Figure 24.19 A gaussian surface in the shape of a small cylinder is used to calculate the electric field immediately outside a charged conductor.

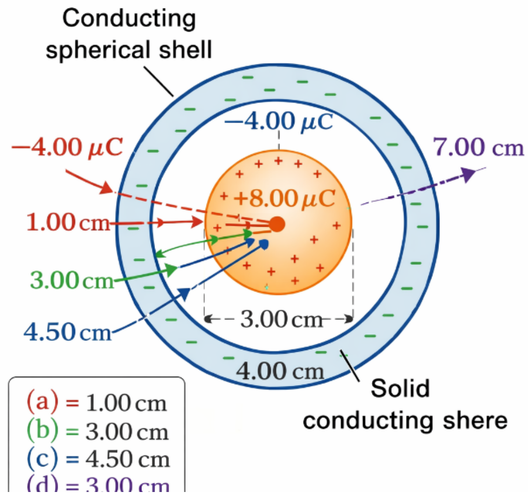
A Gaussian surface in the shape of a small cylinder is used to calculate the electric field just outside a charged conductor. The flux through the Gaussian surface is $E_n A$. Remember that E is zero inside the conductor.

4. On an irregularly shaped conductor, the surface charge density is greatest at locations where the radius of curvature of the surface is smallest.



Exercise: Electric Field of a Conducting Sphere and Spherical Shell

A solid conducting sphere of radius 2.00 cm has a charge of 8.00 μC. A conducting spherical shell of inner radius 4.00 cm and outer radius 5.00 cm is concentric with the solid sphere and has a total charge of −4.00 μC.



Find the electric field at:

(a) r = 1.00 cm,
(b) r = 3.00 cm,
(c) r = 4.50 cm, and
(d) r = 7.00 cm from the center of this charge configuration.

Solution

We apply Gauss's law and the properties of conductors in electrostatic equilibrium.

(a) r = 1.00 cm

This point lies inside the solid conducting sphere. The electric field inside a conductor in electrostatic equilibrium is zero.

$E = 0$

(b) r = 3.00 cm

This point lies in the empty region between the solid sphere and the conducting shell. A Gaussian surface of radius 3.00 cm encloses only the charge on the solid sphere.

$E = k_e Q / r^2 = (8.99 \times 10^9)(8.00 \times 10^{-6}) / (0.0300)^2$

$E = 7.99 \times 10^7$ N/C = 79.9 MN/C, radially outward

(c) r = 4.50 cm

This point lies within the conducting material of the spherical shell. Therefore, the electric field is zero.

$E = 0$

(d) r = 7.00 cm

This point lies outside the entire system. The net enclosed charge is:

$Q_{net} = 8.00\ \mu C - 4.00\ \mu C = 4.00\ \mu C$

$E = k_e Q\_net / r^2 = (8.99 \times 10^9)(4.00 \times 10^{-6}) / (0.0700)^2$

$E = 7.34 \times 10^6$ N/C = 7.34 MN/C, radially outward

Conclusion: The electric field is zero inside conducting regions and nonzero only in regions where the Gaussian surface encloses net charge.