Answer to Essential Question 16.6: We can find the other solution by using the – sign. This gives: $x' = \frac{3.0 \text{ m}}{-\sqrt{2.5}-1} = -1.16 \text{ m}$. This is a subtle point, but because x was defined as the distance of the point to the left of the origin, the negative answer gives us a point 1.16 m to the right of the origin, between the point charges. This is actually the other point on the line joining the charges where the fields from the two charges have the same magnitude. However, between the charges those two fields have the same direction (both pointing right), so they add rather than canceling.

16-7 Electric Field Near Conductors

At equilibrium, the conduction electrons in a conductor move about randomly, somewhat like atoms of ideal gas, but there is no net flow of charge in any direction. If there is a change in the external electric field the conductor is exposed to, however, the conduction electrons respond by redistributing themselves, very quickly coming to a new equilibrium distribution. At equilibrium a number of conditions apply:

1. There is no electric field inside the solid part of the conductor.
2. The electric field at the surface of the conductor is perpendicular to the surface.
3. If the conductor is charged, excess charge lies only at the surface of the conductor.
4. Charge density is highest, and electric field is strongest, on pointy parts of a conductor.

Let's investigate each of these conditions in more detail.

At equilibrium, *E* = 0 within solid parts of a conductor.

If electric field penetrates into a conductor, conduction electrons immediately respond to the field. Because $\vec{F} = q\vec{E}$, and electrons are negative, electrons feel a force that is opposite to the field. As shown in Figure 16.15, there is a net movement of electrons to the region where the field enters the conductor. The field lines end at the electrons at the surface, so *E* = 0 within the conductor. This redistribution of electrons leaves positive charge at the other side of the conductor, so field lines start up again there and go away from the conductor.

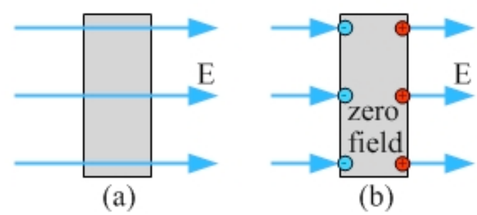

Figure 16.15: Conduction electrons in a conductor quickly redistribute themselves until the field is zero inside the conductor.

At equilibrium, electric field lines are perpendicular to the surface of a conductor.

If the electric field lines end at the surface of a conductor but are not perpendicular to the surface, as in Figure 16.16(a), the charges at the surface feel a force from the field. As Figure 16.16(b) shows, the component of the force parallel to the surface ($F_{\parallel}$) causes the charges to flow along the surface, carrying the field lines with them. The charges are in equilibrium when the electric field lines are perpendicular to the surface, as in Figure 16.16(c).

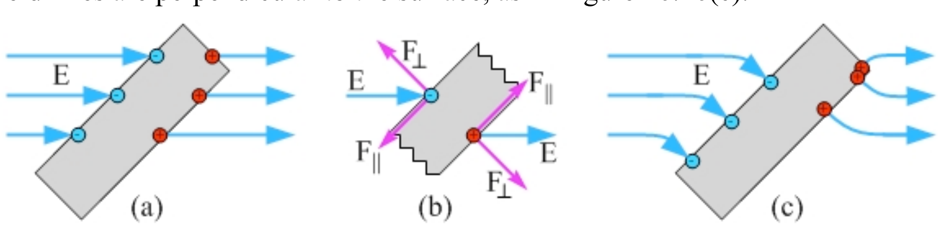

Figure 16.16: If electric field lines are not perpendicular to the surface of a conductor, the charges at the surface redistribute themselves until the field lines are perpendicular.

Electrons at the surface still feel a force component perpendicular to the surface that is trying to remove the electrons from the conductor. In most cases this will not happen because the conductor is surrounded by insulating material (such as air), but if the field is strong enough electrons will jump off the surface. When this happens there is a spark from the conductor.

At equilibrium, any excess charge lies only at the surface of a conductor.

This statement is a consequence of the fact that at equilibrium $E = 0$ within the conductor. If there was excess charge in the bulk of the conductor field lines would either start there, if it was positive, or end there, if it was negative. This non-zero field inside the conductor would cause the charge to move to the surface to bring the field to zero within the conductor.

Charge tends to accumulate on pointy parts of a conductor.

Figure 16.17 shows three different situations. In Figure 16.17(a) a metal sphere has a net positive charge. At equilibrium the excess charge is distributed uniformly over the surface of the sphere. Moving any of the charges around results in forces that act on these charges, driving them back to the equilibrium distribution. In contrast, Figure 16.17(b) shows excess charge (negative in this case, but our analysis is equally valid for positive charge) distributed evenly along a conducting rod. The charge at the center experiences no net force from the other charges, but the other charges experience net forces that push them toward the ends of the rod: each charge on the right experiences a net force pushing it further right, while each charge on the left experiences a net force pushing it further left. The equilibrium situation for the rod is more like that shown in Figure 16.17(c), where there is a much larger charge density at the ends than in the middle.

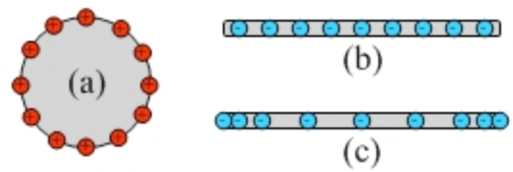

Figure 16.17: In (a), excess positive charge is uniformly distributed over the surface of a metal sphere. The charge is at equilibrium because there are no forces acting on the charges to move them around the sphere. In (b), however, uniformly distributing charge along the length of a conducting rod results in net forces on the charges that shift them toward the ends of the rod, as in (c).

This helps us to understand how a lightning rod works. Lightning occurs when charge builds up, increasing the local electric field to a large enough value that charge can travel between a cloud and, say, your house. Without a lightning rod this can take a long time, requiring a lot of charge, so that when the discharge finally happens it can involve a great deal of energy and cause significant damage. With a sharply-pointed lightning rod, attached to ground, on your house, however, charge and field builds up quickly at the tip of the lightning rod. This causes a slow and steady drain of charge from the cloud to the rod and then the ground, much safer than one sudden large discharge. The lightning rod was invented by Benjamin Franklin.

Related End-of-Chapter Exercises: 62 – 64.

Essential Question 16.7: A point charge with a charge of $+Q$ is placed at the center of a hollow thick-walled metal sphere. The sphere itself has no net charge on it. Which of the three pictures in Figure 16.18 correctly shows the equilibrium charge distribution on the metal sphere?

Figure 16.18: Three possible equilibrium situations for when a charge of $+Q$ is placed at the center of a hollow thick-walled metal sphere that has no net charge. In (a) the sphere has a total charge $+Q$ on its outer surface and $-Q$ on its inner surface; in (b) the sphere has a charge $-Q$ on both its inner and outer surfaces, and in (c) the sphere has a charge of $-Q$ on its inner surface.