Answer to Essential Question 16.7: Figure 16.18(a) shows the correct result. Enough conduction electrons in the sphere are attracted to the inner surface that the field lines from the center +*Q* charge do not penetrate into the sphere. This takes –*Q* worth of charge. That leaves a net positive charge +*Q* on the outer surface, as shown. In addition, (a) is the only picture that shows no net charge on the sphere itself.

Chapter Summary

Essential Idea: Electric Charge.
In many situations the interaction between objects that have a net electric charge, or the behavior of a charged object in a uniform electric field, is analogous to that of objects with mass that interact with each other via the force of gravity, or that are in a uniform gravitational field.

Key Facts about Charge
- The symbol for charge is *q* or *Q*. The MKS unit for electric charge is the Coulomb (C), although we will also use units of *e*, the magnitude of the charge on the electron.
- Unlike mass, which is always positive, charges can be either positive (+) or negative (–).
- Like charges (i.e, both + or both –) repel one another; unlike charges (a + and a –) attract.
- Charge is quantized – it can only be particular values. Since charging an object generally involves a transfer of electrons, the charge on an object is an integer multiple of *e*.
- Charge is conserved. This is another of the fundamental conservation laws of physics, that the net charge of a closed system remains constant.
- Most materials fall into one of two categories. Charge can flow easily through **conductors**, while it does not readily flow through **insulators**. Metals are good conductors, while plastic and rubber are examples of good insulators.
- When an insulating rod of one material is rubbed by another material, electrons can be transferred from one to the other. Which material ends up with a negative charge, and how much charge is transferred, depends on where the two materials lie in the **triboelectric series** (see Table 16.1).

Coulomb's Law for the Force Between Charged Objects
The force that an object with a charge *q* exerts on a second object with a charge *Q* that is a distance *r* away is given by Coulomb's Law:

$$\vec{F}_E = \frac{kqQ}{r^2}\hat{r} \qquad\qquad \text{(Equation 16.2)}$$

where $k = 8.99 \times 10^9 \text{ N m}^2 / \text{C}^2$ is a constant. The unit vector $\hat{r}$ indicates that the force is directed along the line joining the two charged objects. If the charges are of opposite signs then the product qQ is negative and the force is attractive, directed back toward the object applying the force. If the charges have the same sign then qQ is positive and the force is repulsive, directed away from the object applying the force.

The principle of superposition applies – the net force on a charged object is the vector sum of the individual forces acting on that object.

Electric Field

The electric field, $\vec{E}$, at a particular point can be defined in terms of the electric force, $\vec{F}_E$, that an object of charge q would experience if it were placed at that point:

$$\vec{E} = \frac{\vec{F}_E}{q}, \quad \text{or} \quad \vec{F}_E = q\vec{E} \qquad \text{(Eq. 16.3: \textbf{Connecting electric field and electric force})}$$

The units for electric field are N/C. An object with a positive charge experiences a force in the direction of the field, while an object with a negative charge experiences a force opposite in direction to the electric field.

Visualizing the Electric Field

We can visualize the electric field by drawing field lines or field vectors. Field lines are continuous lines that start on positive charges, or come from infinity, and that end on negative charges, or go off to infinity. The direction of the field at a point is tangent to the field line passing through that point. The magnitude of the field increases as the density of the field lines increases. In a field vector pattern equal-length arrows are drawn at equally spaced points. The direction of an arrow shows the direction of the field at that point, and the darkness of an arrow indicates the strength of the field at that point.

A Charged Object in a Uniform Electric Field

A uniform field has the same magnitude and direction at all points. A charged object in a uniform electric field experiences a constant acceleration that is given by $\vec{a} = \vec{F}/m = q\vec{E}/m$.

Because the acceleration is constant we can apply the constant-acceleration equations from Chapter 2 (for one-dimensional motion) or from Chapter 4 (for projectile motion in two dimensions) to determine equations of motion for the object.

Electric Field from a Point Charge

Electric fields are set up by charges. One special case is the electric field from a point charge, which is a charged object so small that it can be considered to be a point. If the point charge has a charge Q the magnitude of the electric field a distance r away from it is given by:

$$E = \frac{kQ}{r^2}. \qquad \text{(Equation 16.4: \textbf{Electric field from a point charge})}$$

Electric field is a vector. The electric field points away from a positive charge and toward a negative charge. The net electric field from multiple point charges can be found by superposition, adding the fields from each charge as vectors.

Electric Field near a Conductor, at Electrostatic Equilibrium

When a conducting object has a net charge, and/or when the conducting object is placed in a region in which there is an electric field, a number of conditions apply when electrostatic equilibrium is reached. Electrostatic equilibrium is defined as there being no net flow of charge within or on the conducting object.

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.