

Answer to Essential Question 16.1: Dividing the total charge by the charge on one electron gives the number of electrons involved:

$$n = \frac{q}{-e} = \frac{-1.0 \text{ C}}{-1.602 \times 10^{-19} \text{ C/electron}} = 6.2 \times 10^{18} \text{ electrons .}$$

Because electrons are transferred from the glass rod to the silk, the mass of the glass rod decreases while the mass of the silk increases. Multiplying the number of electrons transferred by the mass of each electron (see Table 16.1) gives the total mass involved, which is very small:

$$m = (6.242 \times 10^{18} \text{ electrons}) \times (9.11 \times 10^{-31} \text{ kg/electron}) = 5.7 \times 10^{-12} \text{ kg .}$$

16-2 Extending our Model of Charge

Key facts about charge: keep the following in mind when dealing with electric 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 (both + or both -) repel one another; unlike charges (a + and a -) attract.
- Charge is quantized – it can only be particular values. Charging an object generally involves a transfer of electrons, so 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. See Example 16.2 for an application.

Conductors and Insulators

When an electric appliance, such as a television or refrigerator, is on, electric charges flow through the wires connecting the appliance to a wall socket, and through the wires within the appliance itself. Even so, it is generally safe to touch the cable connecting the appliance to the wall socket as long as the metal wires inside that cable are completely covered by rubber. This exploits the different material properties of metal and rubber, specifically the differences in their conductivity. Metals (which we classify as conductors) generally have conductivities that are orders of magnitude larger than the conductivities of materials like rubber and plastic – those materials we call insulators. The major difference between these two classes of materials is that, in an insulator, each electron is closely tied to its molecule, while some fraction of the electrons in a conductor (these are known as the conduction electrons) are free to move around.

Charge is Quantized

When something is quantized it can not take on just any value – only particular values are possible. An example is money, which is quantized in units of pennies (in the USA and Canada, at least). It is possible to have \$1.27, the equivalent of 127 pennies, but it is not possible to have 2/7 of a dollar. For something to be quantized does not necessarily mean that its allowed values are integer multiples of its smallest unit, but that is how things work with money and charge.

For now, we can say that the smallest unit of charge is $e = 1.602 \times 10^{-19} \text{ C}$, the magnitude of the charge on the electron and the proton. Expressing charge quantization as an equation:

$$q = ne, \quad (\text{Eq. 16.1: Charge is quantized, and comes in integer multiples of } e)$$

where n is any positive or negative integer.

Charging by Induction

An uncharged conducting object like a metal sphere can be charged by rubbing it with a charged rod, acquiring charge of the same sign as that of the rod. However, it can also be charged without touching it with a charged rod, in the process known as charging by induction:

1. **Bring a charged insulating rod close to the conductor, without allowing the rod to touch the conductor.** Bringing the charged rod close causes conduction electrons in the conductor to move in response to the presence of the charge. The electrons move toward the rod, if the rod is positive, or (as shown in Figure 16.1), they move away from the rod if the rod is negative. The conductor is now polarized, but it still has no net charge.
2. **Ground the conductor.** A ground is a large object, like the Earth, that can accept or give up electrons without being affected. We can ground the conductor by connecting a wire from the conductor to a metal pipe. This allows electrons to be transferred from ground to the conductor, if the rod is positive, or from the conductor to ground if the rod is negative. The conductor now has an excess charge with a sign opposite to that of the charge on the rod.
3. **Remove the ground connection.** This strands the transferred charge.
4. **Remove the charged rod.** The charge on the conductor redistributes itself, but the conductor keeps the net charge it has by the end of step 2.

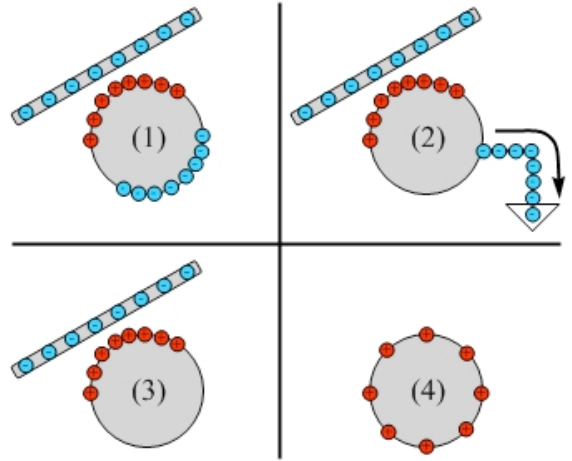


Figure 16.1: The process of charging by induction.

In the charging by induction process, the conducting object ends up with a net charge of the opposite sign as the charge on the rod. Note that steps 1 and 2 in the process can be reversed – the charge is only transferred after both these steps have been done. However, steps 3 and 4 must be done in the order above. Removing the charged rod before removing the ground connection allows charge transferred between the conductor and ground to return to where it started. The presence of the rod keeps the net charge on the conductor until the ground connection is removed.

EXAMPLE 16.2 – Two spheres touch

Two identical conducting spheres sit on separate insulating stands. Sphere A has a net positive charge of $+8Q$, while sphere B has a net negative charge of $-2Q$. The spheres are touched together briefly and then separated again. How much charge is on each sphere now?

SOLUTION

Each sphere has a charge of $+3Q$. The net charge in the system is $+6Q$, so, if each sphere ends up with half of this, we satisfy the law of Conservation of Charge and also get the symmetry we expect because the spheres are identical. Even though sphere B has a net charge of $-2Q$, it transfers $-5Q$ to sphere A. The extra $-3Q$ is made up of some of sphere B's conduction electrons.

Related End-of-Chapter Exercises for this section: 2 and 3.

Essential Question 16.2: In Example 16.2, the spheres are conducting. Would we get the same result if the spheres were both made of rubber, an insulating material? Explain.