16.1: Electric Charge

You have likely experienced or heard about electric charge in your life. For example, on a dry Winter day, you might find that after rubbing your bare feet on a polyester carpet you feel a small electric shock upon touching a metallic surface such as a doorknob. This is a manifestation of the electric charge that has built up on you being released onto the doorknob. You probably also have a notion of the existence of positive and negative charges, and that equal charges repel each other whereas opposite charges attract. In this chapter, we develop the description of how these charges can accumulate and how they exert attractive or repulsive forces on each other.

Ordinary matter is made of atoms, which are themselves made of a small positive nucleus (containing positive protons and neutral neutrons) surrounded by a “cloud” of negatively charged electrons. Within a solid object, the atoms in the object can be modeled as being effectively stationary due to inter-atomic forces that hold the atoms together. As a result, the nuclei (the positively charged part of atoms) can be considered to be fixed in space. The negative electrons, depending on the material, can often move from one atom to another. If an atom looses an electron to another atom, it becomes positive, whereas the atom that acquired the extra electron becomes negative.

We define the net charge on an atom (or an object) based on whether there are more protons (positive), more electrons (negative) or an equal amount (neutral). By default, atoms are neutral and have an equal number of protons and electrons. The reason that anything acquires a net electric charge is because it acquired an excess (or deficit) of electrons from another object. We say that “charge is conserved”, since the number of electrons does not change and if one object became positively charged, a different object must have become negatively charged by the same amount, so that the total net charge (in the Universe) is zero.

When you rub your feet on the carpet, electrons are being removed from one surface (your feet) and deposited on the other (the carpet). Your feet thus acquire a net positive charge (having lost electrons). When you touch a doorknob, the little spark comes from electrons jumping from the doorknob and onto your body. The reason that the electrons leave your feet in the first place is that different materials have different “affinities” for electrons. When you rub two materials together (placing their atoms in close proximity), electrons will transfer to the material with the highest affinity for electrons. This way of creating a net charge on an object is called “charging by friction”.

The “triboelectic series” is a list of materials that tend to give up or acquire electrons when they are placed in close contact with each other; some common materials from the series are shown in Figure 16.1.1. The greatest charge is generated by rubbing together materials that are the furthest apart from each other in the diagram. Rubbing silk on a piece of glass results in more charge than rubbing wool on the same piece of glass.

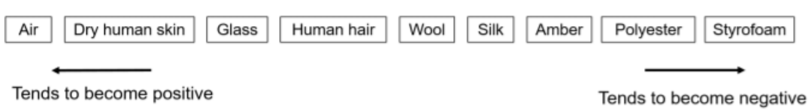

Figure 16.1.1: A sample of a triboelectric series of materials.The materials on the right-hand side have the greatest affinity to acquire electrons.

? Exercise 16.1.1

If you rub a glass rod with silk, which object ends up with an excess of electrons?

A. glass rod.
B. silk.
C. neither, they remain neutral.
D. both will acquire an excess of electrons.

Answer

B.

16.1.1: Conductors and Insulators

We can broadly classify materials into **conductors** (such as metals), and **insulators** (such as wood), depending on how easily the electrons can move around in the material. In a conductor, electrons (rather, the outer electron(s) of an atom) are only loosely bound to their nuclei, and they can thus move around the material freely. In an insulator, the electrons are tightly bound to the nuclei of their atoms and cannot easily move around. There is a third class of materials, semi-conductors, that falls somewhere between a conductor and an insulator. In a semi-conductor, electrons are typically bound to their atoms, but any additional electrons present in the material can move around as if they are in a conductor.

Within a conductor, such as a solid metallic sphere, charges can move around freely. If that sphere has a net charge, for example an excess of electrons, those excess electrons will migrate to the outer surface of the sphere. Electrons in the sphere repel each other and will quickly settle into a position where they are, on average, the furthest from all of the other electrons, which occurs if all of the electrons migrate to the surface. This is illustrated by showing the charges on the surface of the charged sphere in the left panel of Figure 16.1.2. If an initially neutral conducting sphere is connected to the charged sphere by a conducting wire (right panel of Figure 16.1.2), some of the electrons will "conduct" (transfer) onto the surface of the neutral sphere, so that, on average, they are further from all other electrons. This way of adding charge to the neutral sphere is called "charging by conduction", and the second sphere will remain charged if the connection between spheres is broken.

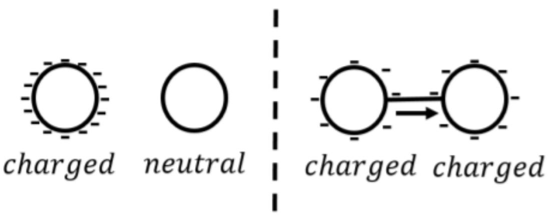

Figure 16.1.2: Charging by conduction: a neutral conducting sphere is connected to a negatively charged conducting sphere. The charges can "spread out more" if some of the charges move ("conduct") from the charge sphere onto the neutral sphere.

16.1.2: Electrostatic induction

Electrostatic induction allows one to "induce" a charge by using the fact that charges can move freely in a conductor. The left panel of Figure 16.1.3 shows a (neutral) rod made of a conducting material, with electrons distributed uniformly throughout its volume. In the right panel, a negatively charged sphere is brought next to the rod. Since the rod is conducting, electrons in the rod can easily move and they will thus accumulate on the end of the rod that is furthest from the negative sphere (which repels the electrons). Those electrons will leave positive charges (corresponding to the atoms that have lost their electrons) on the side closest to the sphere. The electrons in the rod will only accumulate for as long as the force from the negative sphere is less than the repulsive force from the electrons that have already accumulated. In practice, such an equilibrium is reached almost instantly. In equilibrium, we say that the rod is "polarized", or that the "charges in the rod have separated", although the rod is overall still neutral.

Note that we can model this as if it where positive charges that move inside of the rod instead of negative charges. The positive charges are attracted to the negative sphere, and thus accumulate on the end of the rod closest to the sphere, leaving a negative charge on the other end. The choice to call electrons "negative" is completely arbitrary. For convenience, we usually build models assuming that positive charges can easily move around, even if, in reality, it is almost always actually (negative) electrons that move.

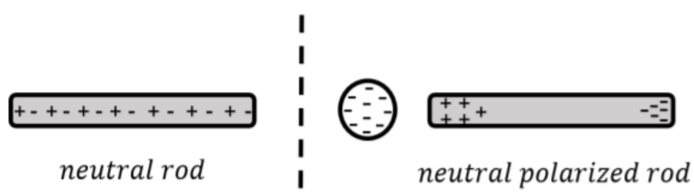

Figure 16.1.3: Electrostatic induction: when a negatively charged sphere is brought close to a neutral conducting rod, the electrons in the rod, which can move freely, accumulate on the side of the rod furthest from the sphere, leaving an excess of positive charge near the sphere.

We can create a net charge on the polarized rod if we provide a conducting path for charges to leave (or enter) the rod. The Earth can be modeled as a very large reservoir of both positive and negative charges. By connecting the rod to the Earth (we say that we connect the rod to "ground"), we provide a path for the electrons in the rod to be even further from the negatively charged sphere, and they can thus leave the rod entirely in order to go into the ground. This is illustrated in the right-hand panel of Figure 16.1.4.

If we then disconnect the rod from the ground, it has now acquired an overall positive charge, as in the right hand panel. We call this "charging by induction". We can also think of this in terms of positive charges moving into the rod from the Earth; when we connect the rod to the ground, the positive charges in the Earth can move into the rod and get closer to the negatively charged sphere. If we disconnect the rod from the ground, the rod stays positive, just as we conclude when using a model where it is the negative charges that move[1].

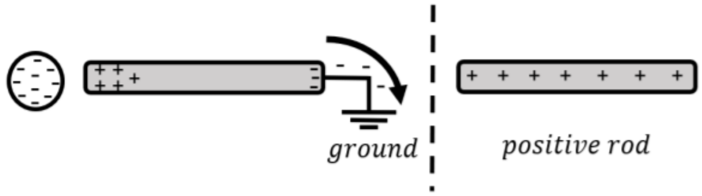

Figure 16.1.4: Charging by induction: when we connect the polarized rod to the ground, electrons can leave the rod. If we now disconnect the rod from ground, the rod is left with an overall positive charge.

16.1.3: Footnotes

1. Unless magnetism is involved, it is not possible to distinguish between a flow of positive charges moving in one direction or negative charges moving in the opposite direction.
