Electricity and Magnetism

First lecture

Electric Charge and the Structure of Matter

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first stage

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1.1 Introduction

You are surrounded by devices that depend on the physics of electromagnetism, which is the combination of electric and magnetic phenomena. This physics is at the root of **computers, television, radio, telecommunications**.

The physics of electromagnetism was first studied by the early **Greek philosophers**, who discovered that if a piece of amber is rubbed and then brought near bits of straw, the straw will jump to the amber. We now know that the attraction between amber and straw is due to an **electric force**. The Greek philosophers also discovered that if a certain type of stone is brought near bits of iron, the iron will jump to the stone. We now know that the attraction between magnet and iron is due to a **magnetic force**.

From these modest origins with the Greek philosophers, the sciences of electricity and magnetism developed separately for centuries—until 1820, in fact, when **Hans Christian Oersted** found a connection between them: an **electric current in a wire can deflect a magnetic compass needle**.

In the mid-nineteenth century, **James Clerk Maxwell** put **Faraday's** ideas into **mathematical form**, introduced many new ideas of his own, and put electromagnetism on a sound theoretical basis.

Our discussion of electromagnetism is spread through the next 10 lectures. We begin with electrical phenomena, and our first step is to discuss the nature of electric charge and electric force.

1.2 Electric Charge

Electric Charge is the intrinsic property (that comes automatically with those particles) of subatomic particles that causes it to experience a force when placed in an electric and magnetic field. Electric charge is a scalar quantity.

After rubbing a glass rod with a silk cloth, we hang the rod by means of a thread tied around its center (Fig. 1- a). Then we rub a second glass rod with the silk cloth and bring it near the hanging rod. The hanging rod magically moves away. We can see that a force repels it from the second rod, but how?

In the second demonstration we replace the second rod with a plastic rod that has been rubbed with fur. This time, the hanging rod moves toward the nearby rod (Fig. 1- b). Like the repulsion, this attraction occurs without any contact or obvious communication between the rods.

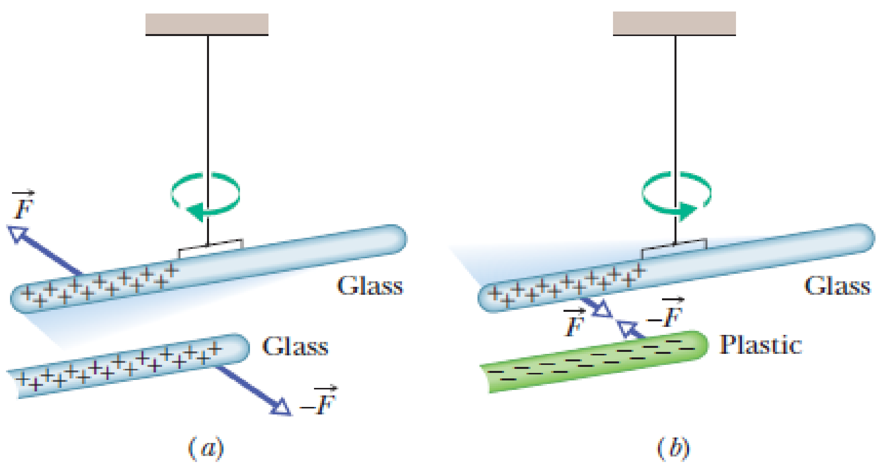

Figure. 1: (*a*) The two glass rods were each rubbed with a silk cloth and one was suspended by thread. (*b*) The plastic rod was rubbed with fur.

In the first demonstration, the force on the hanging rod was ***repulsive***, and in the second, ***attractive***. After a great many investigations, scientists figured out that the forces in these types of demonstrations are due to the **electric charge** that we set up on the rods when they are in contact with silk or fur.

Particles with the same sign of electrical charge repel each other, and particles with opposite signs attract each other.

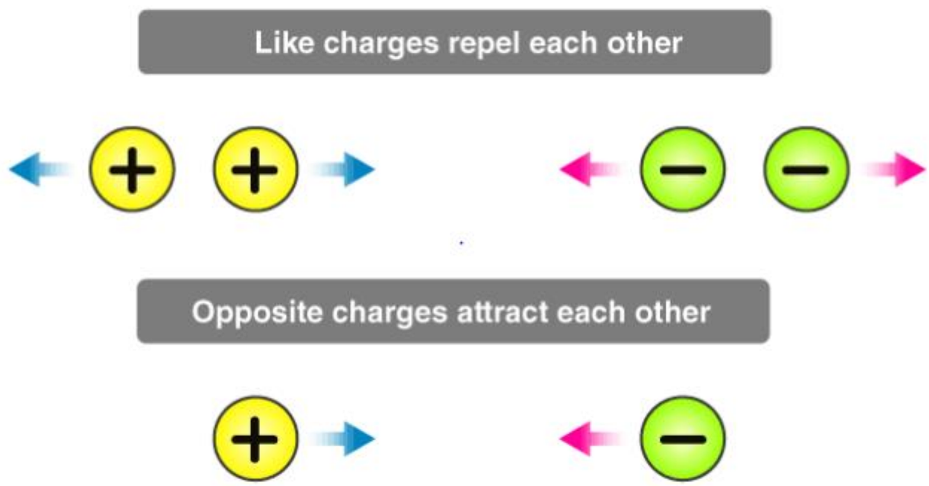

Figure. 2: Forces between charges.

When we rub the glass rod with a silk cloth, a small amount of negative charge moves from the rod to the silk, leaving the rod with a small amount of excess positive charge. When we rub the second rod with the silk cloth, it too becomes positively charged. So when we bring it near the first rod, the two rods repel each other (Fig. 1-a).

Next, when we rub the plastic rod with fur, it gains excess negative charge from the fur. When we bring the plastic rod (with negative charge) near the hanging glass rod (with positive charge), the rods are attracted to each other (Fig. 1-b).

***1.2.1 Two Types of* charges:** There are two types of electric charge, named by the American scientist and statesman **Benjamin Franklin** as **positive charge** and **negative charge**.

Positive and Negative, commonly carried by charge carriers (subatomic particles) (Fig. 2): Protons are positively charged, electrons are negatively charged. And neutrons have zero charge.

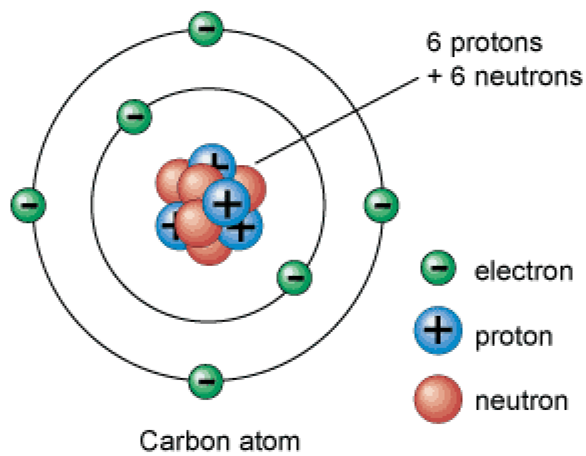

Figure. 3: charge carriers (subatomic particles).

In most everyday objects, such as a **mug**, there are about equal numbers of negatively charged particles and positively charged particles, and so the net charge is zero, the charge is said to be *balanced*, and the object is said to be *electrically neutral*.

1.2.2 Excess Charge: Either you gain negative charge from the carpet and become negatively charged, or you lose negative charge and become positively charged. Either way, the extra charge is said to be an *excess charge*. Such *charging and discharging* does not happen in humid conditions because the water in the air *neutralizes* your excess charge about as fast as you acquire it.

1.2 Charge is Conserved

Conservation of charge is the property that the total electric charge in an isolated system never changes. The net quantity of electric charge, the amount of positive charge minus the amount of negative charge in the universe, is always conserved.

If you rub a glass rod with silk, a positive charge appears on the rod. Measurement shows that a negative charge of equal magnitude appears on the silk. This suggests that rubbing does not create charge but only transfers it from one body to another, upsetting the electrical neutrality of each body during the process. This hypothesis of **conservation of charge,** first put forward by **Benjamin Franklin**, has stood up under close examination, both for large-scale charged bodies and for atoms, nuclei, and elementary particles.

1.3 Charge is Quantized

Quantization of charge meaning that the charge can only take certain discrete values.

In Benjamin Franklin's day, electric charge was thought to be a continuous fluid—an idea that was useful for many purposes. However, we now know that fluids themselves, such as air and water, are not continuous but are made up of atoms and molecules; matter is discrete. Experiment shows that "electrical fluid" is also not continuous but is made up of multiples of a certain elementary charge. Any positive or negative charge q that can be detected can be written as:

$$q = ne, \qquad n = \pm 1, \pm 2, \pm 3, \ldots,$$

in which e, the **elementary charge,** has the approximate value:

$$e = 1.602 \times 10^{-19}\ \text{C}.$$

The elementary charge *e* is one of the important constants of nature. The electron and proton both have a charge of magnitude *e*.

Quarks, the constituent particles of protons and neutrons, have charges of $\pm e/3$ or $\pm 2e/3$, but they apparently cannot be detected individually. For this and for historical reasons, we do not take their charges to be the elementary charge.

1.5 Electric Charge and the Structure of Matter

The matter is made up of atoms that combine into molecules and crystals.

- Atoms are made up of electrons and nuclei.
- The sizes of atoms are determined by the distribution of the atom's electrons.
- The nuclei are small but contain almost all of the mass of the atom.
- The bonding between atoms that builds molecules and crystals arises from the electrical forces between the electrons and nuclei and the sharing of electrons between different atoms.

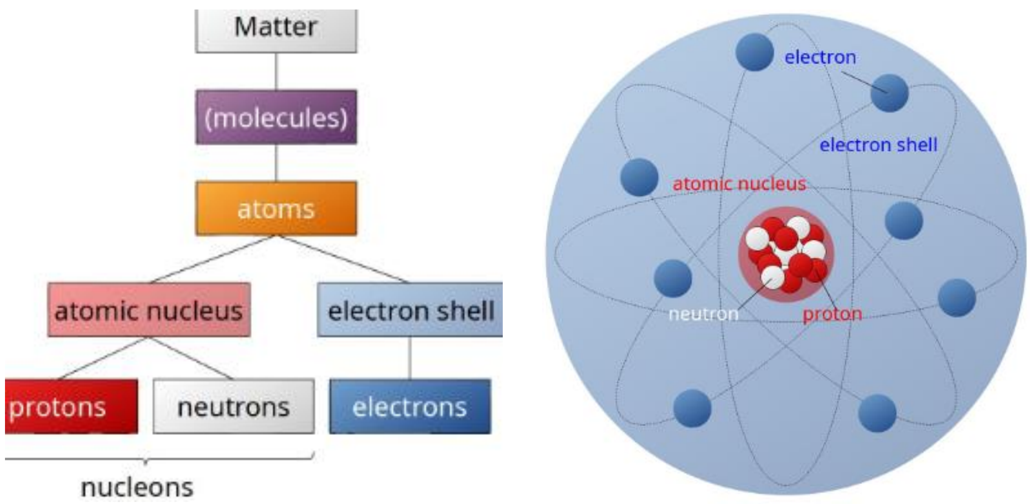

Figure. 4: Structure of matter, structure of an atom.

Our model of matter has all matter made up of electrons and nuclei, and the nuclei made up of protons and neutrons. The charge on the electron is in some sense opposite to the charge on a proton, in that an electron and proton at the same place will produce forces on a third charge that cancel. This maps nicely onto positive and negative numbers which cancel when we add them. We call the charge on a proton positive and the charge on the electron negative.

Since most matter is made up of equal numbers of positive and negative charges, mostly all electric forces cancel and we don't usually see their effects.

An atom or molecule that has more or fewer electrons than it has protons has a net charge and is called an ion. Electrons and ions are the primary sources of electrical effects in matter.

1.6 References

Walker, Jearl, Robert Resnick, and David Halliday. Halliday and resnick fundamentals of physics. Wiley, 2014.