Electricity and Magnetism

First lecture

Electric Charge and the Structure of Matter

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Outline

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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 13 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

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.

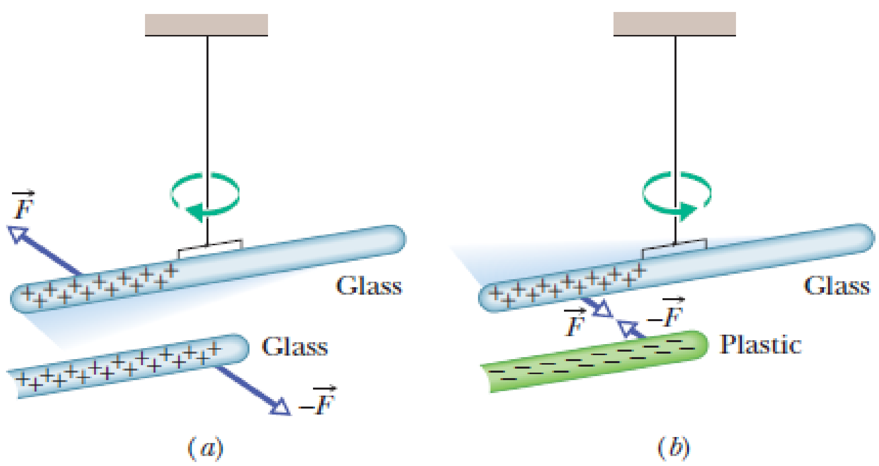

Figure. 1: (*a*) The two glass rods were each rubbed with a silk cloth and one was suspended by thread. When they are close to each other, they repel each other. (*b*) The plastic rod was rubbed with fur. When brought close to the glass rod, the rods attract each other.

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. Electric charge is an intrinsic property of the fundamental particles that make up objects such as the rods, silk, and fur. That is, charge is a property that comes automatically with those particles wherever they exist.

***1.2.1 Two Types of* charge:** There are two types of electric charge, named by the American scientist and statesman **Benjamin Franklin** as **positive charge** and **negative charge**. 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 (at the points of contact between your shoes with 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.

Why does the universe have particles with electric charge? and *why* does electric charge come in two types? Nevertheless, with lots of experiments similar to our two demonstrations scientists discovered that:

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

In a moment we shall put this rule into quantitative form as Coulomb's law of *electric force.*

1.2.3 demonstration: Now let's get back to the demonstrations to understand the motions of the rod as being something other than just magic. When we rub the glass rod with a silk cloth, a small amount of negative charge moves from the rod to the silk (a transfer like that between you and a carpet) , leaving the rod with a small amount of excess positive charge. We rub the silk over the rod to increase the number of contact points and thus the amount, still tiny, of transferred charge. We hang the rod from the thread so as to electrically isolate it from its surroundings. 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. 21-2*b*).

1.3 Charge is 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.

Important examples of the conservation of charge occur in the *radioactive decay* of nuclei, in which a nucleus transforms into (becomes) a different type of nucleus. For example, a uranium-238 nucleus (^{238}U) transforms into a thorium- 234 nucleus (^{234}Th) by emitting an *alpha particle.* Because that particle has the same makeup as a helium-4 nucleus, it has the symbol ^{4}He.

The number used in the name of a nucleus and as a superscript in the symbol for the nucleus is called the *mass number* and is the total number of the protons and neutrons in the nucleus. For example, the total number in ^{238}U is 238. The number of protons in a nucleus is the *atomic number Z*, which is listed for all the elements in Appendix F.

$$^{238}\mathrm{U} \rightarrow {}^{234}\mathrm{Th} + {}^{4}\mathrm{He},$$

From that list we find that in the decay the *parent* nucleus ^{238}U contains 92 protons (a charge of $+92e$), the *daughter* nucleus ^{234}Th contains 90 protons (a charge of $+90e$), and the emitted alpha particle ^{4}He contains 2 protons (a charge of $+2e$). We see that the total charge is $+92e$ before and after the decay; thus, charge is conserved. (The total number of protons and neutrons is also conserved: 238 before the decay and 234 + 4 = 238 after the decay.)

1.4 Charge is Quantized

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:

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

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 5. Electric Charge and the Structure of Matter

All matter is composed of **atoms**, each of which has a central **nucleus** and one or more electrons that travel in orbits around the nucleus, like satellites around the earth. The nucleus contains one or more **positively** charged particles called **protons**. The positive charge of a proton is 'opposite' to the negative charge of an electron, in the sense that the total, or net, charge of the combination is zero. Thus, an atom that has the same number of electrons in orbit as it has protons in its nucleus is **electrically neutral**. The nucleus of every atom except that of hydrogen also contains one or more neutrons, which carry no electrical charge. The number of protons and neutrons in the nucleus of an atom uniquely determines the element it represents - iron, copper, oxygen, and so on - and all the atoms of a given element have identical nuclei.

Summary of Subatomic Particles		
Proton	**Neutron**	**Electron**
In nucleus	In nucleus	Outside nucleus
Tightly Bound	Tightly Bound	Weakly Bound
Positive Charge	No Charge	Negative Charge
Massive	Massive	Not very massive

1.6 References

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