Electricity and Magnetism

Lecture Seven

Current and current density, Electromotive force

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2022- 2023

Outline

1. **Current and current density**
2. **Ohm's law-A microscopic view**
3. **Multi loop circuits**
4. **RC-circuits**
5. **References**

1. Current and current density

Electric current is a net flow of charge through that surface. Figure 1 shows a section of a conductor, part of a conducting loop in which current has been established. If charge dq passes through a hypothetical plane (such as aa-) in time dt, then the current i through that plane is defined as:

$$i = \frac{dq}{dt} \quad \text{(definition of current).}$$

We can find the charge that passes through the plane in a time interval extending from 0 to t by integration:

$$q = \int dq = \int_0^t i\,dt,$$

in which the current i may vary with time.

The SI unit for current is the coulomb per second, or the ampere (A), which is an SI base unit:

$$1 \text{ ampere} = 1\text{ A} = 1 \text{ coulomb per second} = 1\text{ C/s.}$$

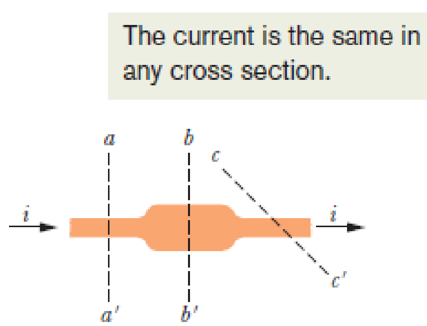

Figure 1: The current i through the conductor has the same value at planes aa-,bb-, and cc-.

2. The Directions of Currents

In Fig. 2 we drew the current arrows in the direction in which positively charged particles would be forced to move through the loop by the electric field. Such positive charge carriers, as they are often called, would move away from the positive battery terminal and toward the negative terminal. Actually, the charge carriers in the copper loop of Fig. 2 are electrons and thus are negatively charged. The electric field forces them to move in the direction opposite the current arrows, from the negative terminal to the positive terminal. For historical reasons, however, we use the following convention:

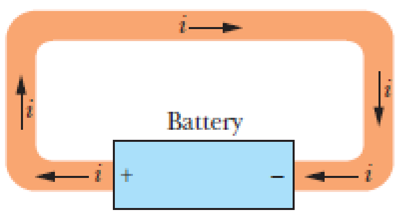

Figure 2: Adding a battery imposes an electric potential difference between the ends of the loop that are connected to the terminals of the battery.

A current arrow is drawn in the direction in which positive charge carriers would move, even if the actual charge carriers are negative and move in the opposite direction.

3. Current Density

Sometimes we are interested in the current i in a particular conductor. At other

times we take a localized view and study the flow of charge through a cross section of the conductor at a particular point. To describe this flow, we can use the **current density** $\vec{J}$ which has the same direction as the velocity of the moving charges if they are positive and the opposite direction if they are negative. For each element of the cross section, the magnitude J is equal to the current per unit area through that element. We can write the amount of current through the element as $\vec{J}.d\vec{A}$ where $d\vec{A}$ is the area vector of the element, perpendicular to the element. The total current through the surface is then:

$$i = \int \vec{J} \cdot d\vec{A}.$$

If the current is uniform across the surface and parallel to $d\vec{A}$ then $\vec{J}$ is also uniform and parallel to $d\vec{A}$ Then Equation above becomes:

$$i = \int J\,dA = J \int dA = JA,$$

$$J = \frac{i}{A},$$

where A is the total area of the surface. From Equation above we see that the SI unit for current density is the ampere per square meter (A/m2).

4. Ohm's Law

As we just discussed, a resistor is a conductor with a specified resistance. It has that same resistance no matter what the magnitude and direction (polarity) of the applied potential difference are. Other conducting devices, however, might have resistances that change with the applied potential difference.

We distinguish between the two types of device by saying that one obeys Ohm's law and the other does not.

Ohm's law *is an assertion that the current through a device is always directly proportional to the potential difference applied to the device.*

A conducting device obeys Ohm's law when the resistance of the device is independent of the magnitude and polarity of the applied potential difference.

A conducting material obeys Ohm's law when the resistivity of the material isindependent of the magnitude and direction of the applied electric field.

5. A Microscopic View of Ohm's Law

To find out why particular materials obey Ohm's law, we must look into the details of the conduction process at the atomic level. Here we consider only conduction in metals, such as copper. We base our analysis on the free-electron model, in which we assume that the conduction electrons in the metal are free to move throughout the volume of a sample, like the molecules of a gas in a closed container. We also assume that the electrons collide not with one another but only with atoms of the metal.

According to classical physics, the electrons should have a Maxwellian speed distribution somewhat like that of the molecules in a gas (Module 19-6), and thus the average electron speed should depend on the temperature. The motions of electrons are, however, governed not by the laws of classical physics but by those of quantum physics. As it turns out, an assumption that is much closer to the quantum reality is that conduction electrons in a metal move with a single effective speed v_{eff}, and this speed is essentially independent of the temperature. For copper, $v_{eff} = 1.6 * 10^6$ m/s.

6. Multiloop Circuits

Figure 3 shows a circuit containing more than one loop. For simplicity, we assume the batteries are ideal. There are two junctions in this circuit, at b and d, and there are three branches connecting these junctions.The branches are the left branch (bad), the right branch (bcd), and the central branch (bd).What are the currents in the three branches? We arbitrarily label the currents, using a different subscript for each branch. Current i_1 has the same value everywhere in branch bad, i_2 has the same value everywhere in branch bcd, and i_3 is the current through branch bd. The directions of the currents are assumed arbitrarily. Consider junction d for a moment: Charge comes into that junction via incoming currents i_1 and i_3, and it leaves via outgoing current i_2. Because there is no variation in the charge at the junction, the total incoming current must equal the total outgoing current:

$$i_1 + i_3 = i_2.$$

You can easily check that applying this condition to junction b leads to exactly the same equation. Equation 27-18 thus suggests a general principle:
JUNCTION RULE: The sum of the currents entering any junction must be equal to the sum of the currents leaving that junction.

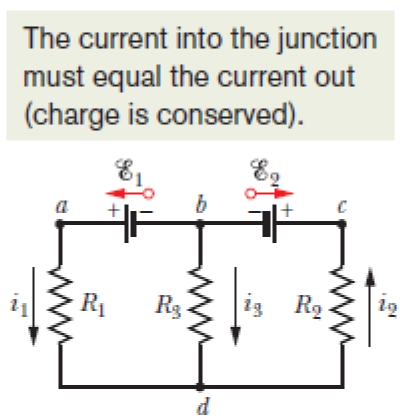

Figure 3: A multiloop circuit consisting of three branches: left-hand branch bad, righthand branch bcd, and central branch bd. The circuit also consists of three loops: lefthand loop badb, right-hand loop bcdb, and big loop badcb.

7. RC Circuits

In preceding modules we dealt only with circuits in which the currents did not
vary with time. Here we begin a discussion of time-varying currents.

8. Refrences

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