OHM'S LAW

This note explains Ohm's law connecting current, voltage, and resistance. It also describes the concepts of work and power in this context.

Definition

The current (I for intensity) is the movement, or flow, of electrons through an electrical circuit. It is measured in amperes A[1]. The force required to move the electrons is referred to as voltage (V) measured in volts V[2]. The third element of basic electronic circuitry is the resistance (R) against the flow of electrons, which is measured in ohms Ω[3].

Ohm's law states that in a closed, electronic circuit current (I) is proportional to the voltage (V) and inversely proportional to the resistance (R). Put in equation form

$$I = \frac{V}{R}$$

which can be rewritten, to express voltage and resistance.

$$V = I \times R$$
$$R = \frac{V}{I}$$

The law can also be expressed using the next figures.

[1] The ampere A is named after André Ampère, French physicist and mathematician, who in the late 18^{th} century worked with magnetism and current flow to develop some foundations for understanding the behavior of electricity. One ampere represents the movement of 6.25×10^{18} electrons (or one coulomb) past one point in a conductor in one second.

[2] The name comes from the Italian physicist and chemist Alessandro Volta. One volt is the amount of pressure (force) required to move one ampere of current through one ohm of resistance.

[3] Georg S. Ohm was a German physicist and mathematician around 1800 who discovered that all electrical quantities are proportional to each other and therefore have a mathematical relationship.

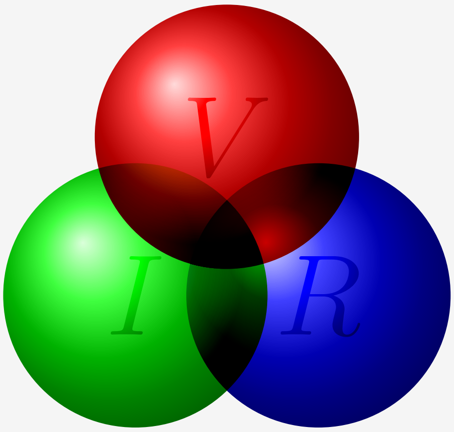

Figure 1: Ohm's law.

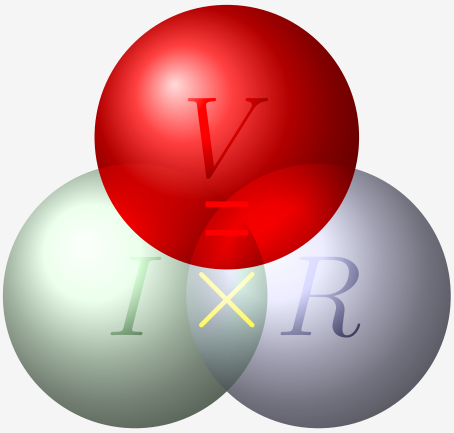

Figure 2: $V = I \times R$.

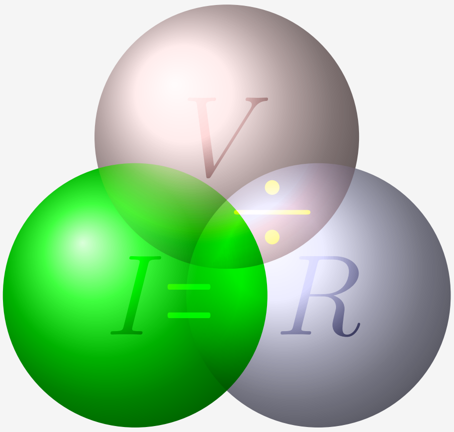

Figure 3: $I = \frac{V}{R}$.

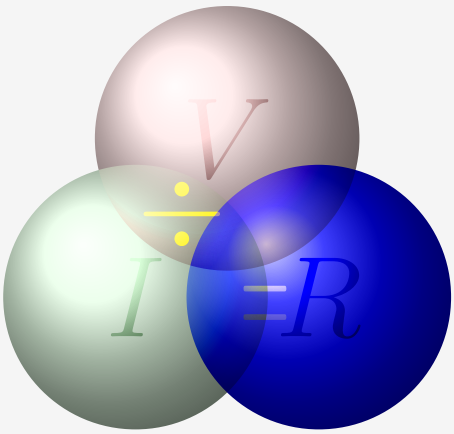

Figure 4: $R = \frac{V}{I}$.

Intuition

Two examples allow understanding the intuition behind the law. First, using a garden hose. Replace the electrons with water pouring (current) through the hose (the conductor). How far you open the tap determines the force to push the water that controls the pressure (voltage). Then, if you kink the hose it produces a resistance, which slows the current. Add a couple more resistance kinks and it really slows down the current, unless you increase the force (voltage).

A second example uses a waterwheel, a large wheel turning with the help of water, used e.g. to grind wheat. The turning of the wheel represents the resistance. To fight this resistance you need enough water through the wheel (current) and enough pressure or force (voltage).

Explanation

Current and work

The movement of electrons is called a current. It flows through the wires. It is important to know the amount of electrons flowing, because this current does the work for your car. However, it is almost impractical to count electrons because the number needed to do a reasonable amount of work is extremely large.

The pressure or motive force which induces a current to flow is measured in volts (V). This voltage can be supplied from a battery or produced by a generator. In order for a flow to occur, the ends of a conductor must have a different voltage or, if you like, a voltage differential.

Voltage is often compared to water pressure and in the same way as applying two equal pressures of water to a pipe would result in no flow across the pipe, by connecting two 12V supplies together we produce no current, but by applying this combined potential to another conductor we might produce a flow with a pressure of 24V.

Let us define work in this context. Electricity working gives us light, heat, or magnetic field. It is important to realize that any time work is being done we produce one or more of these results. Most of the time, this work is desired or engineered into the circuit, but sometimes it is not. A bad connection, for example, might get warm as electrons flow through it.

You might be thinking about all of the devices on a car that do work for us. All of them have some current or amperage flowing through them and are doing work to produce light, heat, or magnetic field. Certain devices, however, also give us motion. Starters, heater blowers, or windshield wipers give us motion by setting up magnetic fields.

Work cannot be done by just voltage or just amperage. Both are needed. If you want to water your plants, you need flowing water (current) and some pressure (voltage). Electricity is the same. Voltage without current or current without voltage accomplishes nothing. When you leave your headlights on overnight and run the battery down, you are removing the pressure or voltage. When you try to start the car the next morning, you have electrons available because the whole vehicle is made up of them, but without voltage or pressure behind the electrons there is not any current flow and nothing happens when you turn the key. No pressure with lots of electrons does not do any work.

Wattage (W) is the electrical means of monitoring how much work is being done. It is rated in watts W[4]. A watt is the unit of electrical power, and equals one ampere under the pressure of one volt. It is also equal to 1 joule per second. Consider the light bulb in your home. A $60W$-bulb delivers one-half the light of a $120W$-bulb. Wattage is the result of multiplying the voltage applied by the current flowing. Because it takes both pressure and current to do work, it makes sense that an indication of the amount of work accomplished would use both in its calculations. For example, a $60W$-bulb at home actually draws $0.5A$ of current at $120V$, in equation

$$120 \times 0.5 = 60.$$

We also use wattage when trying to understand starting systems. If a certain amount of work must be accomplished, such as cranking over an engine, the amperage used is based on the voltage applied. For example, if $2000W$ of work is crank over an engine, $200A$ are needed if the voltage can be kept up to $10V$, in equation

$$200 \times 10 = 2000.$$

However, if the voltage drops down to $5V$, the amperage has to go up to $400A$ to crank the engine over at the same speed.

If you look at vehicles today, you see mostly $12V$ systems, and yet years ago many systems were $6V$. Getting the same amount of light, heat, and magnetic field out of a $6V$ system requires twice the amperage. Delivering and generating twice the amperage was not only expensive but difficult to control. Another example of wattage at work can be seen when looking at large diesel engines. Most crank over at $24V$ rather than $12V$ because the starting system draws half the current at $24V$ than it draws at $12V$ to accomplish the same amount of work.

[4]James Watt was an instrument maker and inventor whose steam engine contributed to the industrial revolutions

To sum up:

$$\text{voltage} \times \text{amperage} = \text{wattage}$$

or

$$V \times A = W$$

Resistance

Everything has some resistance to electrical flow, there are no perfect conductors. If you double the length of any cable you will double its resistance to flow. If you double the cross-sectional size then resistance will be halved.

Resistance is the force that opposes the flow of electrons. This back pressure, along with the voltage, dictate the number of electrons able to flow through a circuit. When current is moving through electrical components, such as bulbs and motors, the amount of current flowing is dependent on two other conditions: the voltage, or pressure on the electrons, and the resistance that the circuit puts up against the flow of electrons.

If we decrease the resistance, it is easier for electrons to flow, more electrons flow through the circuit and more work is accomplished. Pressure against the water moved a current and turned the waterwheel. That waterwheel takes some effort to turn. It offers some resistance to the water trying to push it. This waterwheel is equal to the electrical resistance that a light bulb offers to the flow of current.

Ohm's law

Consider now the interrelationship of voltage, amperage, and resistance. This relationship is called Ohm's Law. Diagnosis of most circuits involves looking for changes that occur in voltage, amperage, and resistance. To be practical, we seldom sit alongside the automobile and use Ohm's Law mathematically to repair a problem. We do, however, use the principles of Ohm's Law in virtually every electrical repair.

If we understand that resistance is opposition, increasing or decreasing this opposition has an inverse, or opposite, effect on current flow (assuming the voltage remains the same).

In other words, if we increase the resistance in a circuit whose voltage remains the same, we see that more opposition allows less current to flow. It is now harder for current to flow through the circuit and therefore less will be able to get through the resistance. The opposite is also true. If we decrease the resistance within a circuit, the current will find itself in an easier path and more will flow. This inverse relationship assumes that the voltage remains the same. The more current flowing, the more work accomplished.

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