Ohm's law

From Wikipedia, the free encyclopedia

Ohm's law states that, in an electrical circuit, the current passing through a conductor, from one terminal point on the conductor to another terminal point on the conductor, is directly proportional to the potential difference (i.e. voltage drop or voltage) across the two terminal points and inversely proportional to the resistance of the conductor between the two terminal points.

For real devices (resistors, in particular), this law is usually valid over a large range of values of current and voltage, but exceeding certain limitations may result in losing simple direct proportionality (e.g. temperature effects, see below).

In mathematical terms, this is written as:

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

where I is the current, V is the potential difference, and R is a constant called the resistance. The potential difference is also known as the voltage drop, and is sometimes denoted by E or U instead of V.

The SI unit of current is the ampere; that of potential difference is the volt; and that of resistance is the ohm, equal to one volt per ampere.

The law was named after the physicist Georg Ohm, who, in a treatise published in 1826, described measurements of applied voltage, and current passing through, simple electrical circuits containing various lengths of wire, and presented a slightly more complex equation than the above equation to explain his experimental results. The equation above could not exist until the ohm, a unit of resistance, was defined (1861, 1864).
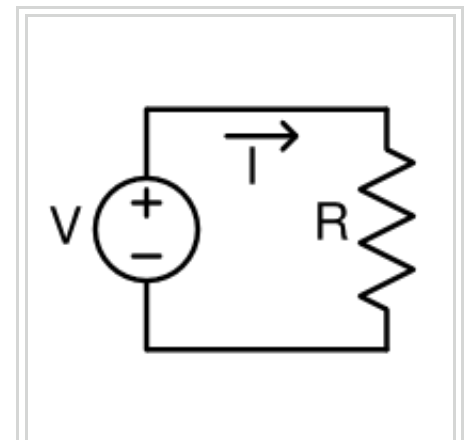
A voltage source, V, drives an electric current, I , through resistor, R, the three quantities obeying Ohm's law: V = IR

Contents

- 1 An elementary explanation of electrical circuits, the above diagram, and how Ohm's Law is used
- 2 Physics
- 3 How electrical and electronic engineers use Ohm's law
  - 3.1 Hydraulic analogy
  - 3.2 Sheet resistance
- 4 Temperature effects
- 5 Strain (mechanical) effects
- 6 AC circuits

An elementary explanation of electrical circuits, the above diagram, and how Ohm's Law is used

Electrical circuits consist of electrical devices connected by wires (or other suitable conductors). (See the article electrical circuits for some basic combinations.) The above diagram shows one of the simplest electrical circuits that can be constructed. One electrical device is shown as a circle with + and - terminals, which represents a voltage source such as a battery. The other device is illustrated by a zig-zag symbol and has an R beside it. This symbol represents a resistor, and the R designates its resistance. The + or positive terminal of the voltage source is connected to one of the terminals of the resistor using a wire of negligible resistance, and through this wire a current I is shown to be passing, in a specified direction illustrated by the arrow. The other terminal of the resistor is connected to the - or negative terminal of the voltage source by a second wire. This configuration forms a complete circuit because all the current that leaves one terminal of the voltage source must return to the other terminal. (While not shown, because electrical engineers assume that it exists, there is an implied current I, and an arrow pointing to the left, associated with the second wire.)

Voltage is the magnitude of the electrical force that moves charge (electrons) through wires and electrical devices, current is the rate of flow of charge, and resistance is the property of a resistor that limits current to an amount proportional to the applied voltage. So, for a voltage source producing a voltage V, and a resistor of resistance R, Ohm's law provides the equation (I=V/R) for computing the current I.

The 'conductor' mentioned by Ohm's law is a circuit element across which the voltage is measured. Resistors are conductors that slow down the passage of electric charge. A resistor with a high value of resistance, say above 10 megaohms, is a poor conductor, while a resistor with a low value, say below 0.1 ohm, is a good conductor. (Insulators are electrical devices that, for most practical purposes, do not allow a current to flow when voltage is applied.)

In a circuit diagram like the one above, the various components may be joined by connectors, contacts, welds or solder joints of various kinds, but for simplicity these connections are usually not shown.

Physics

Physicists often use the continuum form of Ohm's Law:

$$\mathbf{J} = \sigma \cdot \mathbf{E}$$

where $\mathbf{J}$ is the current density (current per unit area), σ is the conductivity (which can be a tensor in anisotropic materials) and $\mathbf{E}$ is the electric field.

The common form $V = I \cdot R$ used in circuit design is the macroscopic, averaged-out version.

The continuum form of the equation is only valid in the reference frame of the conducting material. If the material is moving at velocity **v** relative to a magnetic field **B**, a term must be added as follows

$$\mathbf{J} = \sigma \cdot (\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

The analogy to the Lorentz force is obvious, and in fact Ohm's law can be derived from the Lorentz force and the assumption that there is a drag on the charge carriers proportional to their velocity.

A perfect metal lattice would have no resistivity, but a real metal has crystallographic defects, impurities, multiple isotopes, and thermal motion of the atoms. Electrons scatter from all of these, resulting in resistance to their flow.

Ohm's law is sufficient to derive both Kirchhoff's voltage law (KVL) and Kirchhoff's current law (KCL). Let us first examine only the right-hand side of the equation:

$$\sigma E$$

and calculate the line integral around a closed contour:

$$\oint \sigma E \cdot dl$$

Applying Stokes's theorem, we can write over the surface bounded by the countour:

$$\int_S \sigma \nabla \times E \cdot dA$$

but, since E is the gradient of a scalar potential, yielding:

$$\int_S \sigma \nabla \times (\nabla(\phi)) \cdot dA$$

and gradients are irrotational, we have:

$$\int_S \sigma \times \vec{0} \cdot dA$$

thereby proving KCL. Returning to the original formulation of Ohm's law:

$$J = \sigma E$$

and forming the closed line integrals again:

$$\oint J \cdot dl = \oint \sigma E \cdot dl$$

and recalling from Maxwell's equations that $curl(H) = J$:

$$\oint \nabla \times (H) \cdot dl = \oint \sigma E \cdot dl$$

we apply Stokes's theorem to obtain:

$$\int_S H \cdot dA = \oint \sigma E \cdot dl$$

From our preceding derivation, we know that the right-hand side evaluates to zero:

$$\int_S H \cdot dA = 0$$

thus proving that the net current flow through an open surface is zero, which restates KCL.

How electrical and electronic engineers use Ohm's law

Ohm's Law is one of the equations used in the analysis of electrical circuits, whether the analysis is done by engineers or computers. Even though, today, computers running electronic computer aided design and analysis programs do the bulk of the work predicting and optimizing the performance of electrical circuits (in particular, those circuits to be fabricated on silicon chips), most electrical engineers still use Ohm's Law every working day. Whether designing or debugging an electrical circuit, electrical engineers must have a working knowledge of the practical aspects of Ohm's law.

Virtually all electronic circuits have resistive elements which are almost always considered ideal ohmic devices, i.e. they obey Ohm's Law. From the engineer's point of view, resistors (devices that "resist" the flow of electrical current) develop a voltage across their terminal conductors (e.g. the two wires emerging from the device) proportional to the amount of current flowing through the device.

More specifically, the voltage measured across a resistor at a given instant is strictly proportional to the current passing through the resistor at that instant. When a functioning electrical circuit drives a current **I**, measured in amperes, through a resistor of resistance **R**, the voltage that develops across the resistor is **I R**, the value of **R** serving as the proportionality factor. Thus resistors act like current to voltage converters (just as springs act like displacement to force converters).

Similarly, resistors act like voltage to current converters when a desired voltage is established across the resistor because a current **I** equal to 1/**R** times **V** must be flowing through the resistor. That current must have been supplied by a circuit element functioning as a current source and it must be passed on to a circuit element that serves as a current sink.

The DC resistance of a resistor is always a positive quantity, and the current flowing through a resistor generates (waste) heat in the resistor as it does in one of Ohm's wires. Voltages can be either positive or negative, and are always measured with respect to a reference point. When we say that a point in a circuit has

a certain voltage, it is understood that this voltage is really a voltage difference (a two terminal measurement) and that there is an understood, or explicitly stated, reference point, often called ground or common. Currents can be either positive or negative, the sign of the current indicating the direction of current flow. Current flow in a wire consists of the slow drift of electrons due to the influence of a voltage established between two points on the wire.

Since the resistance of a resistor is always positive and the equation describing Ohm's law does not in itself constrain **R** to be positive (by being written as: $|V|=|I| \backslash \mathbf{R}$), there is the potential for computing a negative value for **R**. Using measurements of voltage and current that are made correctly, the sign of a computed **R** is never negative. When a negative **R** is computed based on a measurement of the voltage drop across a resistor and a measurement of the current passing through the resistor, then one of the two measurements must have been made improperly. When circuits are analyzed, the direction of flow of current between circuit elements may not be known or obvious. In this case, the direction of the current is assigned arbitrarily. Should a sign error (one that implies a negative resistance) arise during the analysis, the error is resolved by asserting that the initially assigned direction of current was incorrect, and that the actual direction of current is in the direction opposite to the initially assigned direction.

Non-ohmic and active components may actually have negative differential resistance, a subject discussed in its own article. The word 'differential' is key, though often omitted, because it describes the characteristics of an interesting portion of the I vs. V curve of the non-ohmic device. At no time is the 'static' resistance itself negative.

Certain powered circuit devices, constructed as two terminal devices and tested as if they were a resistor (by applying a voltage across the two terminals while measuring the current), may exhibit actual negative resistance. Ohm's law is not intended to apply to such devices. Further the law of conservation of energy is not violated because there is an integrated source of power.

Ohm's law applies to conductors whose resistance is (substantially) independent of the applied voltage (or equivalently the injected current). That is, Ohm's law only applies to the linear portion of the I vs. V curve centered around the origin. The equation is just too simple to encompass devices described by a more complicated I vs. V relationship.

Hydraulic analogy

While the terms voltage, current and resistance are fairly intuitive terms, beginning students of electrical engineering might find the analog terms for water flow helpful. Water pressure, measured by international units in pascals (and commonly in units of pounds force per square inch), is the analog of voltage because establishing a water pressure difference between two points along a (horizontal) pipe causes water to flow. Water flow rate, as in liters (or gallons) of water per minute, is the analog of current, as in coulombs per second. Finally, flow restrictors such as apertures placed in pipes between points where the water pressure is measured are the analog of resistors. We say that the rate of water flow through an aperture restrictor is proportional to the difference in water pressure across the restrictor. Similarly, the rate of flow of electrical charge, i.e. the electrical current, passing through an electrical resistor is proportional to the difference in voltage measured across the resistor.

Sheet resistance

Thin metal films, usually deposited on insulating substrates, are used for various purposes, the electrical current traveling parallel to the plane of the film. When describing the electrical resistivity of such devices, the term ohms-per-square is used. See sheet resistance.

Temperature effects

When the temperature of the conductor increases, the collisions between electrons and atoms increase. Thus as a substance heats up because of electricity flowing through it (or by any heating process), the resistance will usually increase. The exception is semiconductors. The resistance of an Ohmic substance depends on temperature in the following way:

$$R = \frac{L}{A} \cdot \rho = \frac{L}{A} \cdot \rho_0 (\alpha(T - T_0) + 1)$$

where ϱ is the resistivity, L is the length of the conductor, A is its cross-sectional area, T is its temperature, T_0 is a reference temperature (usually room temperature), and ϱ_0 and α are constants specific to the material of interest. In the above expression, we have assumed that L and A remain unchanged within the temperature range.

It is worth mentioning that temperature dependence does not make a substance non-ohmic, because at a given temperature R does not vary with voltage or current (V / I = constant).

Intrinsic semiconductors exhibit the opposite temperature behavior, becoming better conductors as the temperature increases. This occurs because the electrons are bumped to the conduction energy band by the thermal energy, where they can flow freely and in doing so they leave behind holes in the valence band which can also flow freely.

Extrinsic semiconductors have much more complex temperature behaviour. First the electrons (or holes) leave the donors (or acceptors) giving a decreasing resistance. Then there is a fairly flat phase in which the semiconductor is normally operated where almost all of the donors (or acceptors) have lost their electrons (or holes) but the number of electrons that have jumped right over the energy gap is negligible compared to the number of electrons (or holes) from the donors (or acceptors). Finally as the temperature increases further the carriers that jump the energy gap becomes the dominant figure and the material starts behaving like an intrinsic semiconductor.

Strain (mechanical) effects

Just as the resistance of a conductor depends upon temperature, the resistance of a conductor depends upon strain. By placing a conductor under tension (a form of strain), which means to mechanically stretch the conductor, the length of the section of conductor under tension increases and its cross-sectional area decreases. Both these effects contribute to increasing the resistance of the strained section of conductor. Under compression (the other form of strain), the resistance of the strained section of conductor decreases. See the

discussion on strain gauges for details about devices constructed to take advantage of this effect.

AC circuits

For an AC circuit Ohm's law can be written $\mathbf{V} = \mathbf{I} \cdot \mathbf{Z}$, where $\mathbf{V}$ and $\mathbf{I}$ are the oscillating phasor voltage and current respectively and $\mathbf{Z}$ is the complex impedance for the frequency of oscillation.

In a transmission line, the phasor form of Ohm's law above breaks down because of reflections. In a lossless transmission line, the ratio of voltage and current follows the complicated expression

$$Z(d) = Z_0 \frac{Z_L + jZ_0 \tan(\beta d)}{Z_0 + jZ_L \tan(\beta d)},$$

where d is the distance from the load impedance Z_L measured in wavelengths, β is the wavenumber of the line, and Z_0 is the characteristic impedance of the line.

Relation to heat conduction

Ohm's principle predicts the flow of electrical charge (i.e. current) in electrical conductors when subjected to the influence of voltage differences; Jean-Baptiste-Joseph Fourier's principle predicts the flow of heat in heat conductors when subjected to the influence of temperature differences. The same equation describes both phenomena, the equation's variables taking on different meanings in the two cases. Specifically, solving a heat conduction (Fourier) problem with *temperature* (the driving "force") and *flux of heat* (the rate of flow of the driven "quantity", i.e. heat energy) variables also solves an analogous electrical conduction (Ohm) problem having *electric potential* (the driving "force") and *electric current* (the rate of flow of the driven "quantity", i.e. charge) variables. The basis of Fourier's work was his clear conception and definition of thermal conductivity. He assumed that, all else being the same, the flux of heat is strictly proportional to the gradient of temperature. Although undoubtedly true for small temperature gradients, strictly proportional behavior will be lost when real materials (e.g. ones having a thermal conductivity that is a function of temperature) are subjected to large temperature gradients. A similar assumption is made in the statement of Ohm's law: other things being alike, the strength of the current at each point is proportional to the gradient of electric potential. The accuracy of the assumption that flow is proportional to the gradient is more readily tested, using modern measurement methods, for the electrical case than for the heat case.

See also

- Poiseuille's law
- Scientific laws named after people
- Ohm's acoustic law

     Electronics Portal
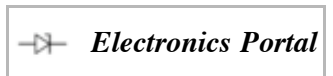
External links

- Calculation of Ohm's law · The Magic Triangle (http://www.sengpielaudio.com/calculator-ohmslaw.htm)
- Calculation of electric power, voltage, current and resistance (http://www.sengpielaudio.com/calculator-ohm.htm)
- Interactive calculator for Ohm's Law and other circuit parameters (http://www.cvs1.uklinux.net/calculators/)
- An interactive simulation of simple electric circuit. (http://www.phy.hk/wiki/englishhtm/Circuit.htm)

Retrieved from "http://en.wikipedia.org/wiki/Ohm%27s_law"

Categories: Articles lacking sources from December 2006 | All articles lacking sources | Electronic engineering | Eponymous laws

---