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# Voltage: Expanded Definition

**Low Context Audience: High school seniors and undecided university students**

## Voltage

Voltage is a fundamental concept in physics that describes an electrical "pressure" between two points in space [5],[6]. It has units of volts (V) and is named after Alessandro Volta, who was an Italian inventor of battery technology in 1800 [5],[6]. Voltage appears in electromagnetic theory through its relationship with electrical potential energy, the electric field, current, and resistance [5].

## Electrical Potential Energy

In physics, energy is an abstract concept that is useful for determining how a collection of objects can change their properties [5]. Energy exists in the form of either kinetic or potential energy, with units of Joules [5]. In the context of electricity, electric potential energy is a concept to quantify how two or more objects with charge (a fundamental property of matter that can be designated as either positive or negative, with similar charges repelling each other and opposite charges attracting one another) will interact depending on how far apart those charges are [3],[5]. Electric potential energy is directly proportional to the charge of two or more objects in the system, and inversely proportional to the distance between those charges [5]. For the sake of computation, it is useful to have an independent quantity for the potential energy of a single object, so voltage is then defined as the energy of the system with respect to a single charged object [5]. Therefore, voltage is directly proportional to the electrical potential energy, and inversely proportional to the charge of the object [5]. Consequently, voltage is also directly proportional to the charge of a single object, and inversely proportional to the distance away in space from that object [5].

## The Electric Field

When there is a difference in voltage between two points in a circuit, this creates an electric field (a property of space that is influenced by electric charges and has SI units of Newtons per Coulomb or Volts per meter) pointing in the direction of decreasing voltage [4],[5]. The electric field can be defined as the ratio of the change in voltage and the change in distance being measured, which implies that the change in voltage is related to the strength of the electric field multiplied by the distance being measured [4],[5]. Essentially, the electric field is a direct consequence of a change in voltage and can be thought of as analogous to gravitational force while voltage can be thought of as a change in elevation for an object [5].

## Ohm's Law

Voltage is related to the concept of resistance (a property of circuit material directly proportional to the length of the wire, and inversely proportional to the cross sectional area of the wire) and current (a rate of movement for electrons in a circuit with respect to time) by Ohm's Law, which is an equation discovered by a German physicist, Georg Simon Ohm [1],[2],[5]. This law states that the current (I) flowing through a wire is directly proportional to the voltage (V) across that

wire and inversely proportional to the resistance (R) of the wire [5],[6],[7]. A useful metaphor for comparison is to consider Ohm's law in the context of a person pushing a rock up a hill, where the person represents voltage, the rock represents electric current, and the hill represents resistance [5]. The person is applying pressure on the rock in order to make it move, the rock is a collection of particles that are changing position with respect to time, but the hill is slowing down the rock's movement because of gravity [5].

**Circuits**

The concept of voltage is commonly used when analyzing electrical circuits [5]. Voltage sources are used to generate electrical fields that drive current [5]. Some common voltage sources include AA batteries, that are usually rated as producing 1.5 volts, and wall sockets in the United States of America that are usually rated as producing 120 volts [5].

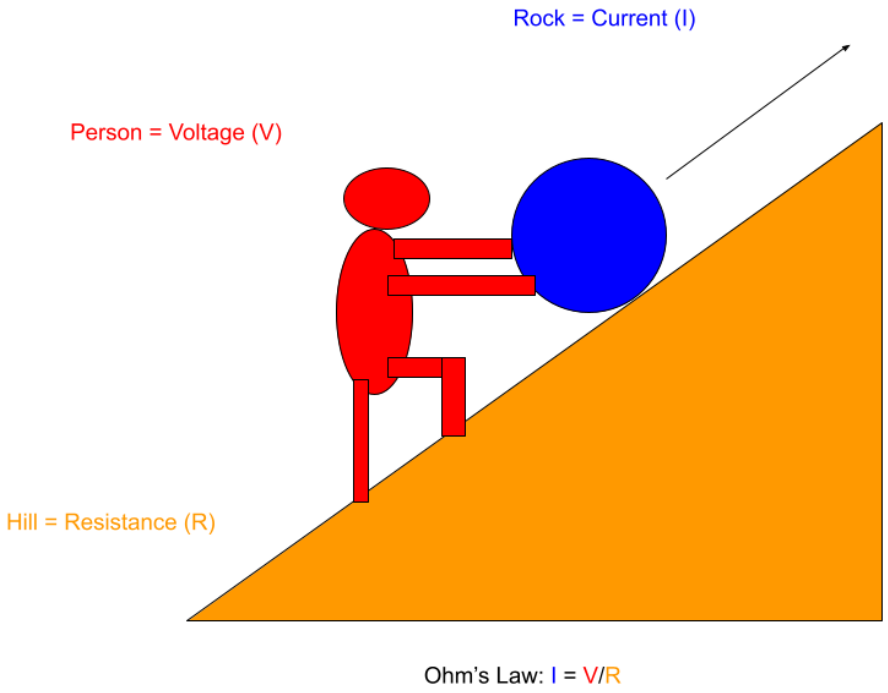


**Figure 1:** An image describing how voltage is related to current and resistance by analogy of a rock being pushed up a hill.

Alt Text: "A representation of the relationship between voltage, current and resistance by analogy of a rock being pushed up a hill. The person represents voltage, the rock represents the current, and the hill represents resistance".

**High Context Audience: Fellow Professionals**

**Voltage**

Voltage is a fundamental concept in physics that describes an electrical potential difference between two points in space [5],[6]. It is a scalar that has SI units of volts (V) or Joules per Coulomb and is named after Alessandro Volta, who was an Italian inventor of battery technology in 1800 [5],[6]. Voltage appears in electromagnetic theory through its relationship with electrical potential energy, the electric field, current, and resistance [5].

**Electrical Potential Energy**

In physics, energy is an abstract concept used for the purpose of calculation in order to quantify how much work a system is able to do [5]. Energy exists in the form of either kinetic or potential energy, with SI units of Joules [5]. In the context of electricity, electric potential energy is a concept to quantify how two or more particles with charge (a fundamental property of matter that can be designated as either positive or negative, with similar charges repelling each other and opposite charges attracting one another) will do work on a system depending on how far apart the charges are [3],[5]. The mathematical relationship for electrical potential energy is given by:

$$U_{Electric} = \frac{kq_1q_2}{r}$$

where U is the electrical potential energy in Joules, k is a constant equal to 8.99×10^9 N m^2 / C^2, q1 and q2 are the net electric charge of two particles with units of Coulombs, and r is the distance that the two particles are from each other in units of meters [5]. Since it is useful to have an independent quantity for the potential energy of a single particle, voltage is the energy of the system with respect to a single charged particle [5]. Therefore, voltage is related to electric potential energy by the relationship:

$$V = \frac{U_{electric}}{q} \text{ or } \Delta V = \frac{\Delta U}{q}$$

Where U is the electrical potential energy in Joules, V is voltage in Volts, and q is the charge of a charged particle in units of Coulombs [5]. Voltage, or electric potential difference can then be described as the mathematical relationship given by:

$$V(r) = \frac{kQ}{r}$$

where V(r) is voltage as a function of distance in units of volts, k is a constant, Q is the net charge of a mass of charged particles, and r is the distance away from a location in space in units of meters [5].

**The Electric Field**

When there is a difference in voltage between two points in a circuit, this creates an electric field (a property of space that influences electric charges where the electric field, E, has SI units of Newtons per Coulomb or Volts per meter) pointing in the direction of decreasing voltage [4],[5]. The electric field vector can be defined as the mathematical relationship:

$$E = \frac{kQ}{r^2}\hat{r} \text{ or } E = \frac{-\Delta V}{\Delta S}$$

Where E is the electric field vector, k is a constant, Q is the net charge of a charged particle in units of Coulombs, r is the distance in space from the charged particle, r^ is the unit normal vector pointing in the direction of the electric field, V is the voltage in units of Volts, and S is the

distance in meters where the change in voltage occurs [5],[4]. The relationship between voltage and the electric field is then given by the relationship:

$$\Delta V = -\int_{a}^{b} E \cdot ds$$

Where V is the voltage in units of volts, E is the electric field in units of Newtons/meter, and ds is the path integral parameterization [5],[4]. Essentially, the electric field is a direct consequence of a change in voltage and can be thought of as analogous to gravitational force while voltage can be thought of as a change in elevation for an object [5].

**Ohm's Law**

Voltage is related to the concept of resistance (a property of a circuit material directly proportional to the length of the wire, and inversely proportional to the cross sectional area of the wire) and current (a rate of movement for electrons in a circuit with respect to time) by Ohm's Law, which is an equation discovered by a German physicist, Georg Simon Ohm [1],[2],[6],[5],[7]. This law states that the current flowing through a wire is directly proportional to the voltage across that wire and inversely proportional to the resistance of the wire, and can be mathematically stated as:

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

Where I is the current in units of Amps, V is the voltage in units of Volts, and R is the resistance in units of Ohms [5],[6],[7]. A useful metaphor for comparison is to consider Ohm's law in the context of a person pushing a rock up a hill, where the person represents voltage, the rock represents electric current, and the hill represents resistance [5]. The person is applying pressure on the rock in order to make it move, the rock is a collection of particles that are changing position with respect to time, but the hill is slowing down the rock's movement because of gravity [5].

This equation is fundamental to analyzing the voltage and current in circuit problems [5].

**Circuits**

The concept of voltage is commonly used when analyzing electrical circuits [5]. Voltage sources are used to generate electrical fields that drive current [5]. Some common voltage sources include AA batteries, that are usually rated as producing 1.5 volts, and wall sockets in the United States of America that are usually rated as producing 120 volts [5].

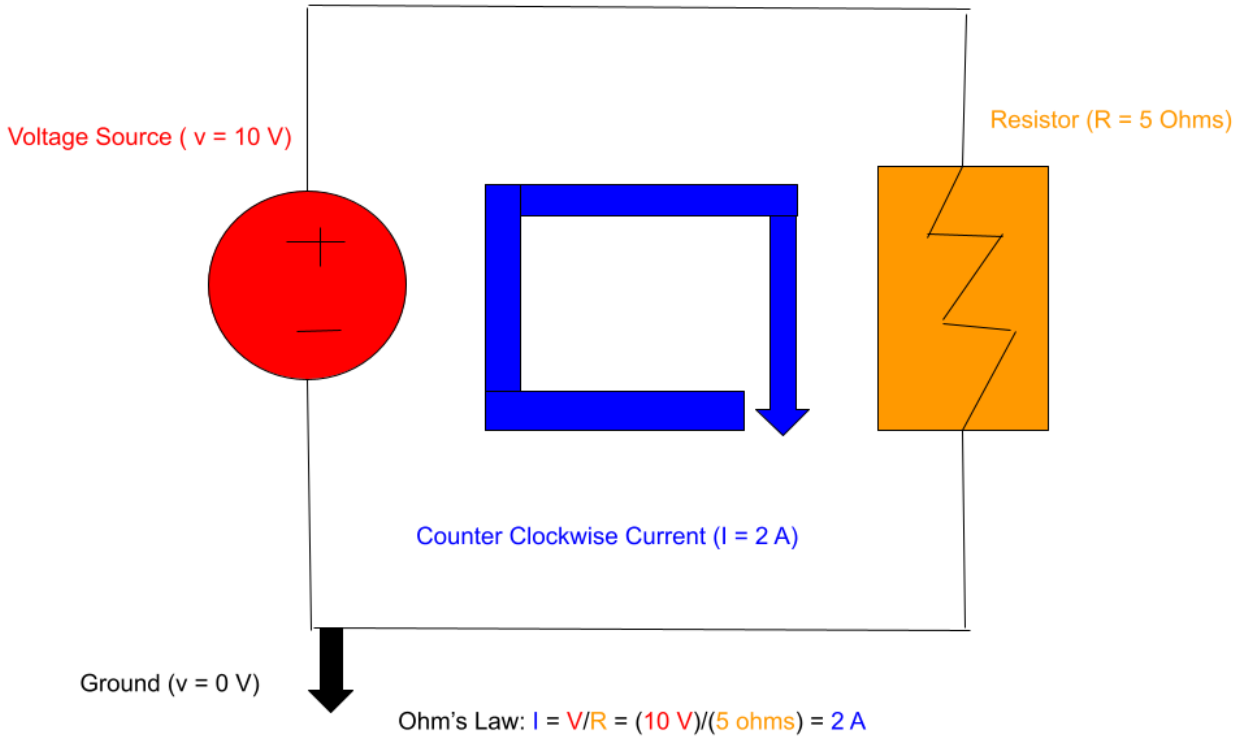


**Figure 2:** An image of an electric circuit and equations for how voltage relates to current and resistance, as well as how voltage is related to the electric field.

Alt Text: "An image of an electric circuit where voltage is represented by a voltage source, current is represented by a clockwise arrow going around the circuit, and resistance is represented by a resistor".

**References:**

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[6] Roos, D. (2022, October 3). *What are amps, Watts, volts and ohms?*. HowStuffWorks Science. https://science.howstuffworks.com/environmental/energy/question501.htm [Accessed July 29th 2023]

*[7] What is Ohm's law?* Fluke. (2023, March 29). https://www.fluke.com/en-us/learn/blog/electrical/what-is-ohms-law [Accessed July 29th 2023]