Electricity: Electric Charge, Electric Potential and More

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The term current defines a directed flow of particles we also find in the blood of our body. In order to be able to measure blood flow, one needs electrical appliances that require electricity. The electric current is generated through an electric circuit over which charges are moved through potential differences. The movement of the potential differences also happens in the human body, for example in the sodium-potassium ATPase.

The following article explains the different aspects of electrical engineering, their relation to the human body and how these different variables are related to each other.

Electric Charge and Electric Current

Whenever there is a directed flow of particles in a medium, we speak of a flow field. Given that a temporally constant particle flow takes place, where the number of particles that enter the field is equal to the number of particles leaving it, then this is referred to as a **stationary flow field**. If the flowing particles are carriers of electric charges, then a stationary electrical flow field is present. For an electric charge to be present, the matter has to experience force when placed in an electromagnetic field.

Such fields are formed, for example, in metals or aqueous solutions also found in the human body, which, after all, consists of around 60 % water. The **ions**, which are electrically charged atoms or molecules, are responsible for the flow field.
All electrical charges are a multiple of the elementary charge that is no longer divisible.

Since antiquity, it is known that there are two different electric charges, which today are known as **positive** and **negative**. The electron carries a single negative elementary charge of:

$$Q_E = e = -1{,}602 \times 10^{-19}\ C$$

I [A] ⇒ Current in Ampere
ΔQ [A*s], [C] ⇒ Quantity of electricity (charge)
Δt [s] ⇒ Time period
QE [C] ⇒ Elementary charge

The unit of electric charge is the **Coulomb** [C]. Ions can carry multiple elementary charges and be positively or negatively charged. Laws of attraction between positive and negative ions apply to charge as well i.e. like charges repel while as unlike charges attract. The total amount of electric charge carried is called **quantity of electricity**.

A property of the electric charge is the ability to cause reactions of variable intensity, which is referred to as the physical quantity **electric current**. The flow of electric charge is electric current. The unit for measuring an electric current is the **Ampere and the instrument of measure is an ammeter**. The ammeter is connected in series with the battery. One Ampere is the constant current that will produce an attractive **force equal to 0.2 N × 10^{-6}** per meter of length between two straight, parallel conductors of infinite length and negligible circular cross-sections placed one meter apart in a vacuum

The electric current is defined as the ratio between the quantity of electricity (charge) and the time period in which it flows:

$$I = \Delta Q / \Delta t$$

From the above equation, the electric current is directly proportional to the amount of charge. Electric currents of about **10 mA** can already have **lethal consequences** for humans.

Note: The electric current corresponds to the periodic change of the electric charge. If the timing of the achieved charge in the cross-sectional area is known, we can calculate the associated current simply by differentiating the charge function.

The Electrical Potential

U [V] ⇒ Electrical Potential (Voltage)
R [Ω] ⇒ Electrical Resistance
G [S], [1 / Ω] ⇒ Electrical conductance

The electrical potential is always measured **between two points**. In an electric circuit, current only flows when there is a **voltage between its poles**. It is the principle of the electric current. The electric potential is measured using an instrument called a voltmeter. The voltmeter is connected in parallel with the component, whose potential is to be measured.

The Voltage (V or U) between two points of a conductor is the **ratio of the in the part of the conductor converted power to the part where current is flowing through the conductor**. The result is the SI unit of the electrical potential:

1 Volt = 1 Watt / 1 Ampere

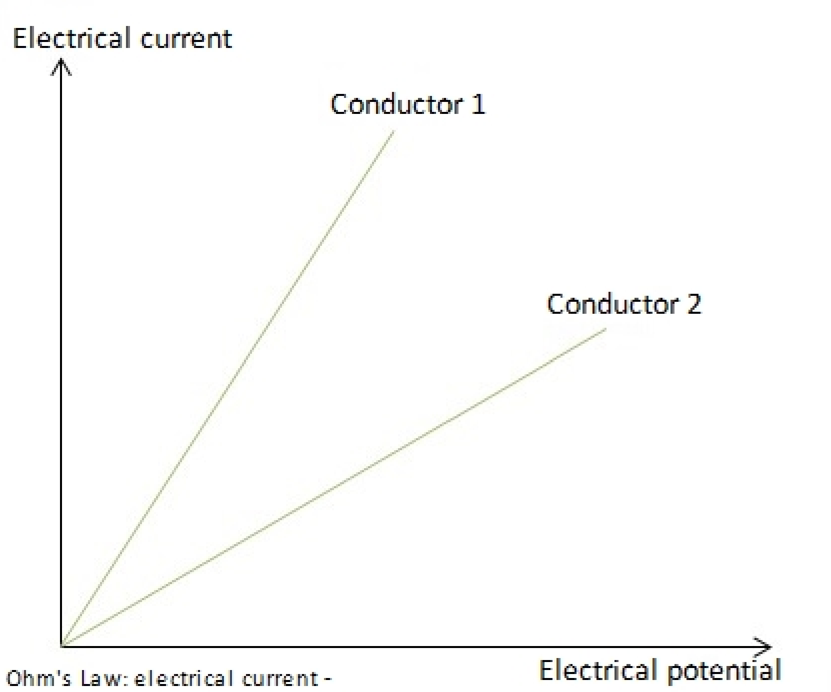
Principles of the Electric Circuit

Ohm’s Law

In 1827, the physicist Georg Simon Ohm investigated the dependence of the electric charge to the current in a conductor piece. He found that the electric **current-voltage U** passing through a conductor between two points is directly proportional to the potential difference across the two points. He described Ohm’s Law as follows:

$$\mathbf{U \sim I \quad R = U / I}$$

Ohm’s Law is only valid when the temperature remains constant.



Ohm's Law: electrical current - electrical potential

The **quotient of voltage and current** is called **electrical resistance**. It is also referred to as the Ohm resistance and is specified with the unit Ohm [Ω]. The electrical resistance of a metallic conductor is only constant at a steady temperature. **When the temperature changes, resistance changes as well**. With increasing temperature, the voltage and current also rise. Thus it is the resistance of the conductor under constant temperature and the electrical potential between two points in the conductor. Thus for a battery with great voltage, there is more current passing through it and vice versa. However, they do so to varying extents. As a result, the resistance of solid conductors increases with increasing temperature. The resistance of liquid conductors decreases with increasing temperature. Ohm’s law cannot be applied for electricity in gases.

Resistance varies from one conductor to another i.e. from the graph above conductor 2 has a higher resistance than conductor 1. These two conductors obey ohm’s law (the electrical current increases with increasing potential). Such conductors are referred as ohmic conductors. Those that do not obey ohm’s law are called non-ohmic conductors.

The **reciprocal of resistance** is called electrical conductivity (**conductance**). It is specified with the unit Siemens.

Example: The current in the body depends on the voltage between the contact points and the bodily resistance. The bodily resistance decreases with increasing voltage and depends on the routes the current can flow through. The skin resistance amounts to several thousand Ohm, but at high voltages, it may drop to zero. The current path between the left and right hand has a body resistance of approximately 650 Ohm.

Coulomb's Law

It allows the calculation of electric forces between forces.

E [V / m] ⇒ electrical field
F ⇒ resulting force on different charges
ε [F / m] ⇒ permittivity

The most important equations which describe the electrical potential force between two charged objects in electrostatic fields are listed hereinafter:

Force on quantity charge Q in the area of an intensity field:

$$F = Q \times E$$

Result of the force of the electrical charge of the bodies Q1 and Q2, which have the distance "a" from one another:

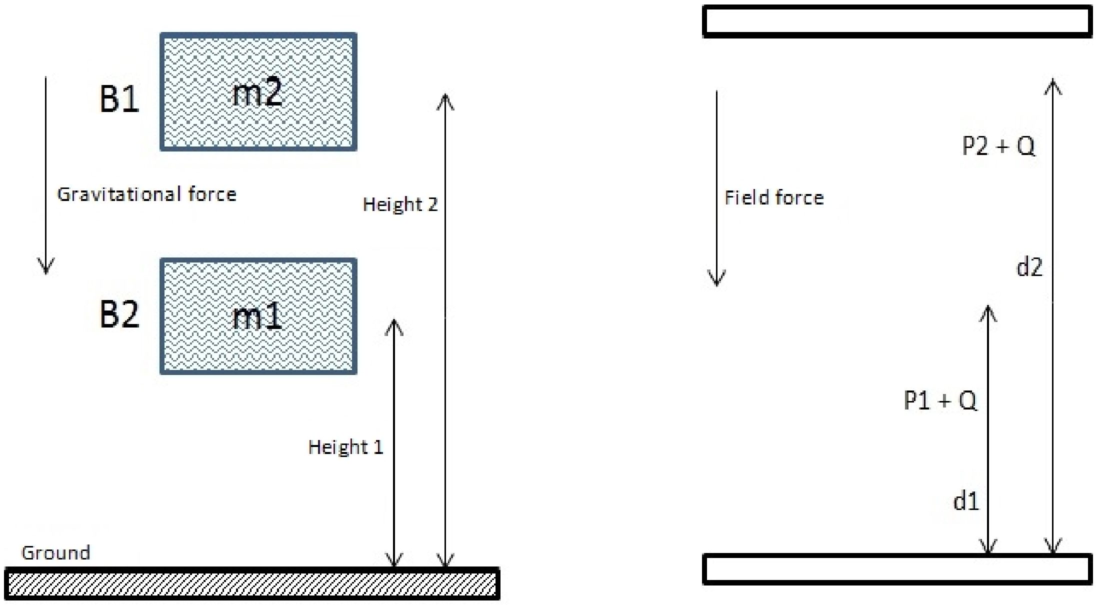
$$F = Q^2 / (2 \times \varepsilon \times A) = (D \times E \times A) / 2$$

This equation is known as Coulomb's law. Two oppositely charged particles will give an attractive potential, whereas if both particles are of the same charge—for example, both are positive or both are negative—the potential is repulsive. Compare the similarity to Newton's Law of Gravitation, in which, however, only attractive forces are possible.

Force between plane-parallel plates, such as plate capacitor:

Potential

Since water and water-flow behave similar to an electrical current, the movement of charge carriers can, therefore, be explained in more detail.



Gravity: electrical field force

Observing the illustration, we will see two containers filled with water – container B1 and container B2. Both containers have their orifices located at the height h1 and h2 above the ground. Gravity acts towards the earth. The potential energy of mass situated above ground is calculated by the gravitational force “g” to:

$$W = m \times g \times h.$$

It can be used, for example, when the valves are opened and water drains out.

A reference point for each potential **specification** (in this case the height) is **needed**. Since W represents the work that has to be performed in order to bring the mass into the corresponding height, the (gravitational) potential can, therefore, be characterized as follows: The gravity, or gravitational potential, of a point with respect to another point corresponds to the work which must be performed against gravity to bring any mass from the reference point to the receiving point, divided by the quantity of the mass.

Back to the flow field: It is referred to as a **flow field**, where a positive charge of the unit Q is located in each point P1 and point P2. As current flows and the two charges also move, a force has to act on them, which is called the **electric field force**. Here it has been randomly drawn as acting downwards from above, in order to allow direct comparison with the gravitational field.

It could also act upwards. Then the charges would “fall upwards” as they are only subject to the field force and, due to their very low mass, are not affected by the gravitational force. Everything that has been said about the gravitational potential now applies equally to a potential in the electric flow field, which is therefore called electrical potential and where the masses take the place of the charges.

Note: The electrical potential energy of a reference point, in relation to another (the receiving point), corresponds to the work that needs to be performed against the electric field strength to be able to bring any charge from the reference point to the receiving point, divided by the quantity of this charge.

The Electrical Circuit

All electrical elements in electrical flow fields or electrical circuits, in which the flowing charge carriers absorbed energy, are called **current or voltage sources**. All component parts, in which the flowing charge carriers released energy are called the electrical circuit's load. Sources are the origin of electromotive force, a voltage or a potential drop that takes place on the electric load.

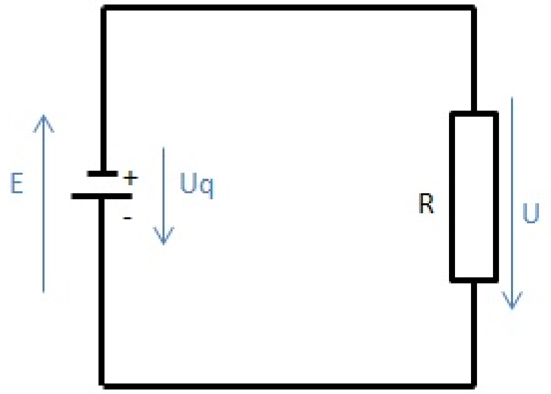
Now, let us observe the last illustration. All charge carriers move under the influence of the field force in the direction of the lower border of the flow field. On the way there, they release electrical energy. This **energy** is **exhausted** upon reaching the lower boundary electrodes.

If energy has to be released from the flow field again, it is necessary to bring the charge carriers to a **higher energy potential** once more. Therefore, it is best to bring them to the upper boundary electrode, in order for them to pass down through the field, during which they release electrical energy. If this process is repeated continuously, a continuous release of electrical energy to the flow field is possible.

The question is, which method is suited to bring the charge carriers either back again or upwards? As this cannot be done in the midst of the flow field, there has to be 'intervention from the outside'. A good example would be **intercepting the charge carriers** that have arrived at the lower boundary electrode and traveled via an electrical access line to a power source. There, due to the effect of the electromotive force, the necessary energy is supplied and then transported in this state via a second connecting line to the upper border of the flow field.

In this manner, a continuous **circular flow is maintained in a system** which is called the electrical circuit. It consists of two locally separate elements:

- The voltage source, in which the current-forming charge carriers receive energy.
- The electrical load, in which they release it again.



The illustration shows the electrical circuit with the two core elements that are interconnected by electric leads. The circuit symbol that is used for the source here is that of a battery. The electrical load is represented by a resistor R, at which a potential drop occurs.

Laws of Kirchhoff

Two laws of Kirchhoff play a significant role throughout the entire field of electrical engineering. Circuits are usually not as simply structured as in the previous illustration but have special junction points. In this way, **current nodes** are formed.

Kirchhoff's Current Law or Nodal Rule

In a node, the sum of all currents is zero. In other words, at any node in an electrical circuit, the sum of the inflowing current is equal to the sum of the current flowing out of that node. Current is conserved and a stationary flow is attained at a node.

Kirchhoff's Voltage Law or Loop Rule

The sum of all voltages in any loop is equivalent to the sum of the potential drops in that loop. This means that whatever energy a charge Q starts within an electrical circuit, must be lost by the time the charge gets to the end. As each point on the circuit is characterized by unique potential value, any number of loops should have the same potential.

Example 1: So far we have become acquainted with the general physical principles which apply for the blood flow through the vascular system. Consider the heart as a node. In this case, the volume of blood that flows into the heart must equal the amount that flows out again. Since blood is not a "Newtonian fluid," based on the resistor, Kirchoff's rules apply as follows:

Kirchoff's first law, in connection with the vascular system of a human being, states that the flow resistances of all 'consecutively connected' blood vessels add up. Therefore, the overall resistance increases with the amount of consecutive blood vessels.

Kirchoff's second law states that the reciprocal value of the total resistance of parallel blood vessels is the result of the reciprocals of the individual resistors. The more parallel blood vessels there are, the more total resistance decreases.

Example 2: In a pulmonary embolism, a pulmonary artery or a pulmonary artery branch and therefore one of many parallel blood vessels is blocked and can no longer contribute to the reduction of the total flow resistance. Therefore, the total resistance of the pulmonary arteries increases (2nd Kirchhoff's law).

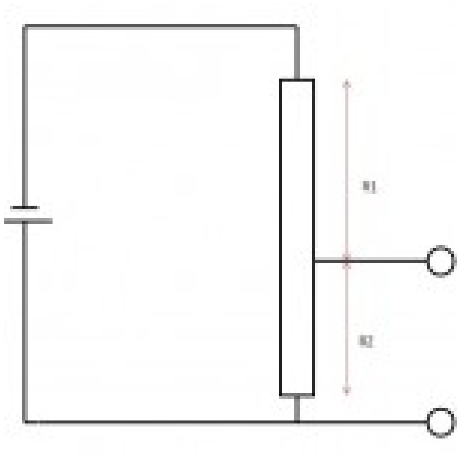
In the second part Electricity II, you will learn more about the alternating current AC.

Review Questions

The answers to the exam questions can be found below the references.

1. What is the value of U in the illustrated potentiometer circuit when R_1 = 600

Ohms, R_2 = 150 Ohms, and U_2 = 1.2 V?

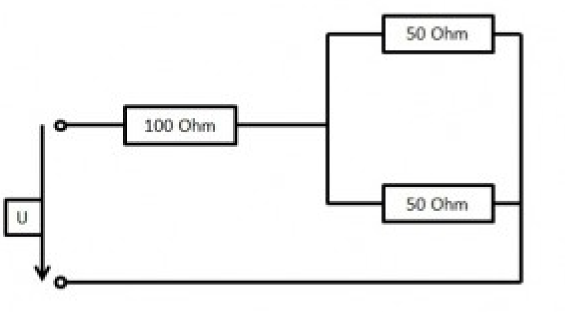


A. 0.9 V
B. 7.5 V
C. 6.0 V
D. 4.5 V
E. 3.0 V

2. On the terminals of a voltage source with an electromotive force of 8 V, a resistor of R = 100 Ohms is connected. On this external resistor, a voltage of 2 V is measured. How high is the internal resistance of this voltage source?

A. 60 Ohm
B. 100 Ohm
C. 200 Ohm
D. 300 Ohm
E. 400 Ohm

3. The power used in a 100 Ohm resistor of this circuit is 10 W. What would be the consumed power in any 50 Ohm resistor?



A. 1.25 W
B. 2.5 W
C. 5 W
D. 10 W
E. 20 W

References

Correct answers: 1C, 2D,3A

legal regulations see our legal information page.

Notes