FACULTY OF INFORMATION TECHNOLOGY department of intelligent systems

Electronics for Information Technology (IELe)

Introductory lecture

Basic concepts of electric circuits.
Direct current circuits.

Doc. Ing. Jiří Kunovský CSc.
Ing. Václav Šátek Ph.D.
Ing. Petr Veigend

22. 9. 2017

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- Introductions
- IELe course structure
- References, links
- Introductory lecture - Basic concepts of electric circuits. Direct current circuits.
- Group calculations – guided calculations,examples of SW usage and maybe, just maybe, we are going to see a magic trick ☺

1. Introductions

- Guarantee:

  Doc. Jiří Kunovský (long term hospitalized… ☹)

- Lecturers:
  - Dr. Václav Šátek (contact person satek@fit.vutbr.cz)
  - Ing. Petr Veigend

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- Laboratories:

  Ing. Petr Veigend

2. IELe course structure

- **Lectures** – every week (2 hrs/week).
- **Labs** – at the end of the semester (end of November 2017)
- **Half-term exam** – probably 3rd November
- **Final exam** – maybe preterm befor Christmas

2. IELe course structure

- Labs – 18 pts
- Term paper – 12 pts
- Half-term exam – 15 pts

- Final exam – 55 pts

Note: measurements and many calculations await you, be ready …

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3. References, links

- You can find everything important (lectures, book links, labs, additional info) on the IELe pages

http://www.fit.vutbr.cz/~kunovsky/erasmus/IELe/

- Course pages

http://www.fit.vutbr.cz/study/course-l.php.en?id=12152

Introductory lecture:

Basic concepts of electric circuits.

Direct current circuits.

Why learn electronics?

- Because almost everything that you use is electric
- In electronic devices, information is carried by electric charge, specifically by its presence, absence or size.
- IELe covers topics from physics, math and hardware.

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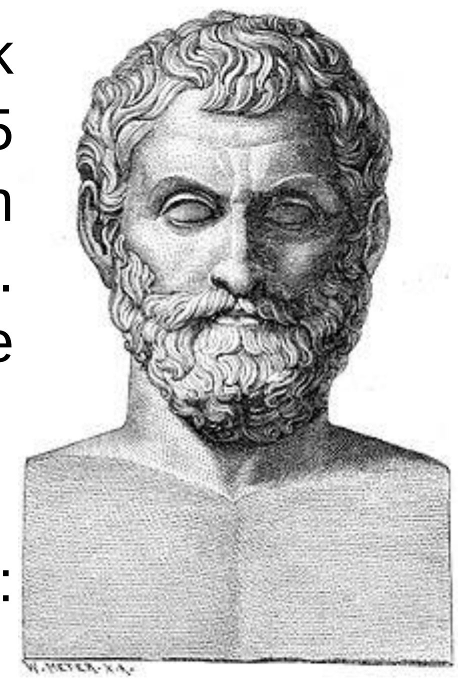
Electric charge

- Electricity discovered in antiquity. Greek philosopher **Thales of Miletus** (635-545 b.c.) discovered, that if we rub amber with woolen cloth, it attracts small light items. Amber in greek is called „elektrón“, so these phenomena were named electrical.



- Additional examples of electric charge: dry hair sticks to the hairbrush,

  rubbing of the ebonite rod (negative charge)

  rubbing of the glass rod (positive charge)

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Electric charge

- **Is the property of a particle or a body**, but also
- Physical **quantity**
- Charge **cannot exists** on its own, its **coupled** with a particle or a body.
- Charge can **create an force effect** with another charge -> electric field.
- Charge **cannot be created or destroyed** (law of the conservation of electric charge in the isolated system).

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Electric charge

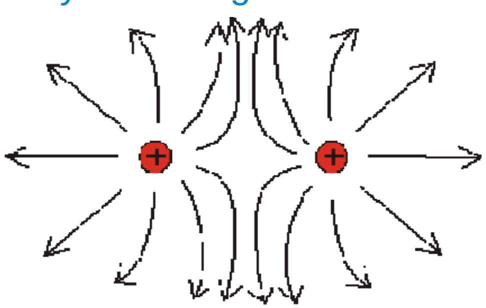
- **Phisical quantitity** called electric charge is usually denoted by ***Q*** or ***q***.
- The unit is **Coulomb** (**C**)
- The law of **quantization of the electric charge** – there is the smallest amount of the electric charge, that cannot be split further.
- It's the charge of an **elektron** or **proton** – an elementary charge e=1,602.10^{-19} C, $Q=n.e$, where n is an integer number.
- Electron has **negative charge**, proton has **positive charge** (according to convention).

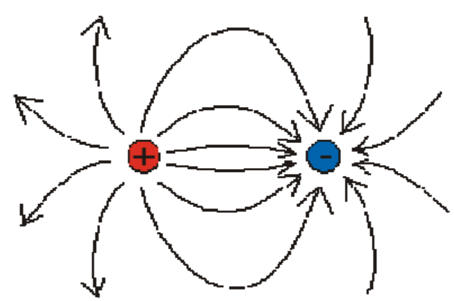
Electric field

- Electric charges **create the electric field in their vicinity**. The most important property of this field is its ability to **influence other nearby charges by force**.

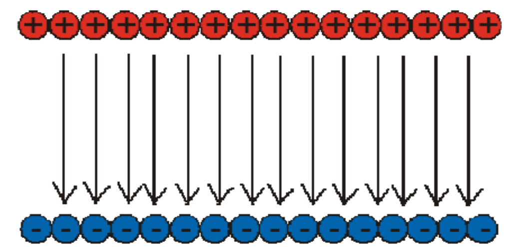
- Charges with the same polarity are **repulsed**, charges with opposite polarity are **attracted** to one another.

Field created by two charges





Homogenous electric field



Electric field

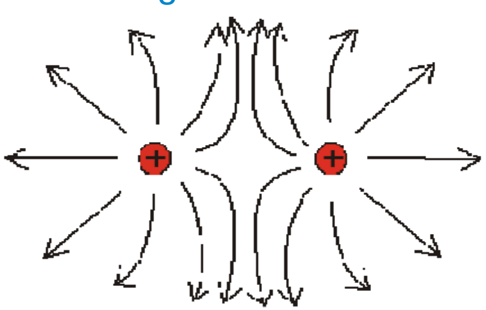
- **Lines of force**

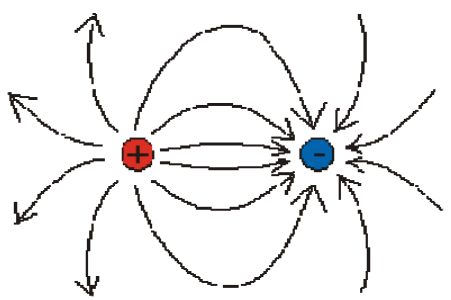
  - are imaginary lines, that have tangent in each point. This tangent is the vector of the intensity of the electric field

  - each place in space is crossed by **exactly one line**

  - they exit from the **positively** charged bodies and end in the **negatively** charged bodies

Field created by two charges





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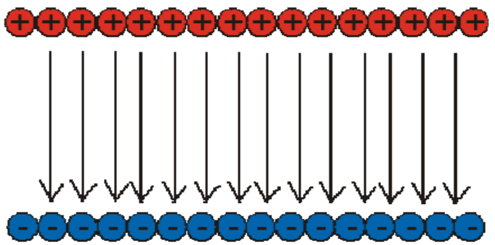
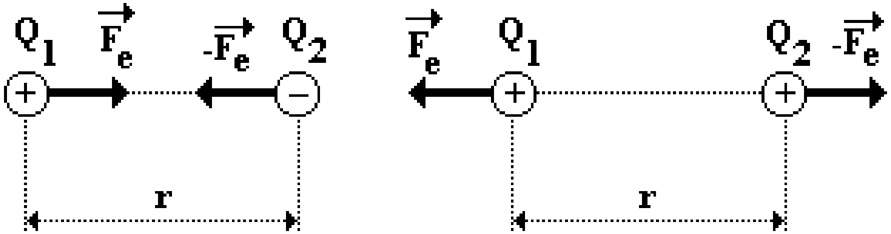


Electric field

Charles-Augustin de Coulomb (1736-1806)

- **Coulomb's Law:** The magnitude of the electrostatic force F of interaction between two point charges is directly proportional to the scalar multiplication of the magnitudes of charges Q_1, Q_2 and inversely proportional to the square of the distance between them.

$$F_e = \frac{1}{4\pi\varepsilon}\frac{|Q_1 Q_2|}{r^2}$$

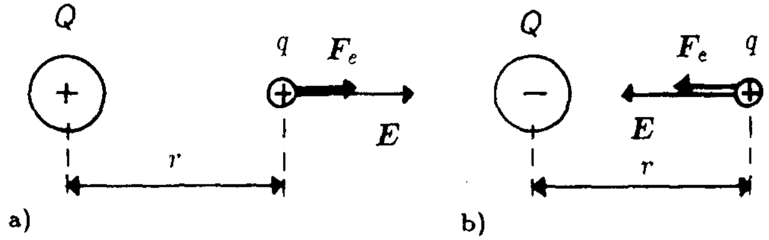


Intensity of the electric field

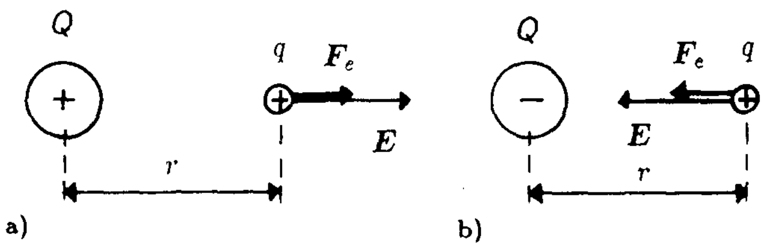
- The intensity of the electric field E can be calculated using the following formula:

$$\vec{E} = \frac{\vec{F}_e}{q}$$

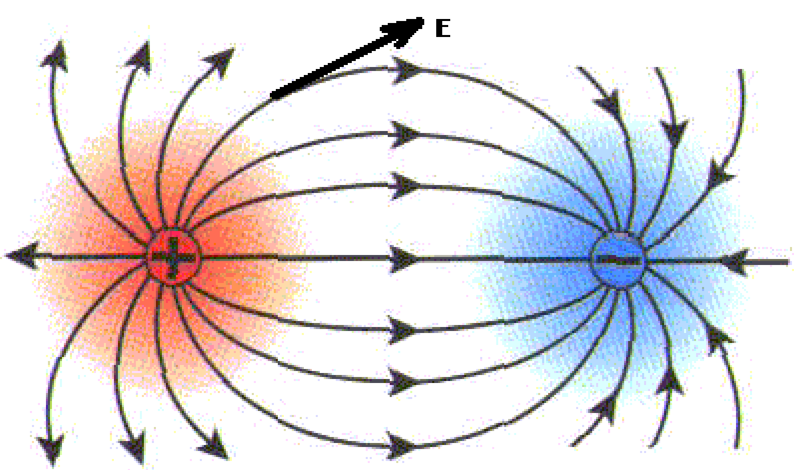
- Force F influences the charge q
- Unit: [V/m, N/C]



Intensity of the electric field



$$\vec{E} = \frac{\vec{F}_e}{q}$$



$$E = \frac{1}{4\pi\varepsilon}\frac{Q}{r^2}$$

Is charge practical for an engineer?

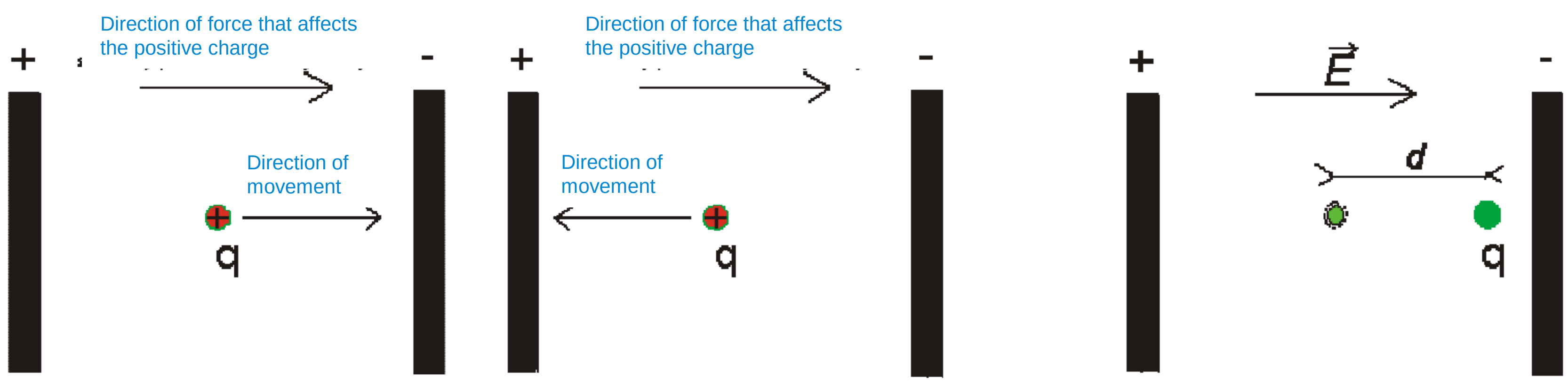
- **Tracking charges** and their interactions is key, but somewhat impractical. Lets leave that to physicists.
- **For us (future) engineers**, it's good to have a quantity, that can **easily describe** the behavior of individual components of the circuits
- These are **voltage** and **current**.

Electric voltage

- Can be calculated as a fraction of work, that the electric force does when moving the point charge.

$U = \frac{W}{Q}$, where $W = F \cdot d$ is work in the electric field. Let's substitute

$$U = \frac{F \cdot d}{Q} = E \cdot d$$



Potential energy of the charge decreases

Potential energy of the charge increases

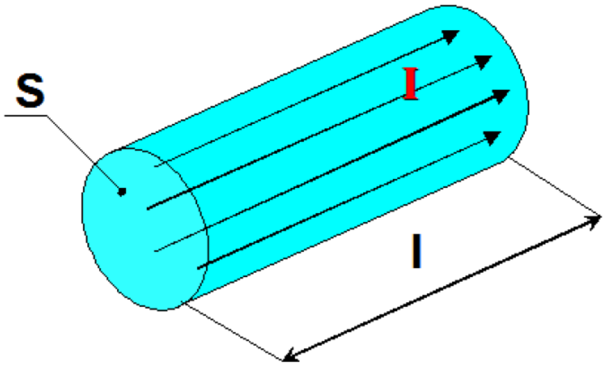
Electric voltage

- Voltage expresses the strength with which the electric field affects the charged particle.
- The trajectory of a particle doesn’t matter.
- It is a difference of electric potentials between two points.
- Ordinary notation U.
- Unit is Volt (abbreviation V).

Electric current

- It's defined as a **ordered movement of charges** in the electric field.
- Current value can be defined as a charge *dq*, that passes through the wire in some amount of time *dt*:

$$i = \frac{dq}{dt}$$



Electric current

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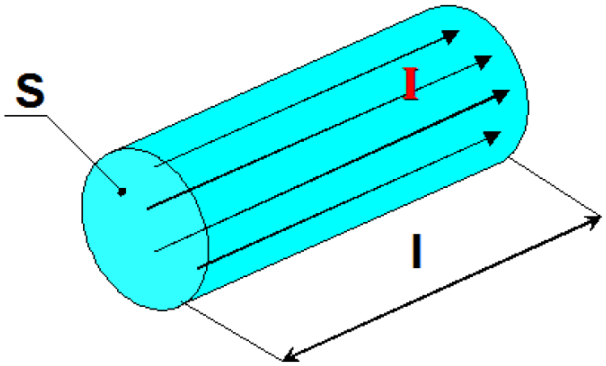
$$i = \frac{dq}{dt}$$

- Ordinary notation for current is I.
- The unit of current is Ampher [A].

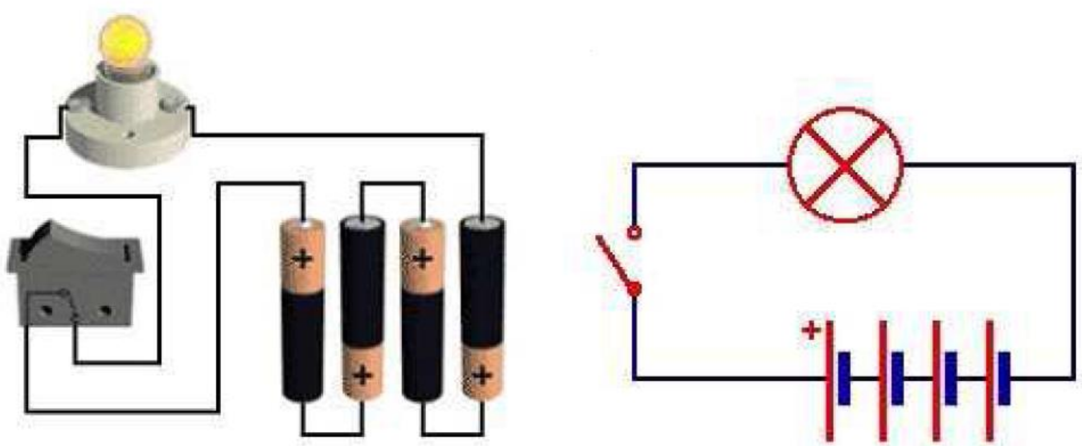


Conductors and insulants

- Primary division of matter in this course.
- **Conductors** allow for the creation of the electric current – they contain free charged particles, that can move through their crystal matrix.
- **Insulants** don’t have free charges.
- If we place the conductor to the electric field, movement of the free charges becomes organized (voltage)
- If we place an insulant to the electric field, nothing like that happens.

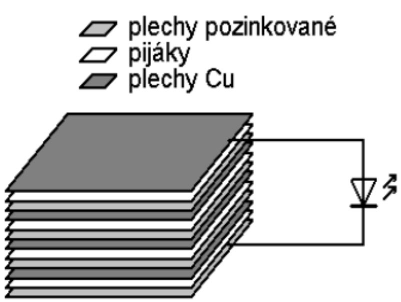
Electric circuit

- The system that consists of connected electronic parts.
- Abbreviated: **sources** + **loads** (appliances) + connecting cables **(**and **switches)**
- To make everything easier, let's assume that every part of the circuit is **ideal**.



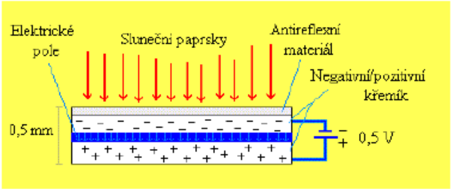
Active parts of el. circuits

- **Sources of energy**.
- Characterized by terminal voltage.
- *Real / ideal*

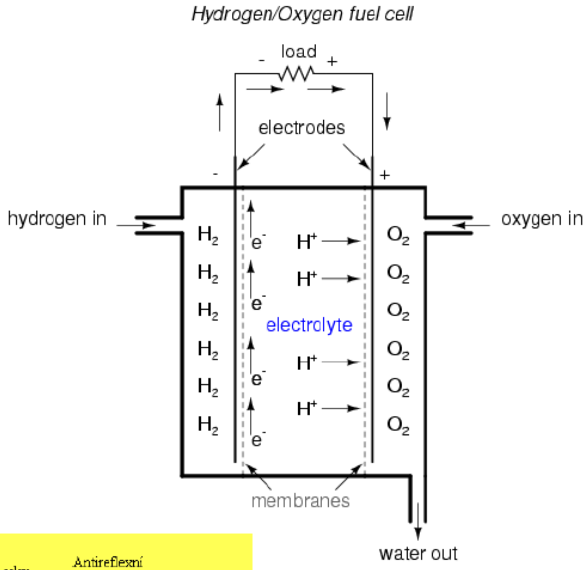


Voltaic cell

Battery

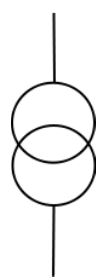


Solar cell

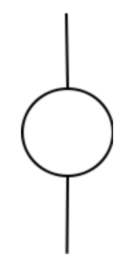


Active parts of el. circuits

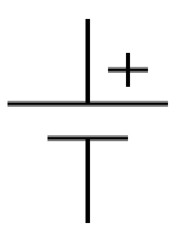
- **Sources of electric power**
- Characterized by terminal voltage.
- *Real / ideal   power supplies*
- *Current*

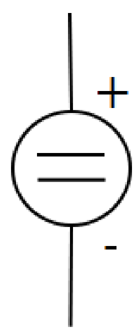


Voltage

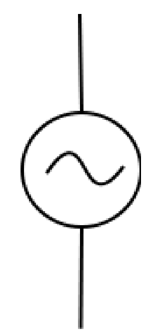


- *Direct current (DC)*





Alternating current (AC)

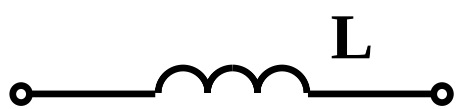


Passive parts of el. circuits

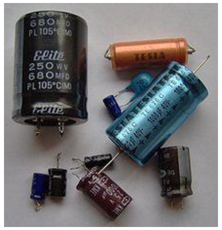
- **Consume** electrical power (change to heat, or work and energy accumulated in the magnetic and electric field)
- We define 3 **basic parts** with given **characteristics**:

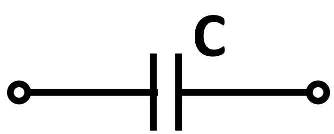
 - **resistor** with *resistance* parameter

- **inductor** with *inductance* parameter



- **capacitor** with *capacity* parameter

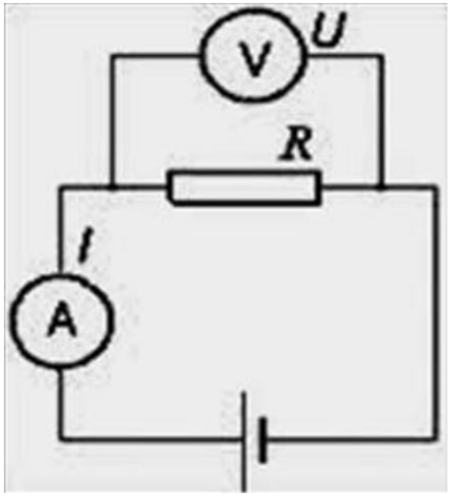




Measuring voltage and current

- Ampermeter – to measure current
  - connects in **series**

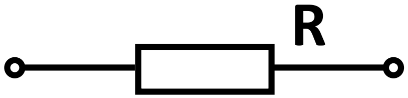
- Voltmeter – to measure voltage
  - connects in **parallel**



Resistances

Georg Simon Ohm (1789-1854)

- Cause resistance to the electric current
- Ideal part – ***resistor***



unit **Ohm** [Ω]

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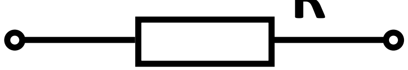
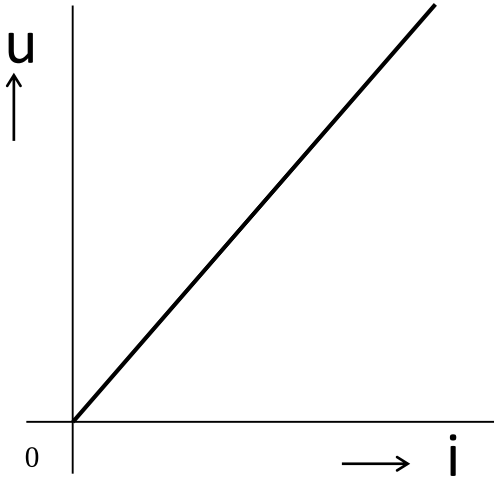


unit **Ohm** [Ω]

- The voltage on the resistor and current that flows through it are connected via the **Ohm's Law**

$$u = R \cdot i$$



Volt-Ampere characteristic of a resistor

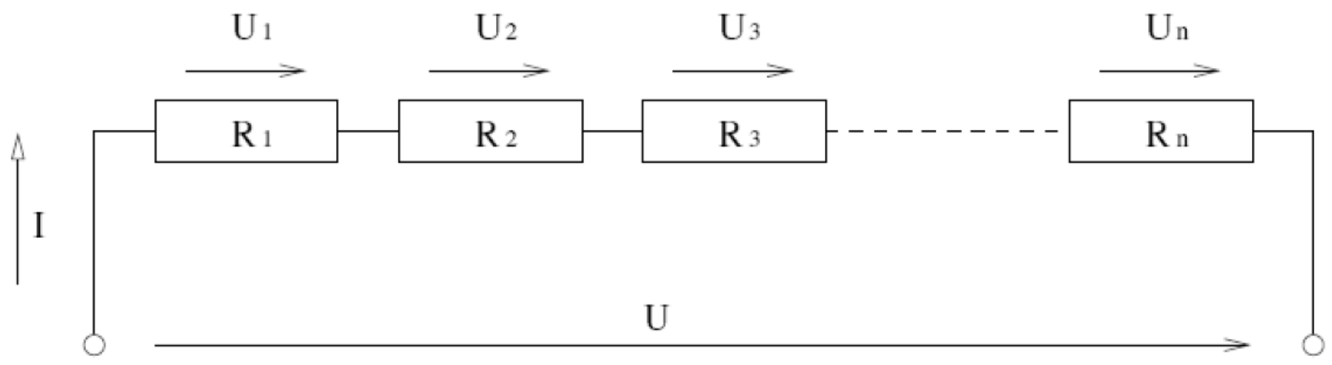
R= const. … linear resistor

Sometimes, it might be useful to use **conductivity**

$$G = \frac{1}{R}$$, unit **Siemens** [S]

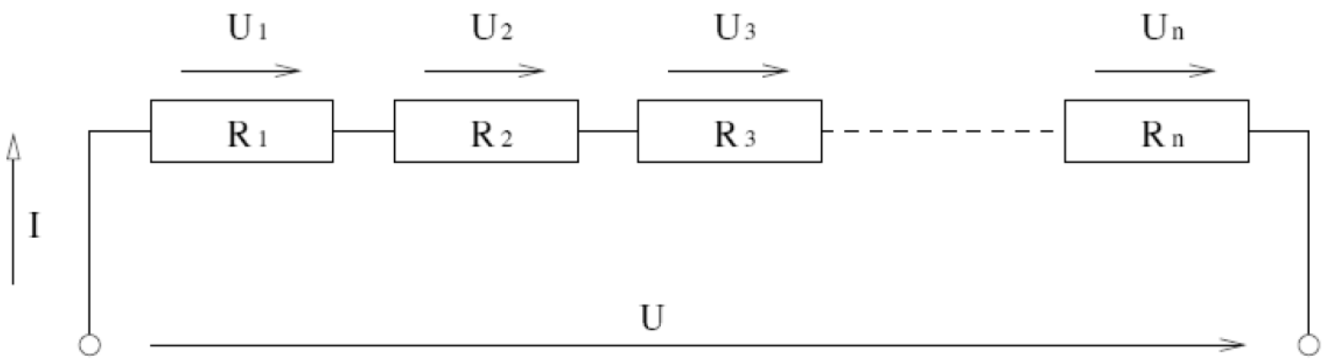
Resistances – connection

- **In series**



Resistances – connection

- **In series**

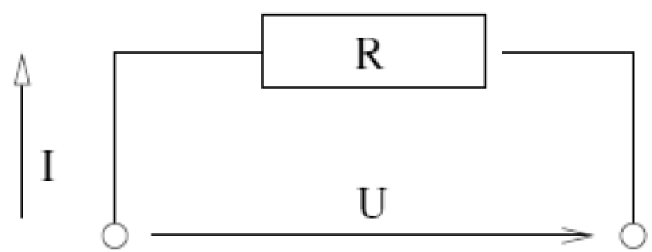


Is equivalent to the circuit below

- We can find the following formula in the "clever books"

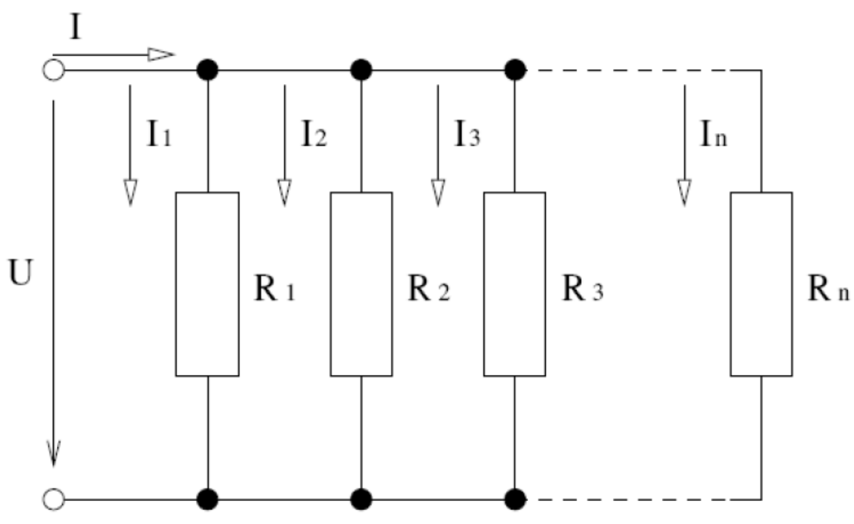
$$R = R_1 + R_2 + R_3 + \cdots + R_n = \sum_{k=1}^{n} R_k$$

or
$$\frac{1}{G} = \frac{1}{G_1} + \frac{1}{G_2} + \frac{1}{G_3} + \cdots + \frac{1}{G_n} = \sum_{k=1}^{n} \frac{1}{G_k}$$

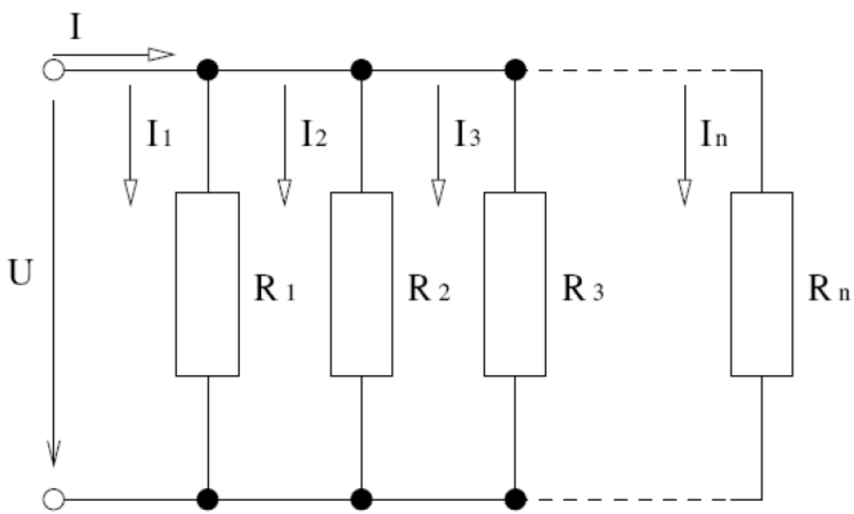


Can be derived from
II. Kirchhoff's law (later)

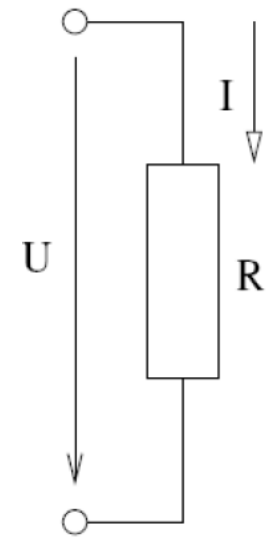
Parallel connection



Parallel connection



Is equivalent to



$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n} = \sum_{k=1}^{n} \frac{1}{R_k}$$

or $$G = \sum_{k=1}^{n} G_k$$

Can be derived from
I. Kirchhoff's law (later)

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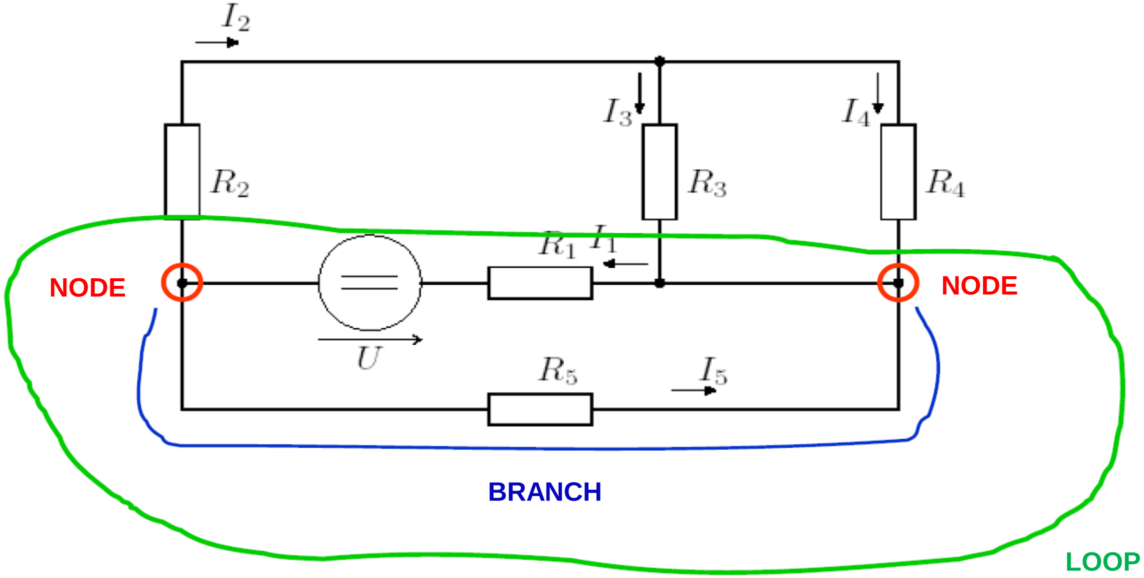
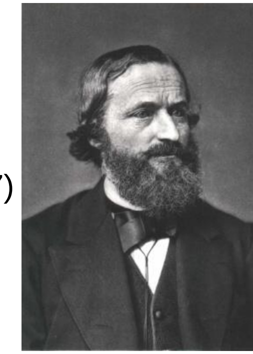
Topology of a electric circuit

- **Node** is a place where at least 3 wires meet
- **Branch** vis a conductive connection between two nodes
- **Loop** is the closed path in the circuit made from branches



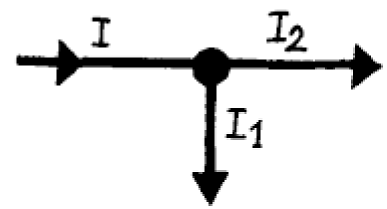
First Kirchhoff's law



Gustav Kirchhoff (1824-1887)

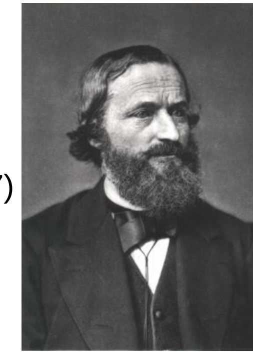
- *The algebraic sum of all currents in the node is equal to zero*

$$\sum_{k=1}^{n} I_k = 0$$



$$I = I_1 + I_2$$

First Kirchhoff's law



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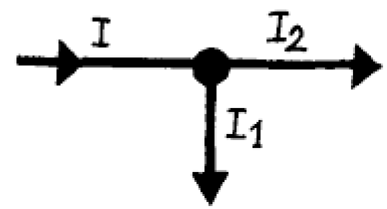


$$I = I_1 + I_2$$

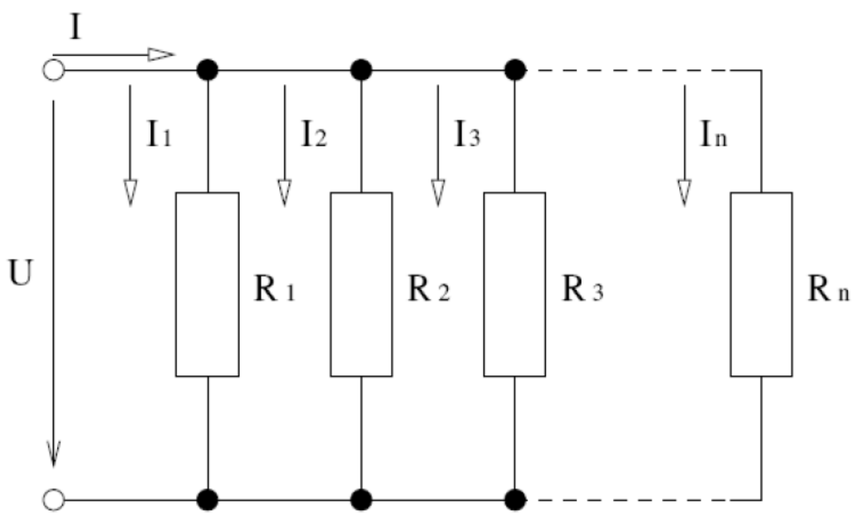
This equation requires, that some currents were considered as positive and some as negative.
Convention: currents that flow into the node are positive **+**
currents that flow out of the node are negative **-**

$$I - I_1 - I_2 = 0$$

It means that the number of electrons that enter and leave the node is the same in every time interval.

From the charge conservation law, we know that that the electrons can’t be created, destroyed or be stored at the node.

First Kirchhoff's law



$$I_1 = \frac{U}{R_1} = G_1 U$$

$$I_2 = \frac{U}{R_2} = G_2 U$$

$$I_3 = \frac{U}{R_3} = G_3 U$$

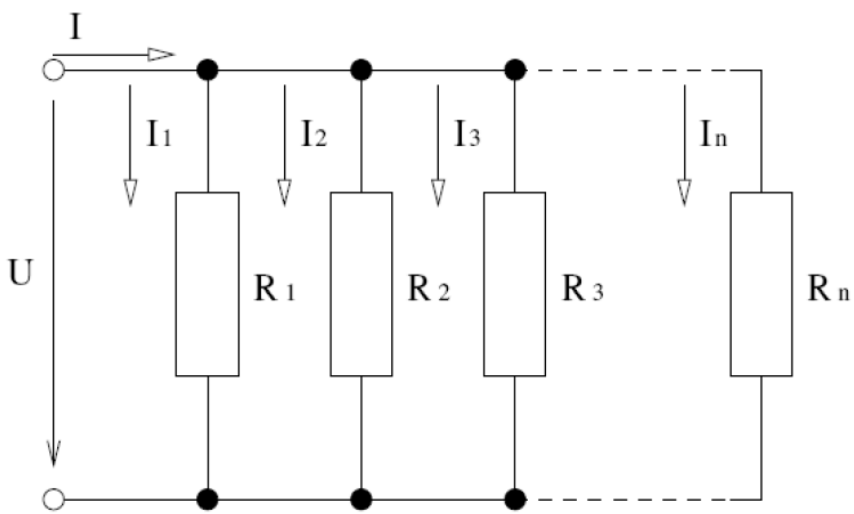
$$\vdots$$

$$I_n = \frac{U}{R_n} = G_n U$$

• On the resistors connected in parallel, the voltage is **the same**.

• The size of the current, that flows through the resistors, is **different** however. The size depends on the resistance/conductance parameter of the resistor (see Ohm's law)

First Kirchhoff's law

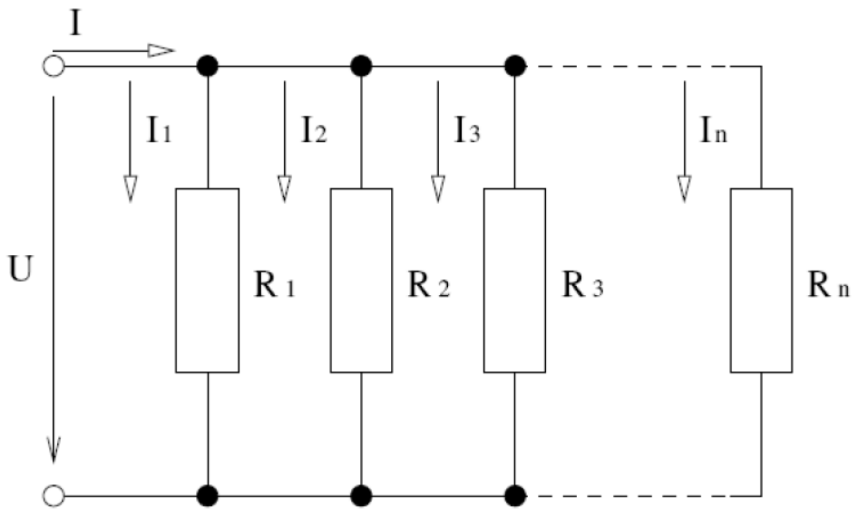


Using I. Kirchhoff's law

$$I = I_1 + I_{234\ldots n}$$
$$I_{234\ldots n} = I_2 + I_{345\ldots n}$$
$$I_{345\ldots n} = I_3 + I_{456\ldots n}$$
$$\vdots$$
$$I_{n-1n} = I_{n-1} + I_n$$

after the reverse substitution $$I = I_1 + I_2 + I_3 + \cdots + I_n$$

First Kirchhoff's law



Using I. Kirchhoff's law

$$I = I_1 + I_{234\ldots n}$$
$$I_{234\ldots n} = I_2 + I_{345\ldots n}$$
$$I_{345\ldots n} = I_3 + I_{456\ldots n}$$
$$\vdots$$
$$I_{n-1n} = I_{n-1} + I_n$$

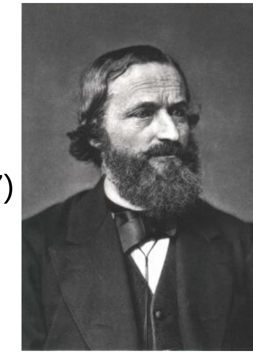
after the reverse substitution $I = I_1 + I_2 + I_3 + \cdots + I_n$

We can substitute for currents $I_k = \dfrac{U}{R_k}$ and receive final equation $I = U\left(\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \cdots + \dfrac{1}{R_n}\right)$

Overall resistance $\dfrac{1}{R} = \sum_{k=1}^{n} \dfrac{1}{R_k}$

This equation should already be somewhat familiar… ☺

Second Kirchhoff's law



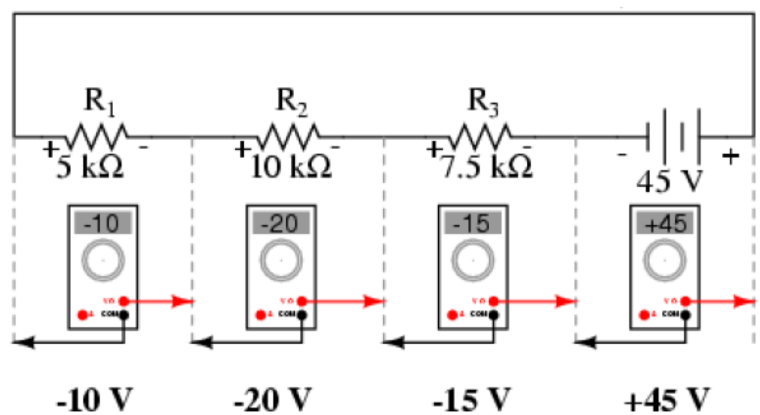
Gustav Kirchhoff (1824-1887)

- *The algebraic sum of all voltages (potential differences) in the loop is equal to zero*

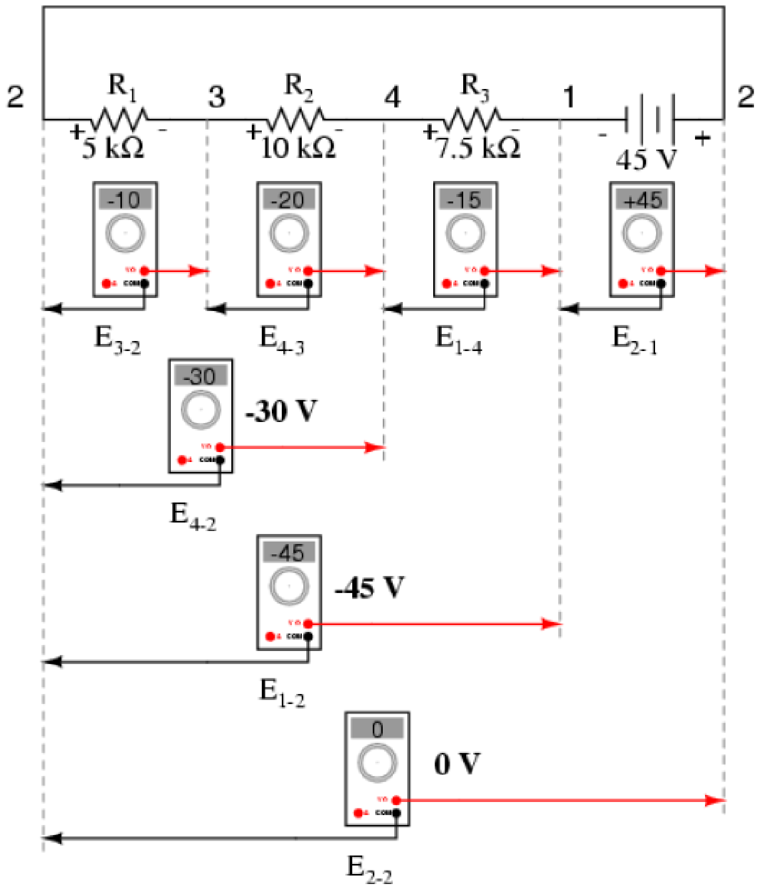
$$\sum_{k=1}^{n} U_k = 0$$

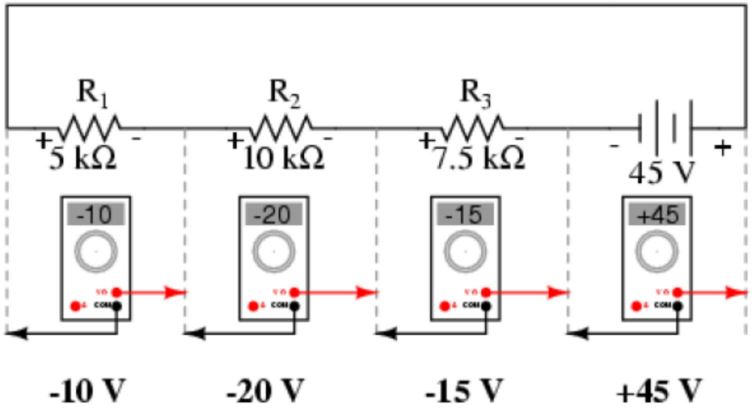
Note that the voltages are both voltages of all voltage sources and all connected appliances.

- This means, that the voltage that the source supplies to the loop has to appear on the appliances.

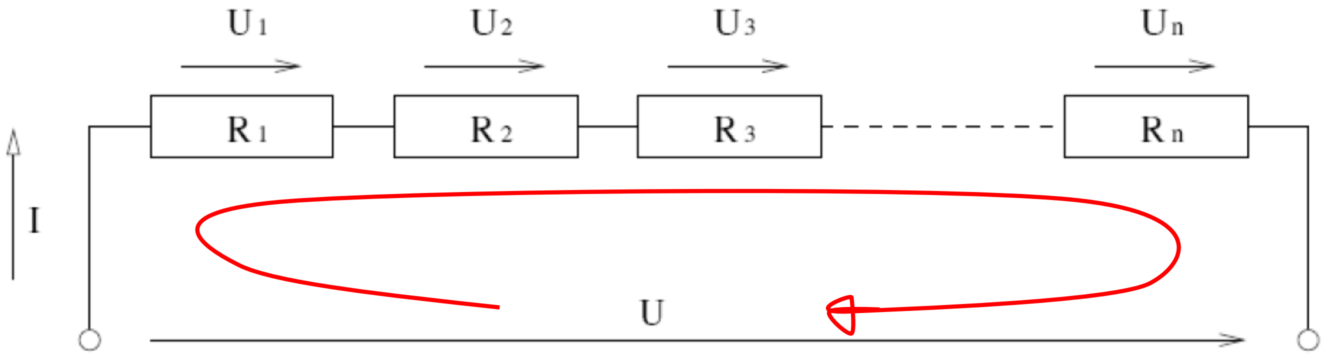


Second Kirchhoff's law





Second Kirchhoff's law



$$U_1 = IR_1 = \frac{I}{G_1}$$

$$U_2 = IR_2 = \frac{I}{G_2}$$

$$U_3 = IR_3 = \frac{I}{G_3}$$

$$\vdots$$

$$U_n = IR_n = \frac{I}{G_n}$$

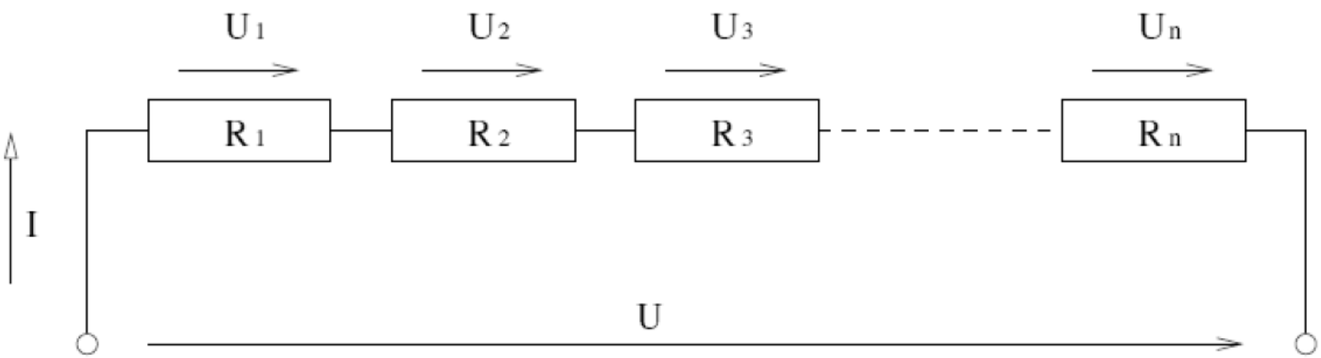
$$\sum_{k=1}^{n} U_k = 0$$

$$U_1 + U_2 + U_3 + \cdots + U_n - U = 0$$

• Through resistors connected in series flows an **equal current**.

• On the individual resistors, the voltage is different. This difference is caused by different resistance/conductance of a resistor.

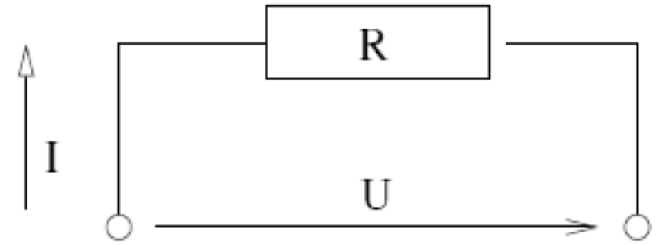
Second Kirchhoff's law



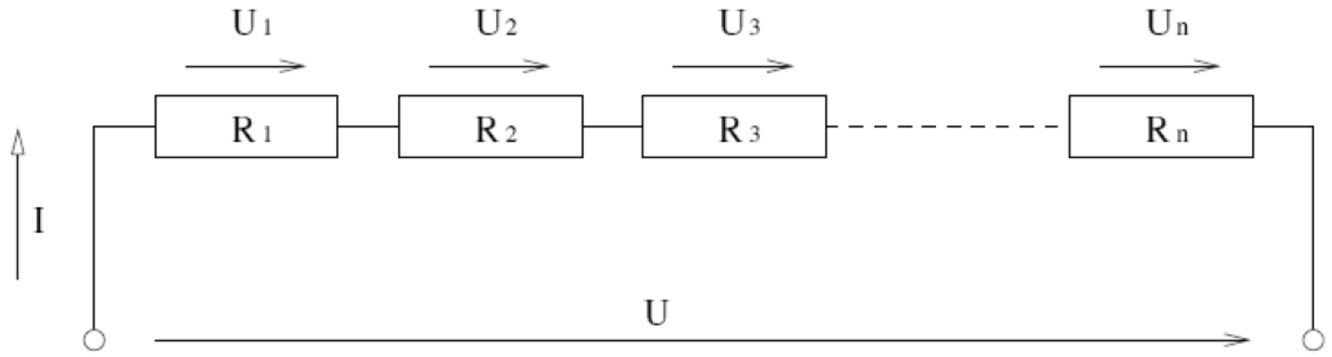
$$U = U_1 + U_2 + U_3 + \cdots + U_n$$

$$U = IR_1 + IR_2 + IR_3 + \cdots + IR_n$$

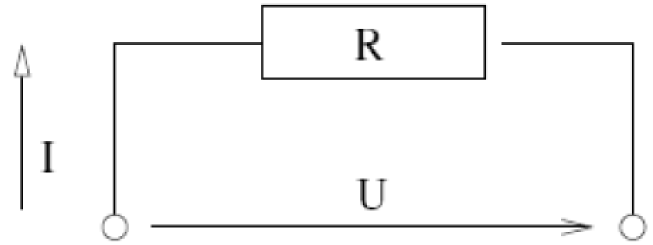
$$U = I(R_1 + R_2 + R_3 + \cdots + R_n) = IR$$



Second Kirchhoff's law



$$U = U_1 + U_2 + U_3 + \cdots + U_n$$
$$U = IR_1 + IR_2 + IR_3 + \cdots + IR_n$$
$$U = I(R_1 + R_2 + R_3 + \cdots + R_n) = IR$$



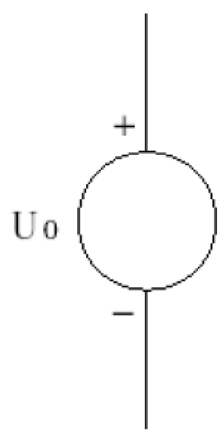
Overall resistance

$$R = \sum_{k=1}^{n} R_k$$

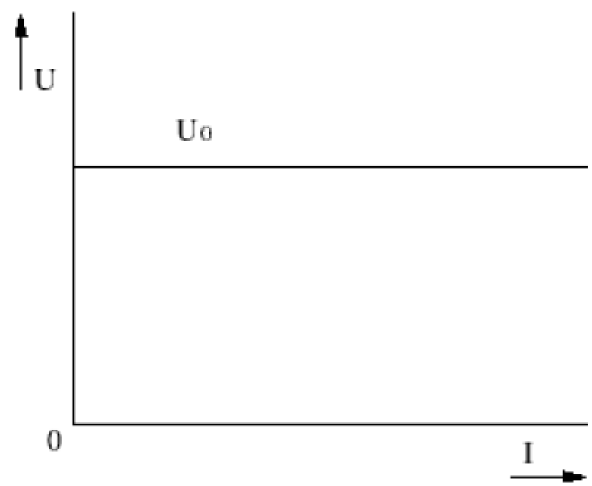
And again, we should already have this equation memorized… ☺

And let’s not forget about sources…

- **Ideal voltage source** – terminal voltage does not depend on load



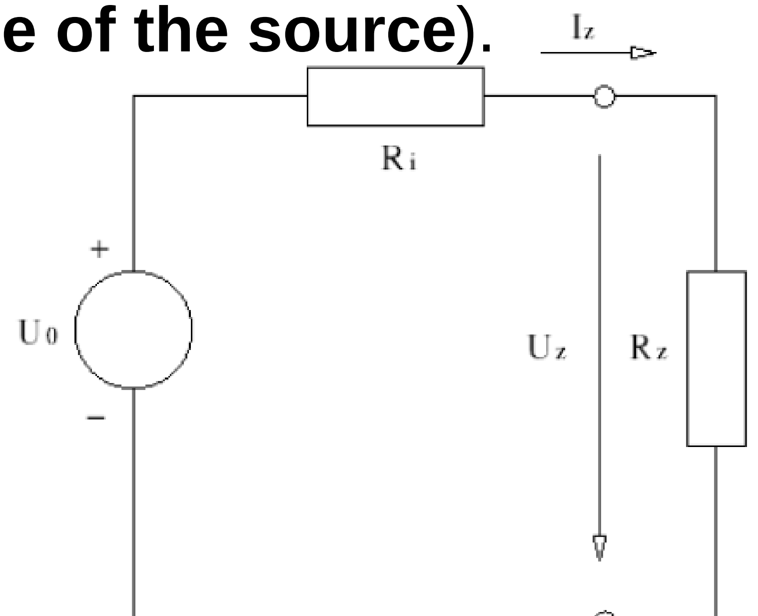
Schematic symbol



Volt-Amphere characteristic

Real voltage source

- With real voltage sources, the terminal voltage **decreases with load** (because some part of the source's voltage is used to overcome the resistance of the environment between the positive and negative electrode – **internal resistance of the source**).



$$I_Z = \frac{U_0}{R_i + R_z} \qquad U_Z = U_0 - R_i I_Z$$

$$U_Z = \frac{R_i}{R_i + R_z} U_0$$

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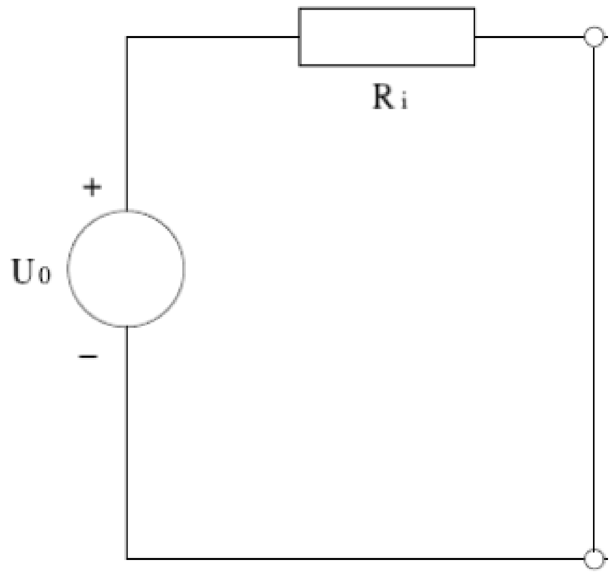
Short

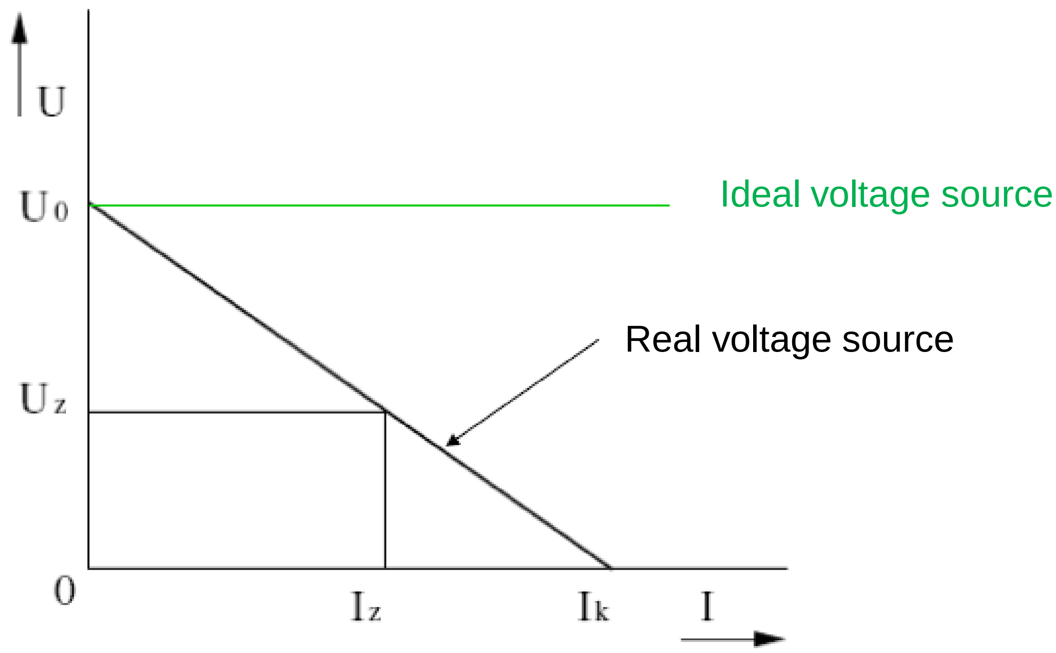
- What would happen, if we would connect the output terminals **shortly** (so $R_Z = 0\Omega$)?
- The size of current that flows through the circuit is quite large:

$$I_k = \frac{U_0}{R_i}$$



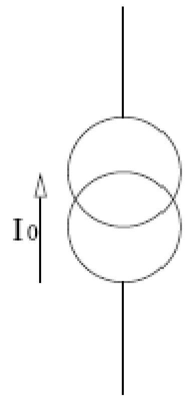
Load characteristic

- The more current is extracted from the source, the smaller the terminal voltage usually is.

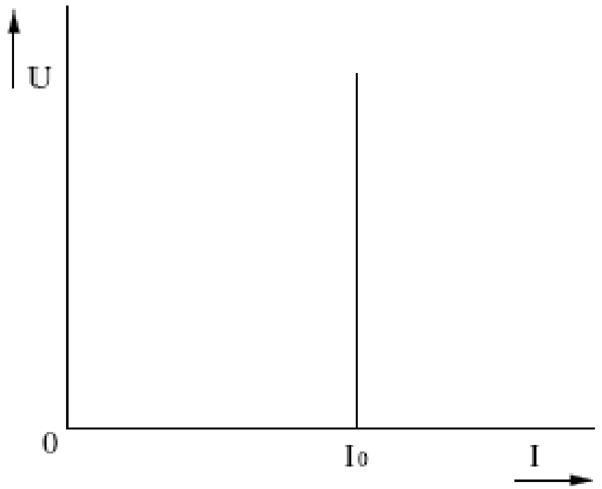


Ideal current source

- Is the source that supplies the **same amount of current**, independent of the load.
- Note: Terminal voltage changes with load (Ohm's law has to apply).



Schematic symbol

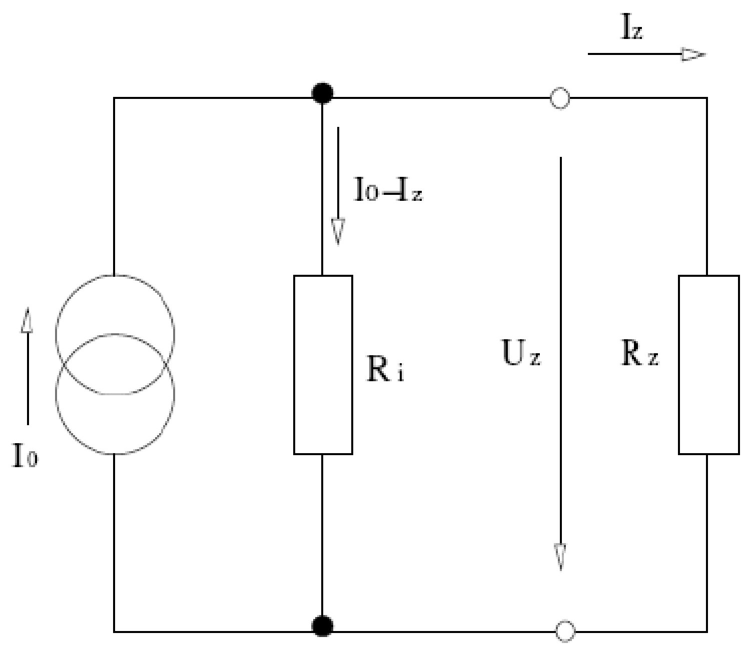


Volt-Amphere characteristic

Real current source

- Real source can be modelled by combining “ideal voltage source” + “internal resistance” in **series** or by combining “ideal current source + internal resistance” in **parallel**.

$$U_Z = R_i(I_0 - I_Z)$$



• Note that the load characteristic is the same for both models.

Demo

- Let’s start with some computations in electric circuits… ☺