Physics 2. Electrical and Electronic Circuits

Introduction. Resistors

Igor Gaponov

Professor, Institute of Robotics and Computer Vision

INNOPOLIS UNIVERSITY

Objectives

The main objectives of today's lecture are:

- Review the basic concepts of **conductivity**
- Review the concept of **electric current**
- Study **resistance and resistors**

Atoms (1)

An **atom** is a basic unit of matter that consist of nucleus surrounded by a cloud of negatively charged electrons.

The atomic nucleus contains a mix of

- **positively** charged **protons** and
- electrically **neutral** **neutrons**.

Orbiting the nucleus are the **negatively** charged **electrons**.

Some facts about atoms:

- The number of electrons is always equal to the number of protons
- Their number depends on the element
- Typical atom size is 0.1-0.5 nm, while the nucleus' size is typically 5 orders smaller than that.

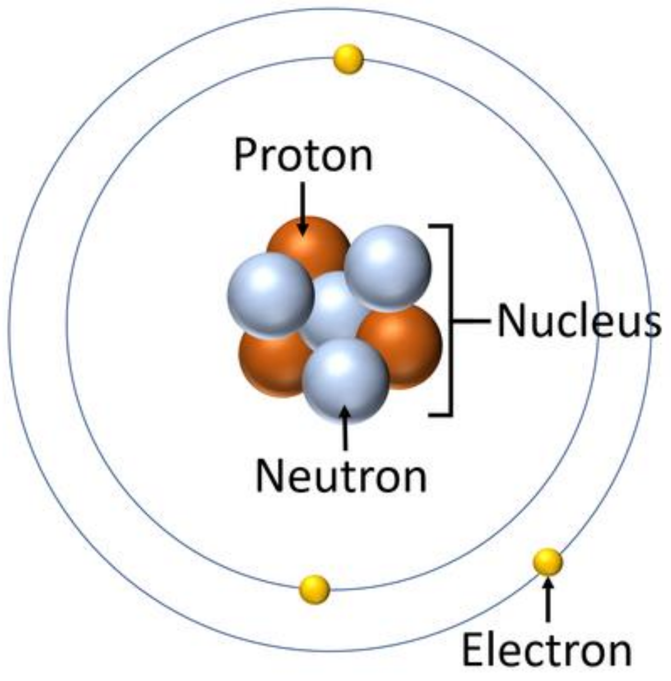
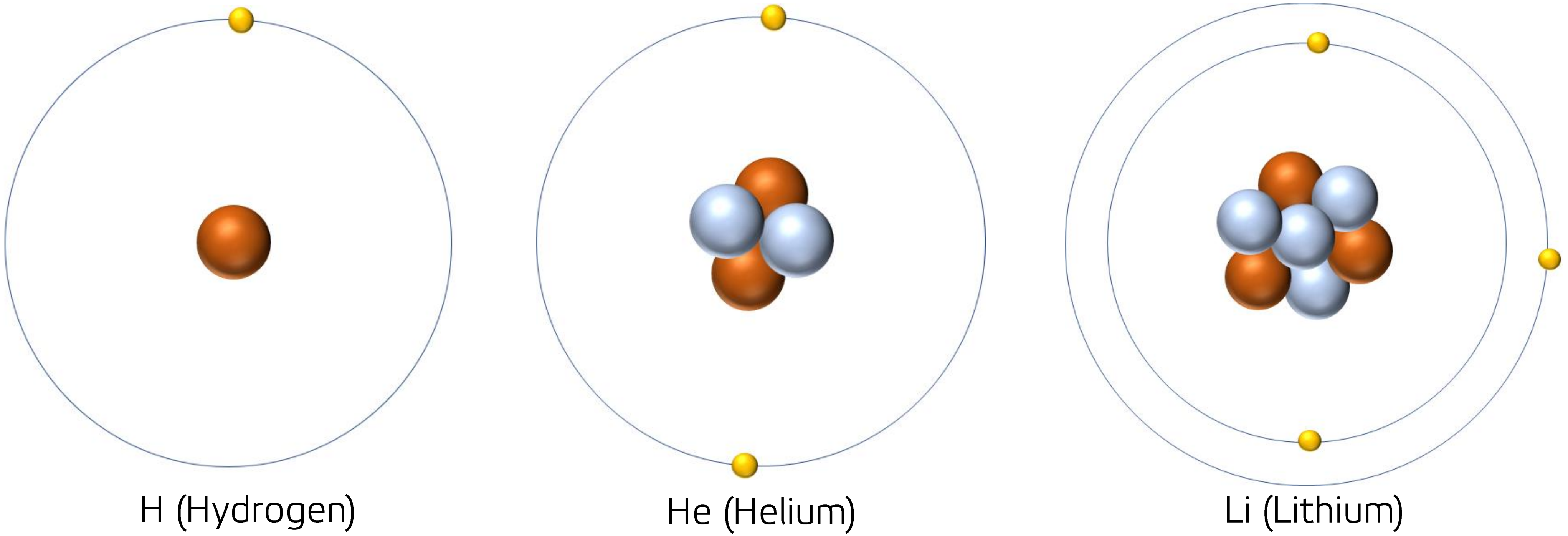


Image credit: Key stage wiki

Atoms (2)

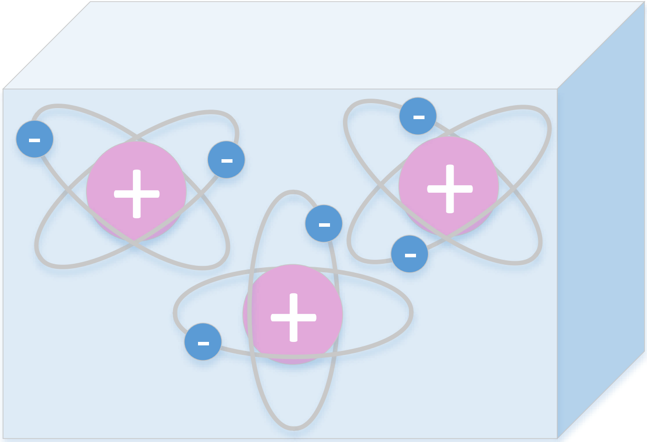
The simplest atom is that of **Hydrogen** (1 proton, 1 electron, no neutrons), followed by Helium (2-2-2), Lithium (3-3-4) and so on and so forth.



Diagrams of different atoms
[(Image credit: Key stage wiki)]

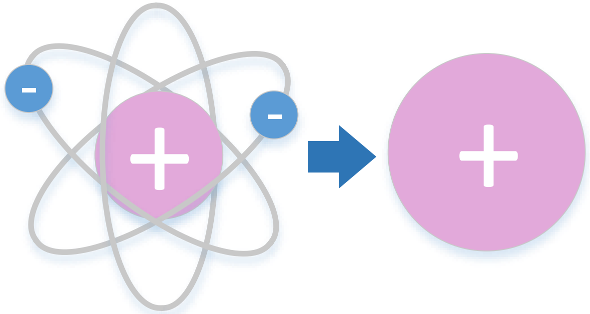
Electric Charge (1)

Assume you have a bulk of some material that contains many atoms (6×10^{23} per mole).

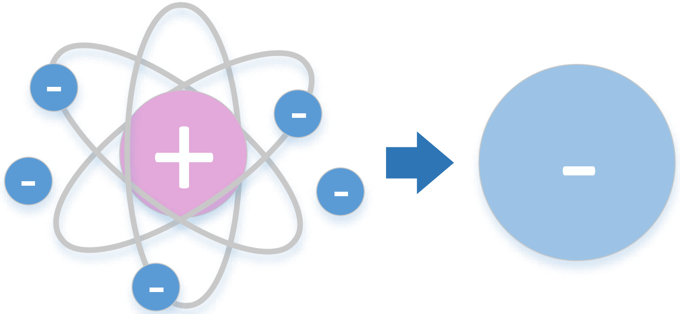


Atoms that have either a deficit or a surplus of electrons are called **ions**.

- If there is an excess of positive ions in a bulk of material, its **net charge** Q will be positive, and vice versa.
- Electric charge is measured in coulomb [C].



Positive ion

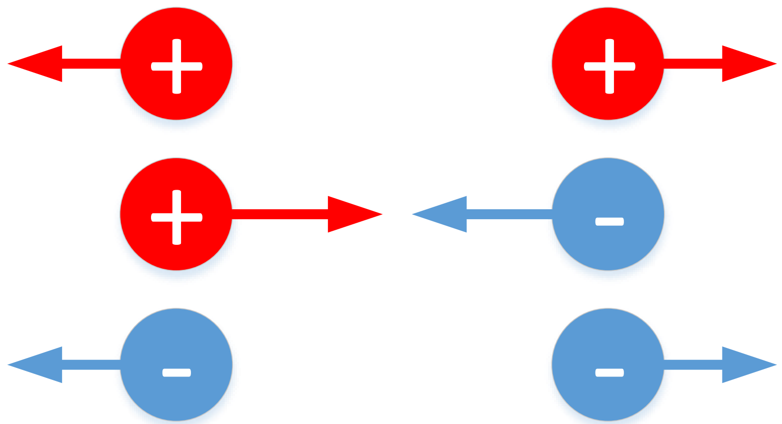


Negative ion

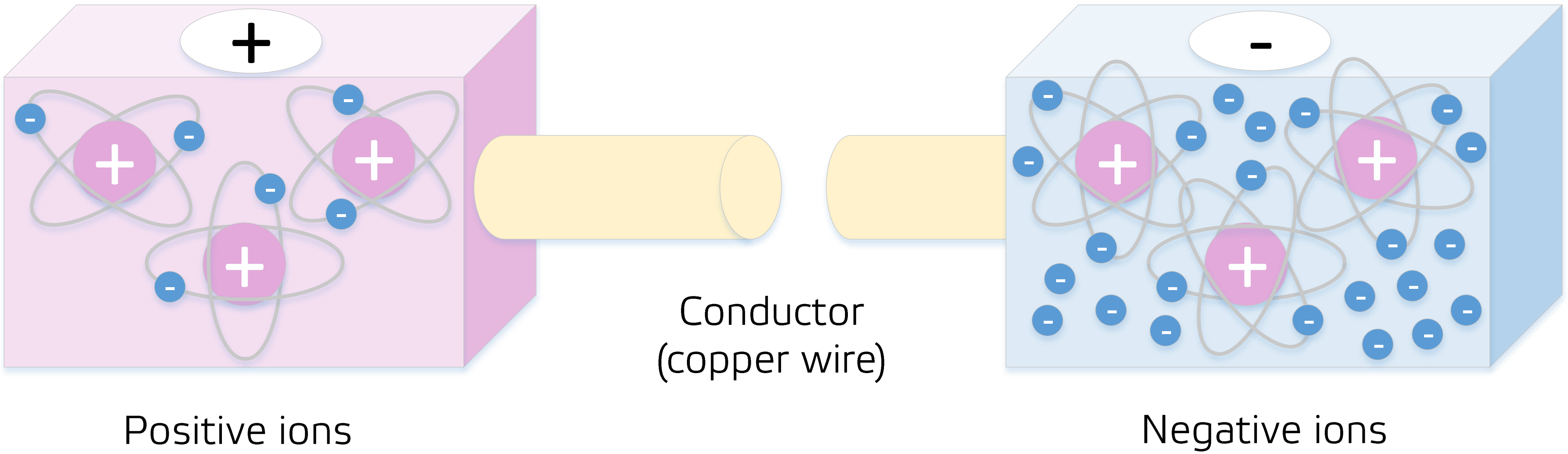
Electric Charge (2)

INNOPOLIS UNIVERSITY

Particles of the same (like) charge repel each other, while particles of **opposite (unlike) charge attract each other**.

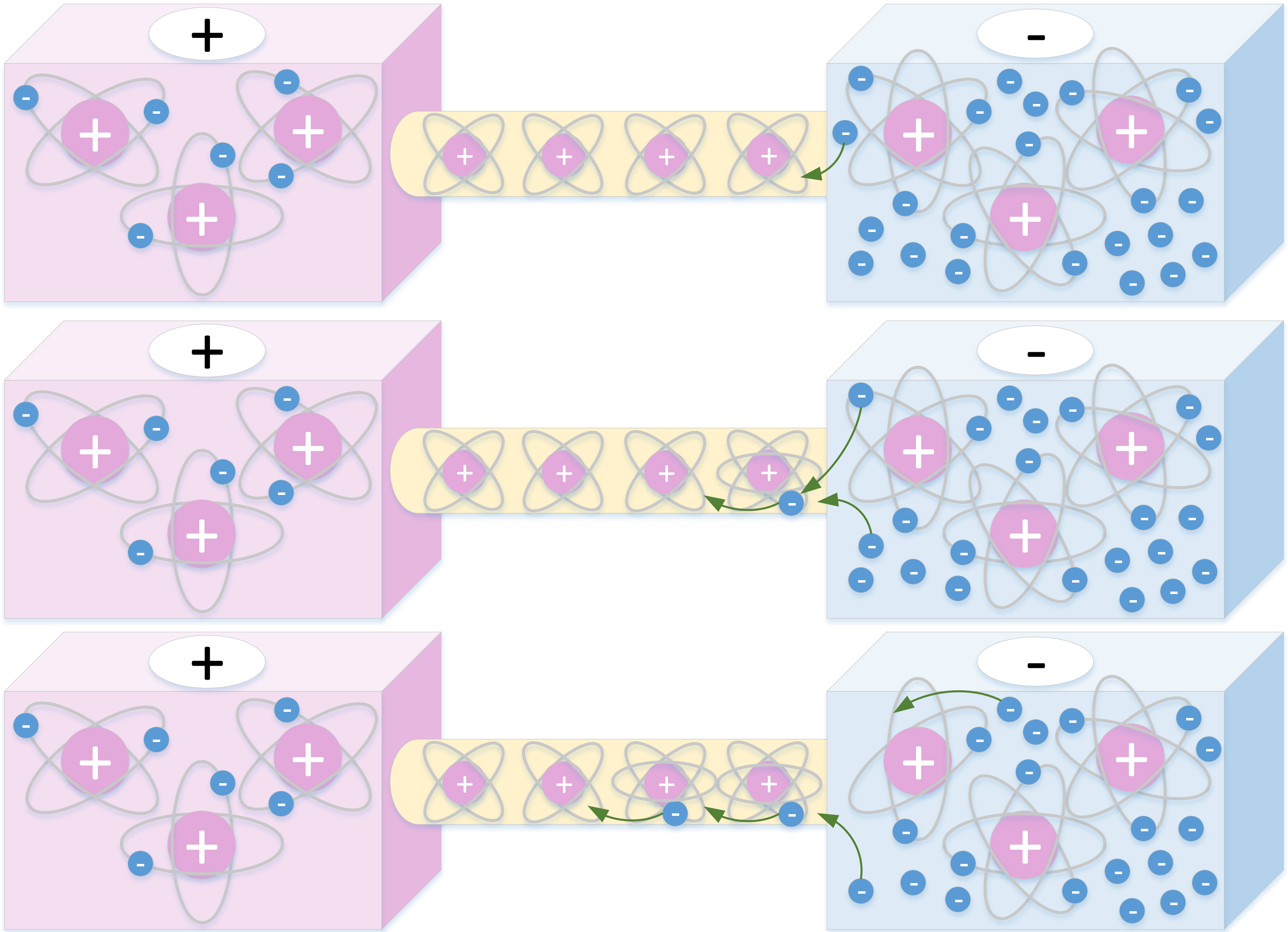


Assume you have 2 pieces of some material with positive and negative net charges, and you connect them with a conductive wire.

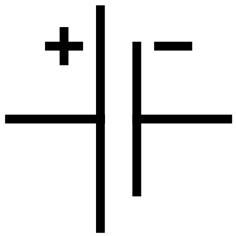


Electric Charge (3)

INNOPOLIS UNIVERSITY



There is a difference in charge levels (**electric potential**)!



Electric Current (1)

Electric **charge can be carried** by subatomic particles, typically – by **moving electrons**.

The stream of such charged particles is called by **electric current** (think water current).

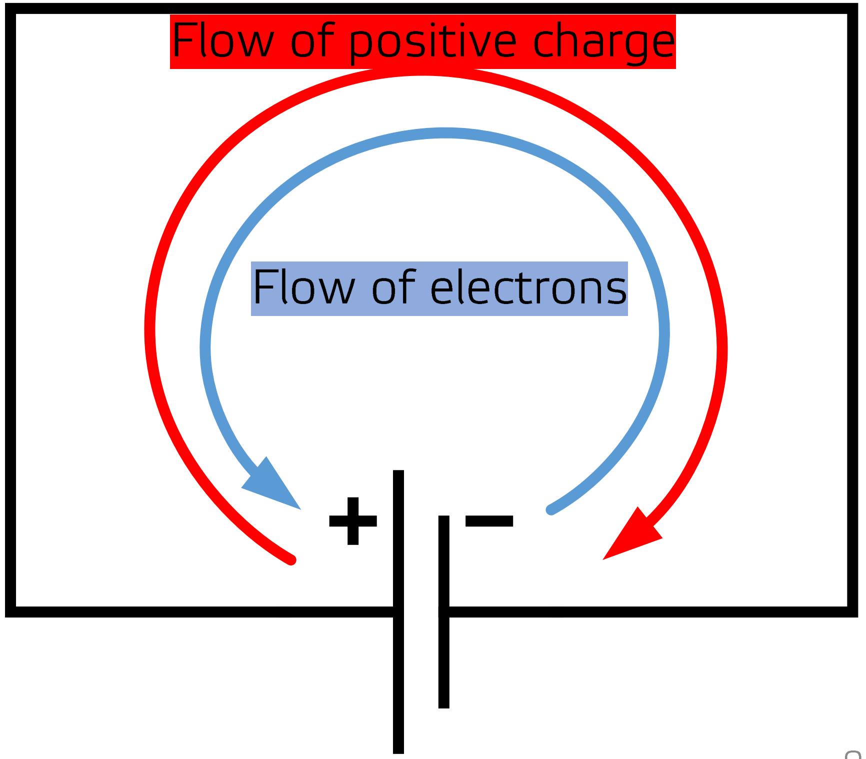
More precisely,

- **Electric current** is the rate of flow of electric charge Q in a region over time t: $I = \dfrac{Q}{t}$
- Notation: I
- Unit: Ampere [A] (*coulomb per sec*)

Electric Current (2)

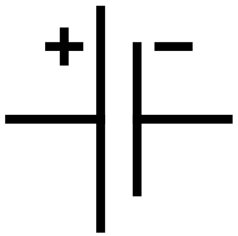
In metals, which are typically used as a conductive material, the positively charged nuclei are held in a fixed position, while the negatively charged electrons can move freely about and carry the charge.

- A flow of positive charges gives the **same electric current**, and has the same effect in a circuit, as an equal flow of negative charges in the opposite direction.

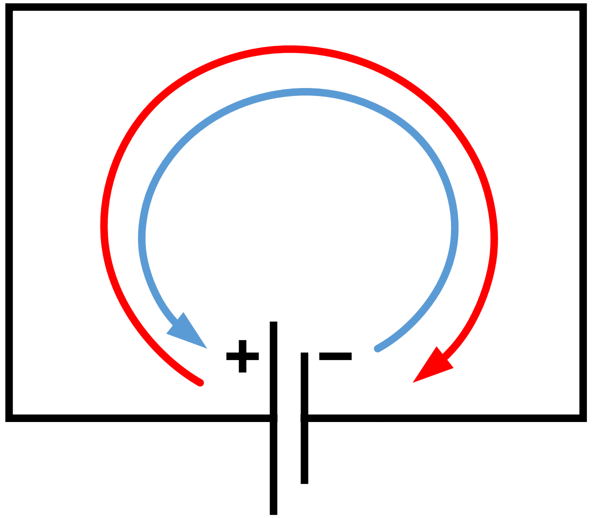


Electric Voltage

Electric voltage is the **difference** in electric potential between two points.



- Notation: V
- Unit: Volt [V]
- The voltage between two points is a short name for the **electrical driving force** (electromotive force: emf) that could determine an electric current between those points.



Electrical Resistivity (1)

The **electric resistivity** and its inverse, **electrical conductivity**, is a fundamental property of a material that quantifies how **strongly it resists** or conducts electric current.

Various materials have different resistivity and conductivity (shown here for 20 ^0C).

Material	Resistivity, ρ	Conductivity
Silver	1.59×10^{-8}	6.30×10^{7}
Copper	1.68×10^{-8}	5.96×10^{7}
Gold	2.44×10^{-8}	4.11×10^{7}
Calcium	3.36×10^{-8}	2.98×10^{7}
Carbon (graphite)	3.10×10^{-3}	3.3×10^{2}
Sea water	2.00×10^{-1}	5
Diamond	10^{12}	10^{-12}
Rubber	10^{13}	10^{-13}
PET	10^{21}	10^{-21}
Teflon	10^{24}	10^{-24}

Electrical Resistance

The **electric resistance** of an electrical element measures its **opposition** to the passage of an electric current.

- Notation: R
- Unit: Ohm $[\Omega]$
- The reciprocal quantity is **electrical conductance** (the ease with which an electric current passes).
- Electrical resistance is a function of conductor's volumetric properties:

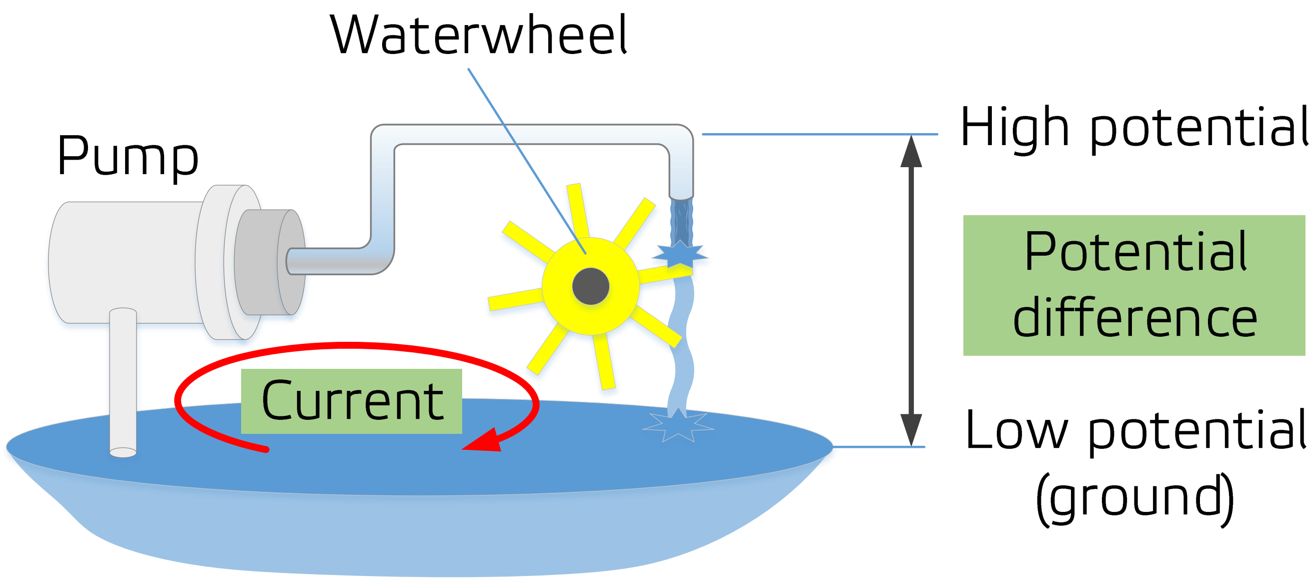
$$R = \rho \frac{l}{A}$$

where ρ is electrical conductivity, l is the length of conductor and A is its cross-sectional area.

Electricity and Mechanics (1)

A simple analogy for an electric circuit is **water flowing** in a closed circuit of pipework, driven by a mechanical pump. This can be called a **water circuit**.

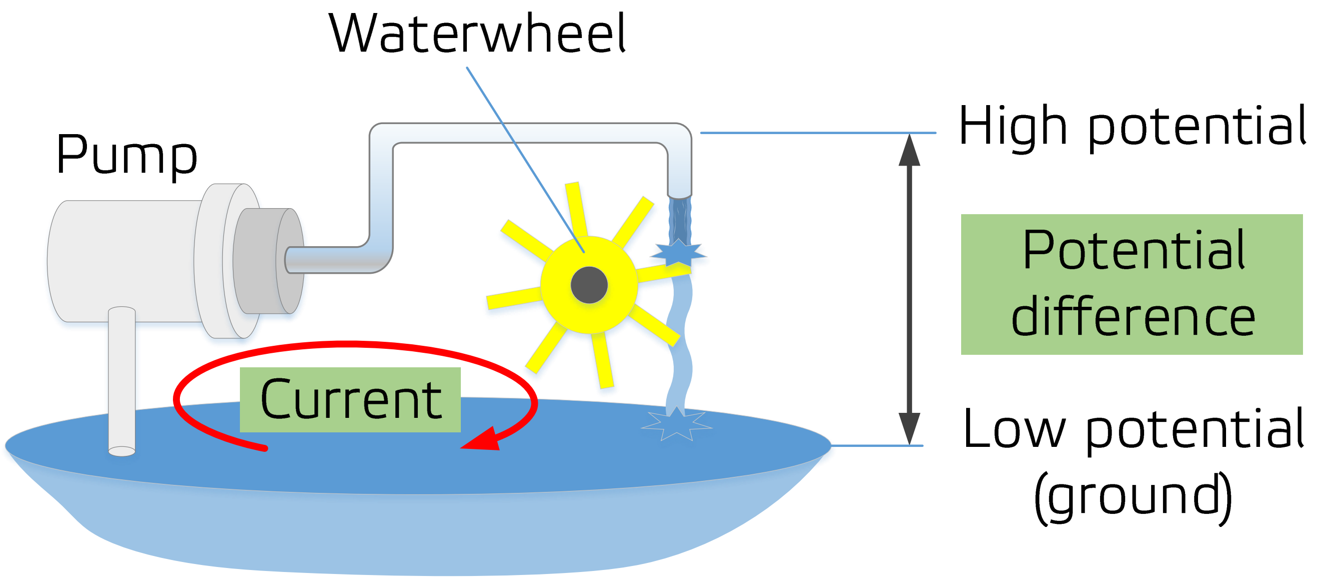
- **Potential difference** between two points corresponds to the water pressure difference between two points.

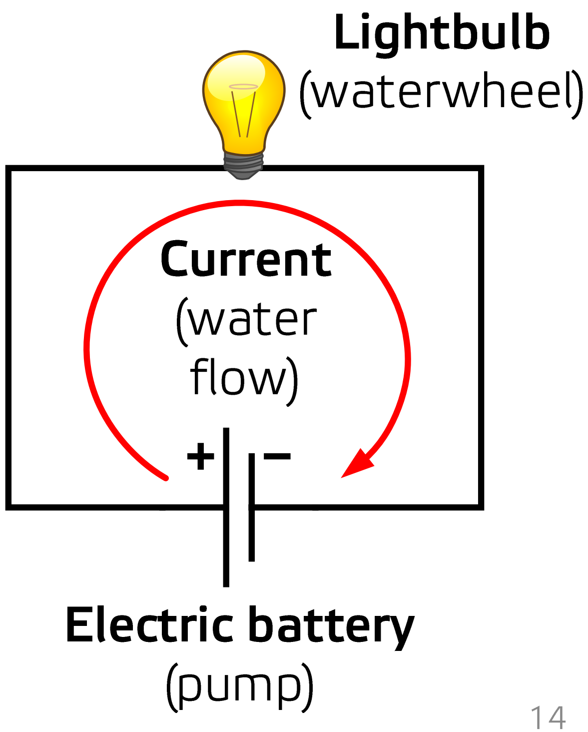


Electricity and Mechanics (2)

If there is a water pressure difference between two points, then

- the water flow (created by the pump) from the will be able to **do work**, such as spinning the waterwheel.
- In a similar way, work can be done by the electric current driven by the potential difference due to an electric battery.



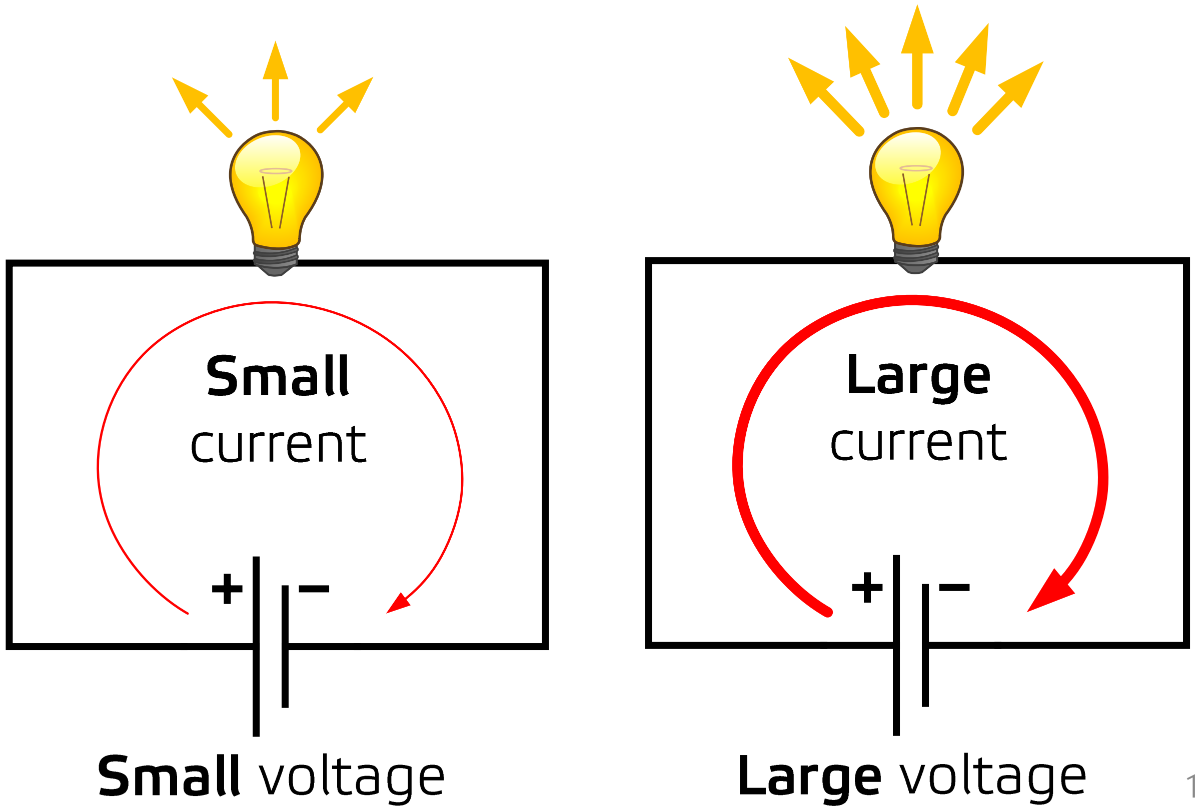


Electric Circuits (1)

INNOPOLIS UNIVERSITY

When you arrange electrical components forming the network in such a way that it has a closed loop, giving a return path for the current, this network is called **an electrical circuit**.

- Researchers discovered that **increasing the voltage** in a simple circuit shown here resulted in **increased current**.



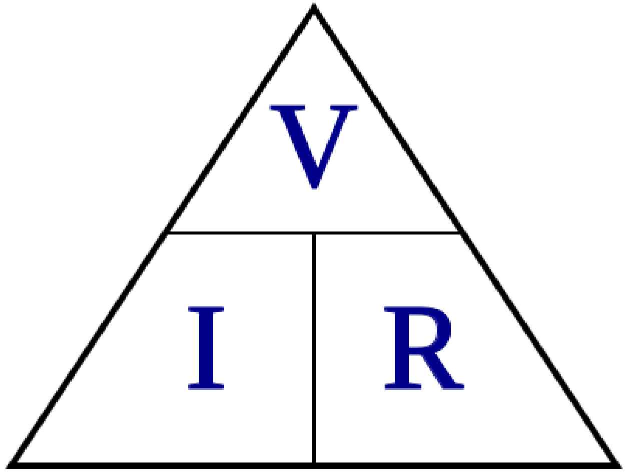
Ohm's Law (1)

INNOPOLIS UNIVERSITY

This observation forms one of the most fundamental laws of electricity, the Ohm's law:

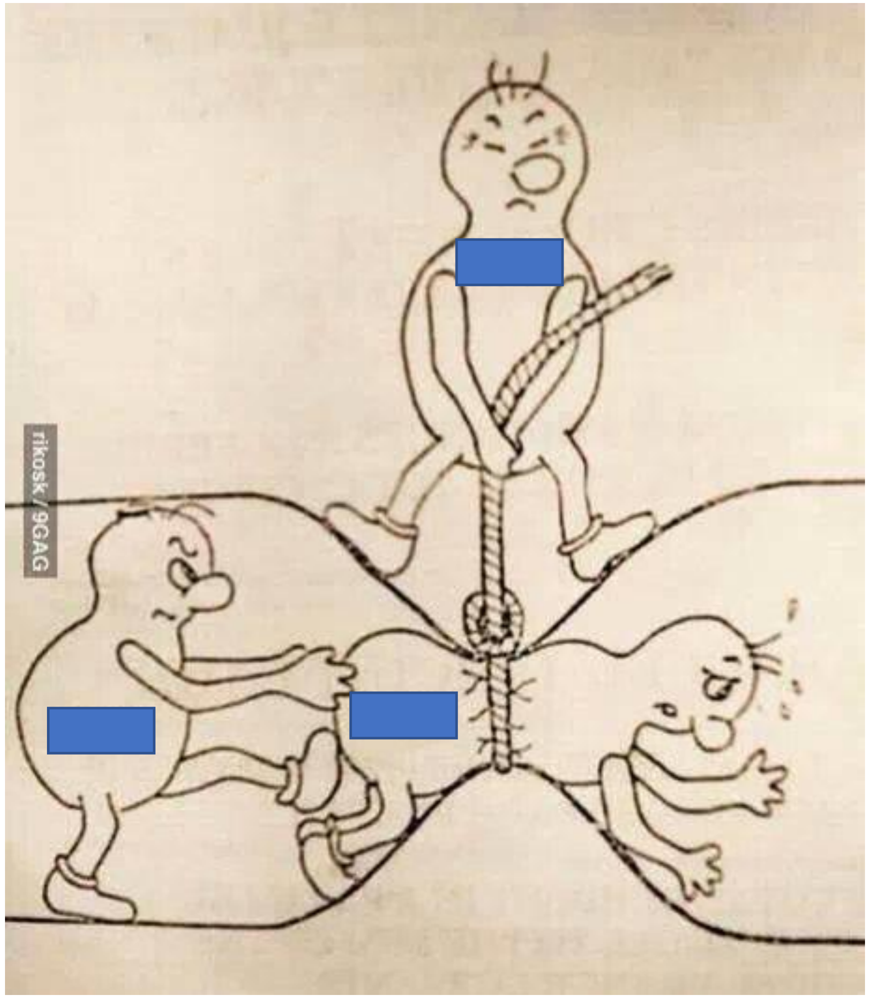
- Current through a conductor between two points is directly proportional to the voltage across the two points, and inversely proportional to the resistance between them.

$$\text{Current}(I) = \frac{\text{Voltage}(V)}{\text{Resistance}(R)}$$



Ohm’s Law (2)

Quiz: whose names is covered by the blocks (electronics-related, of course ☺)?



Electric Power

Electric power is the rate at which electrical energy is transferred by an electric circuit.

- Notation: P
- Unit: Watt [W]

$$\text{Power}(P) = \text{Voltage}(V) \text{ x } \text{Current}(I)$$

- **Q1**: What is the formula for electric power if you substitute the expression for voltage and current derived from the Ohm's law into the equation above?
- **Q2**: Recall the expression of mechanical power. What are the analogies between the 2 worlds?

Resistors

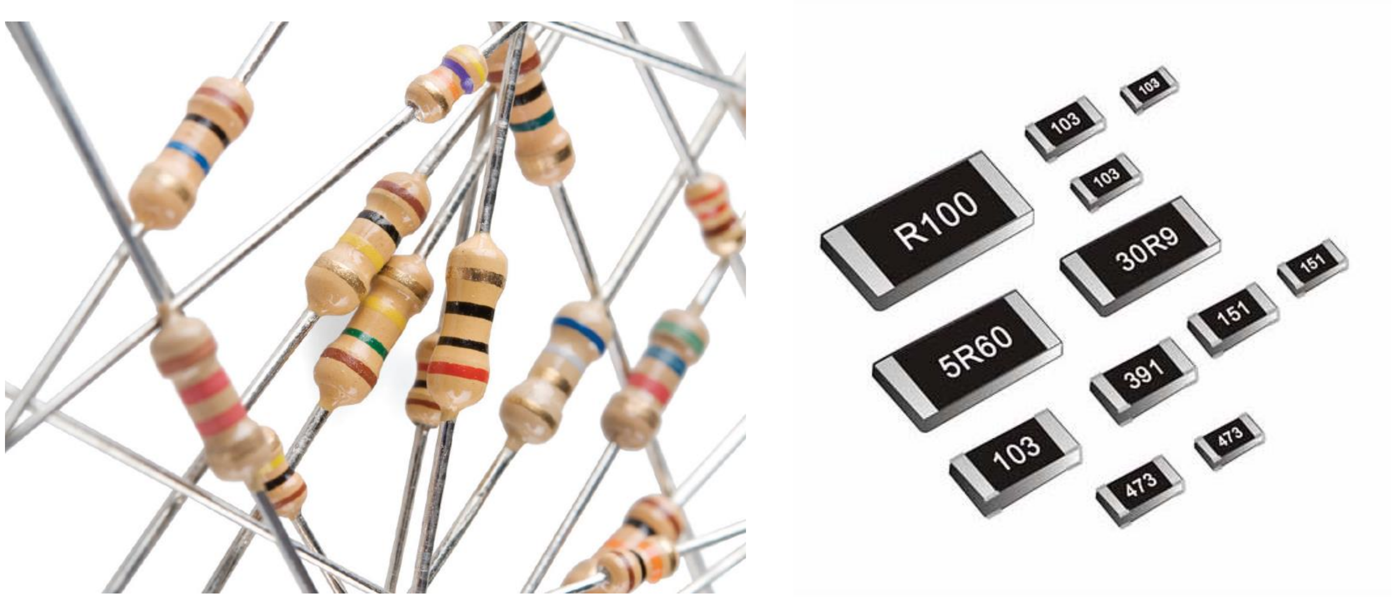
Resistors

A **resistor** is a two-terminal electrical component that implements electrical resistance as a circuit element.

Resistors are common elements of electrical networks and electronic circuits and are ubiquitous in electronic equipment.

- **Q**: Why do we need resistors?

Electronic symbol



Axial-lead vs. SMD resistors

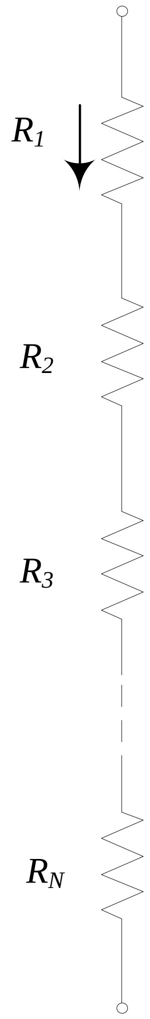
Resistors : Series

The equivalent resistance R_{EQ} of all the resistors in series can be found as

$$R_{EQ} = \sum_{n=1}^{N} R_n$$

- Thus, for instance, for 3 resistors connected in series to the voltage supply V_{supply}, the electrical current is

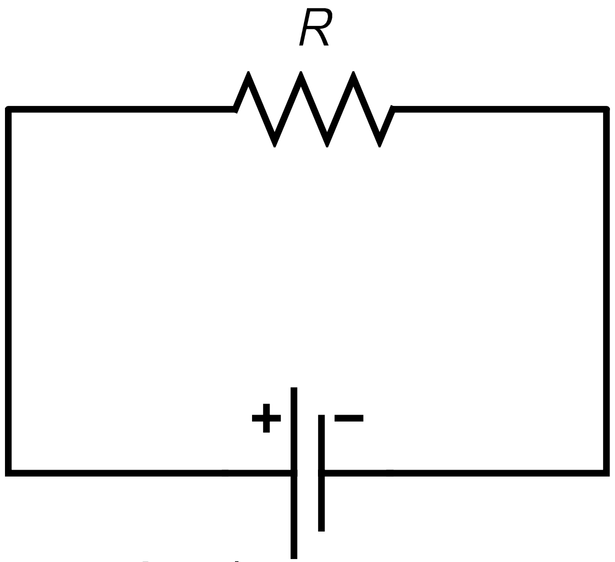
$$i = \frac{V_{\text{supply}}}{R_1 + R_2 + R_3} = \frac{V_{\text{supply}}}{R_{EQ}}$$



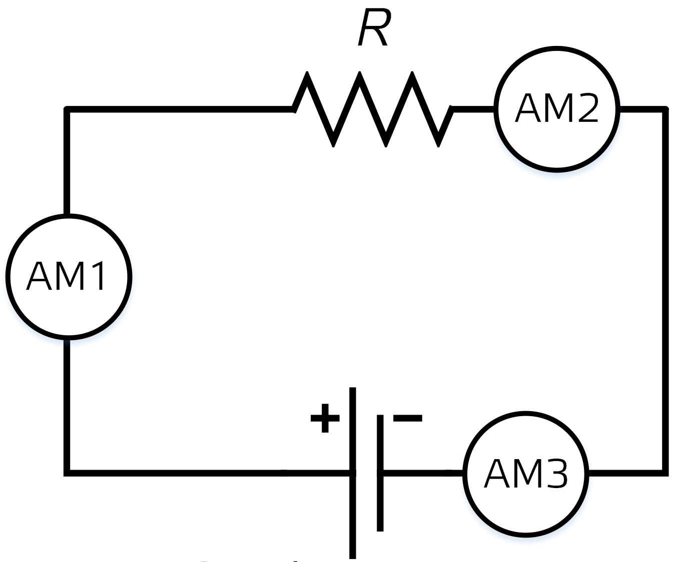
Electric Circuits (2)

Direct current (DC) is a continuous current that flows only in **one direction**.

In a circuit where the elements are placed in **series**, the electrical **current** (measured by ammeters AM1, AM2, AM3 and so on) would be **the same**.



DC voltage source
(battery)

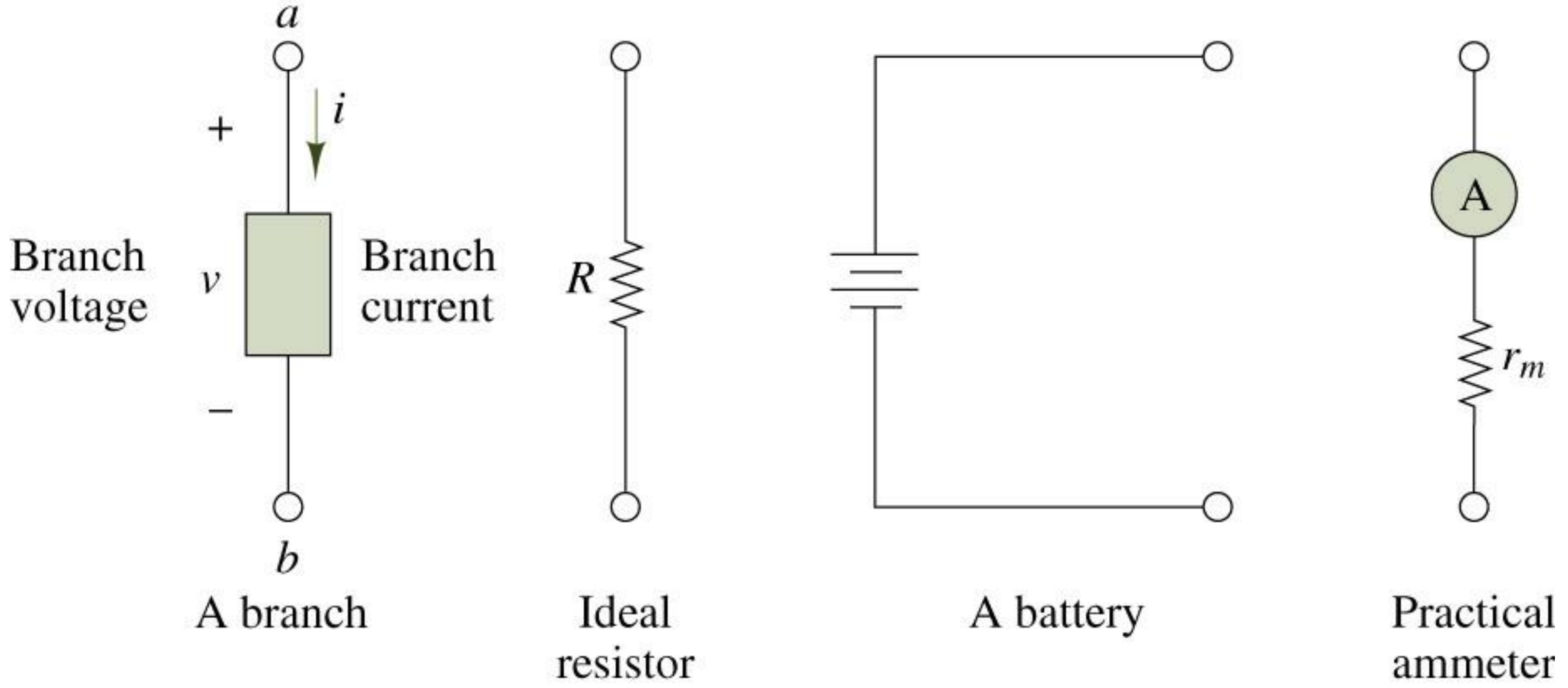


DC voltage source
(battery)

$$I_1 = I_2 = I_3 = \cdots$$

Electric Circuits : Branch

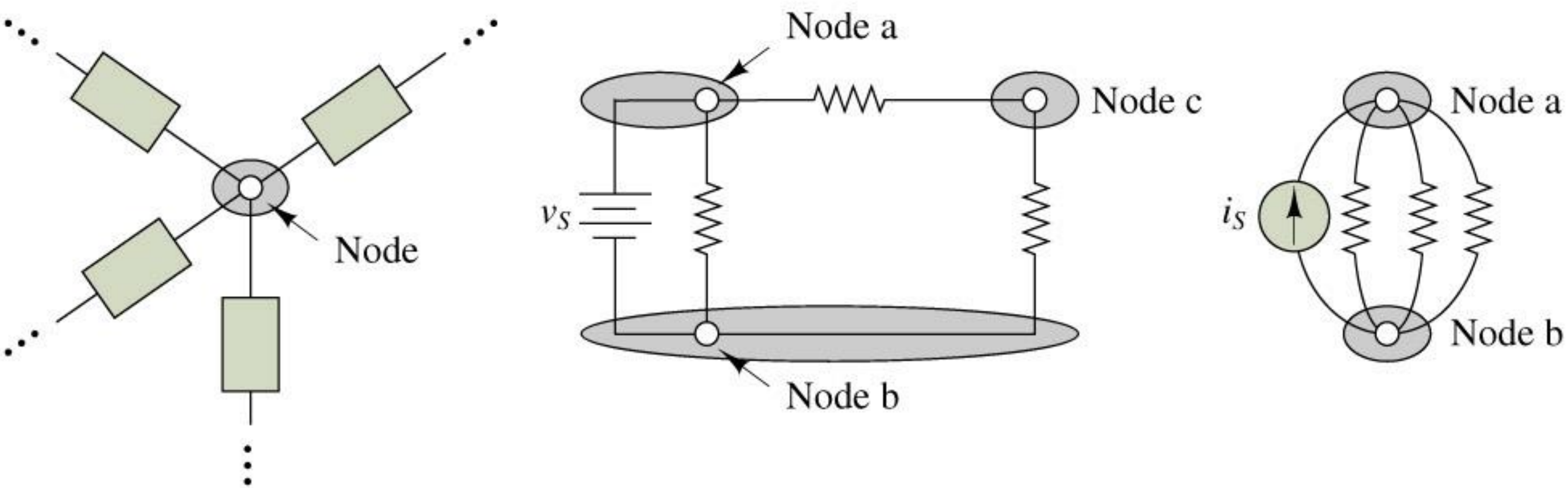
A **branch** is any portion of a circuit with **two terminals** connected to it.



Examples of circuit branches

Electric Circuits : Node

- A **node** is a junction of two or more branches.



Examples of nodes in practical circuits

Kirchhoff's Current Law

KCL: The **sum of the currents** at a node must **equal zero**.

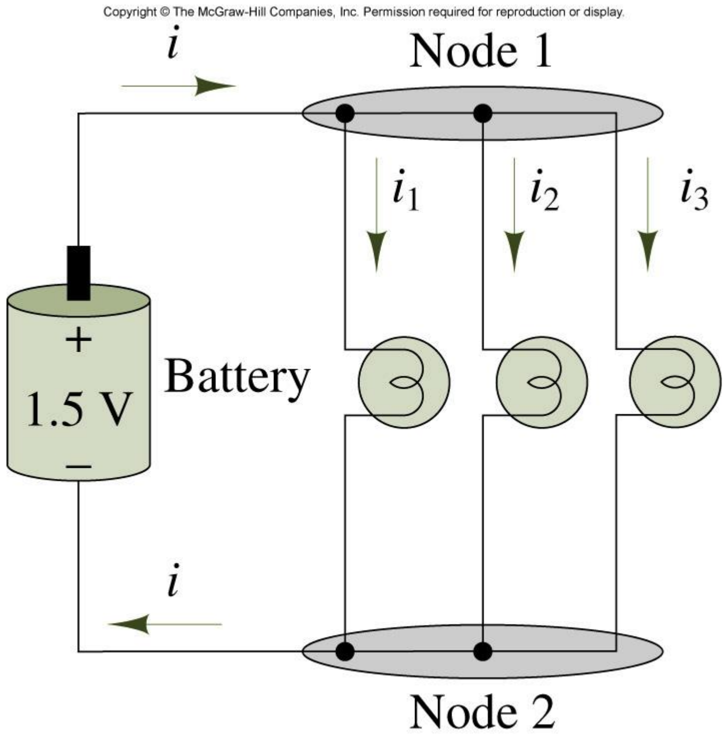


Illustration of KCL at node 1: $-i + i_1 + i_2 + i_3 = 0$

$$\sum_{n=1}^{N} i_n = 0$$

KCL : Example

- Find missing currents in the circuit on the right.

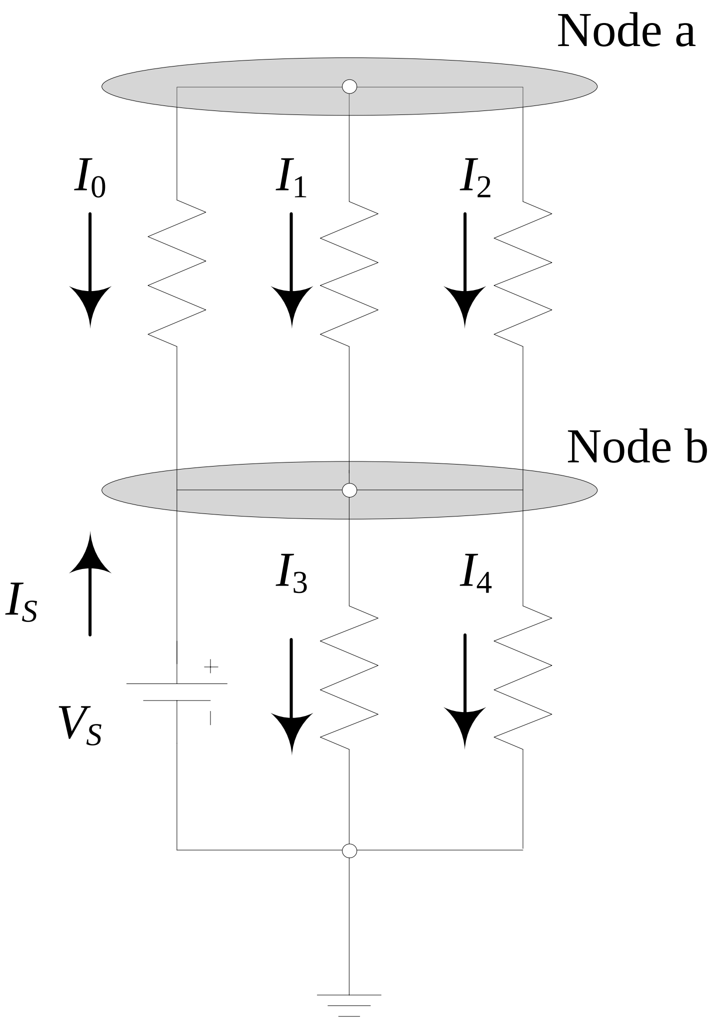
- Known Quantities:

I_S = 5 A; I_1 = 2 A;

I_2 = -3 A; I_3 = 1.5 A.

- Find:

I_0 and I_4



Thank you for your attention!

INNOPOLIS UNIVERSITY

Igor Gaponov

i.gaponov@innopolis.ru