Electromagnetism I

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Discovery of electricity

amber = η λ ε κ τ ρ ο ν

ancient Egyptians: 2750 B.C.
mention electric fish in written text

Thales of Miletos: 600 B.C.
amber rubbed with fur attracted small objects, e.g. feather or leaf

William Gilbert: 1600
coined the term: electric for those materials which attracted small objects after rubbing

Charles F. de Cisternay du Fay, Benjamin Franklin: 1737
discover that there are two forms of electricity
introduce the concept of positive and negative charge

Joseph John Thomson: 1897
the elementary unit of electric charge is the charge of the electron

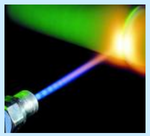
Robert Millikan: 1909
determined the charge of the electron:
$-1.6 \cdot 10^{-19}$ coulomb

Effects of electromagnetism

electromagnetism = electricity and magnetism
a convenient and clean way to transport and use energy

— heat effect

— light effect

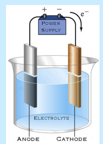


— magnetic effect

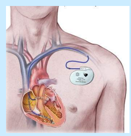
Effects of electromagnetism

— mechanic effect

— chemical effect



— physiological effect



Charge

symbol of charge: Q

unit: coulomb (C)

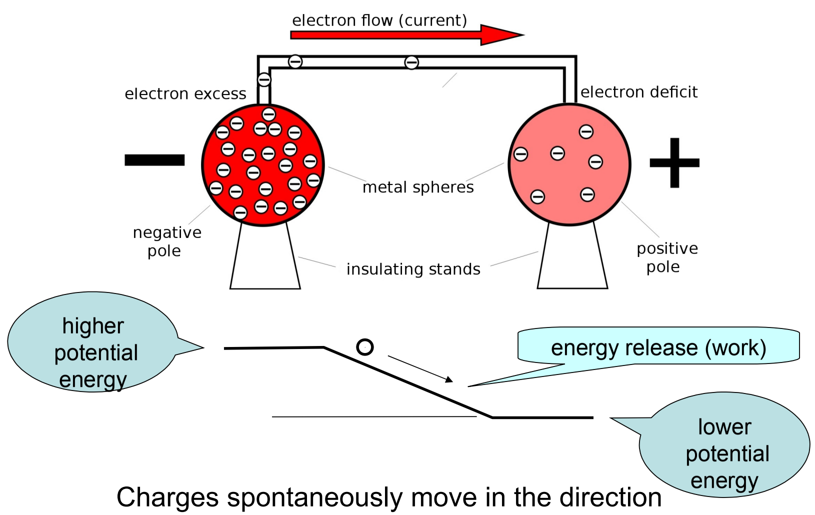
Electric charge is a physical property of matter which causes it to experience a force when near other electrically charged matter.

charge is quantized:

1 C = $6.24 \cdot 10^{18}$ elementary charges

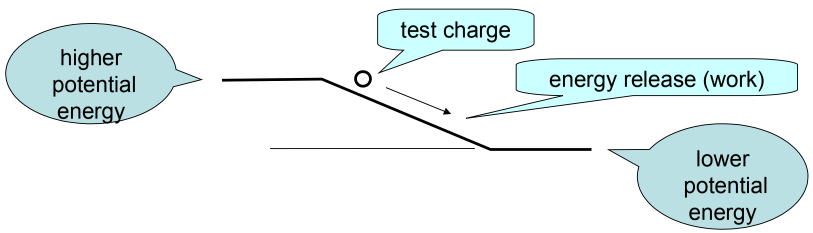
the elementary charge is: **$1.6 \cdot 10^{-19}$ C**

Movement of charges

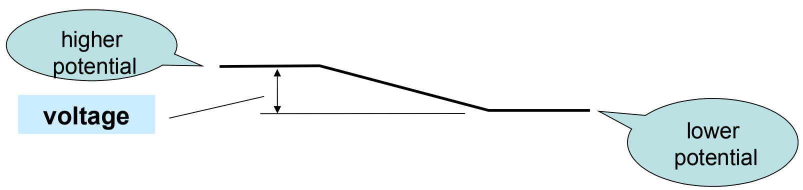


Charges spontaneously move in the direction that decreases potential energy.

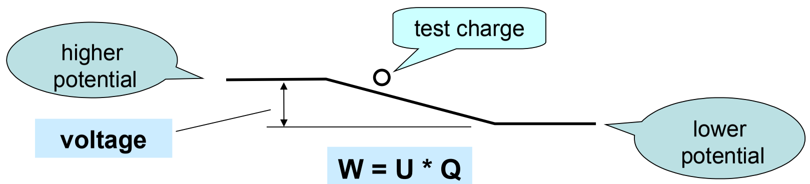
Electrostatic potential energy, electrostatic potential



electrostatic potential = electric potential energy / charge
Electrostatic potential is the potential energy of positive unit (1 coulomb) charge.

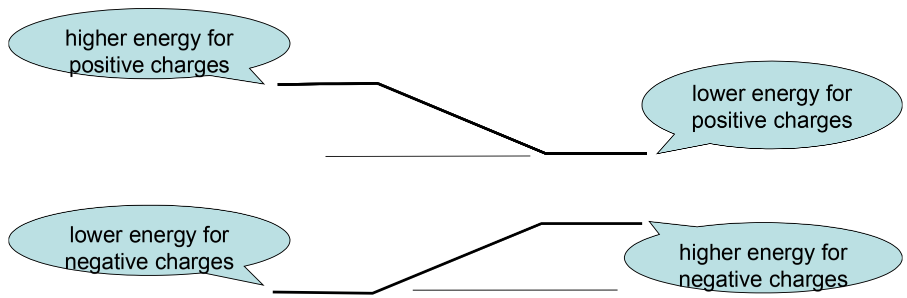


Electrostatic potential, electrostatic potential energy



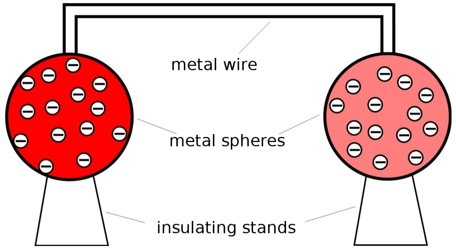
W = U * Q

potential energy = electric potential * charge



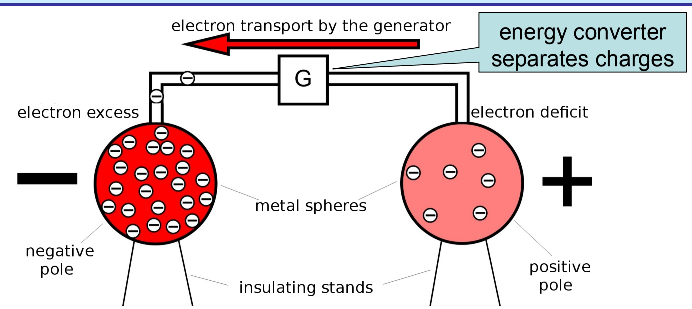
Equilibrium

no current



voltage = 0

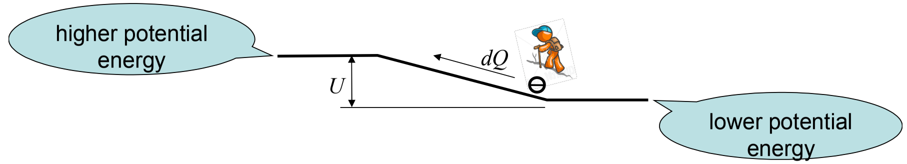
Generating electric potential difference



Work needs to be done to separate charges.

$$dW = U \cdot dQ$$

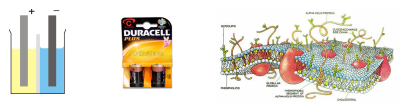
work (dW) ~ moved charge (dQ)
work (dW) ~ potential difference (U)



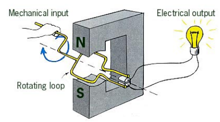
Electrical generators

Tools that use other forms of energy to separate charges and produce electric energy.

— electrochemical batteries



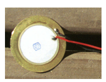
— induction generators



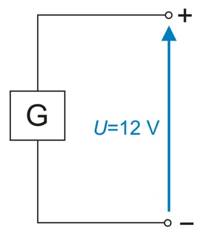
— solar cells

— thermoelectric cells

— piezoelectric cells



generator:



Voltage

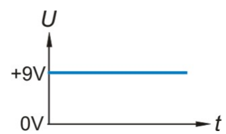
voltage: electric potential difference between two points

symbol of voltage: U

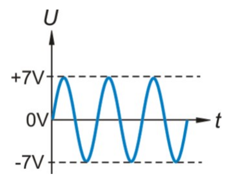
unit: volt (V)

$$U = \frac{W}{Q} \left[\frac{J}{C} = \frac{V \cdot A \cdot s}{A \cdot s} = V \right]$$

DC voltage



AC voltage



Electric current

electric current: amount of charge crossing the cross section of the wire in unit time

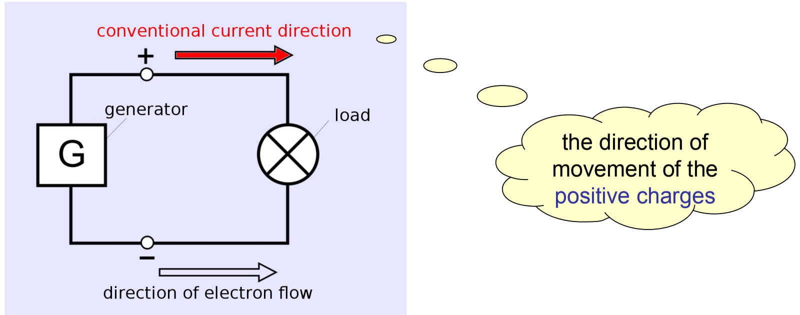
symbol of current intensity: I

unit: ampere (A)

$$I=\frac{\Delta Q}{\Delta t}\quad\left[\frac{C}{s}=\frac{A\cdot s}{s}=A\right]$$

1 A means that 1 C charge flows through the cross section of the wire in 1 s.

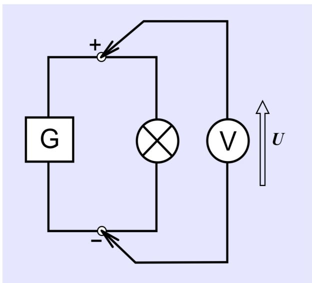
Direction of current



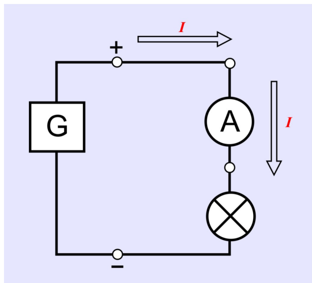
Charge carriers in different materials:

1. metals — electrons
2. electrolytes — positive and negative ions
3. gases — ions, electrons

Measuring voltage and current



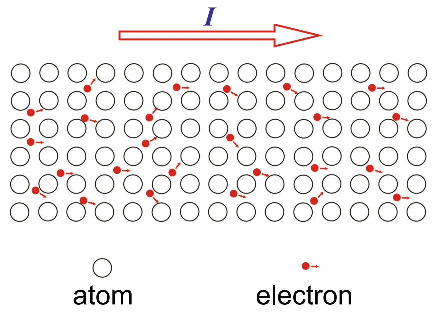
Very small (ideally zero) current flows through the voltage meter.

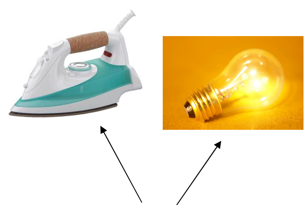


There is very small (ideally zero) voltage drop on the ampere meter.

Electrical resistance

Moving electrons bump in the metal atoms.
The material shows **resistance** to the electron flow.





Work is needed to maintain current because of the resistance of the conductor. The conductor heats up.

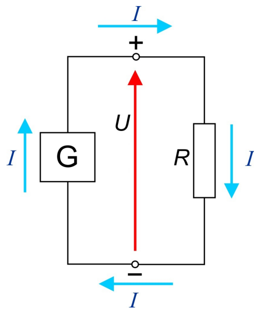
Ohm's law

experiment:

current intensity flowing through different objects measured at different voltages

finding:

the current intensity I and the voltage U are proportional



$$U \sim I$$

$$\downarrow$$

$$U = R \cdot I$$

The proportionality constant R in the Ohm's ($U = R{\cdot}I$) law is called electrical resistance.

Electrical resistivity

The electrical resistivity is the resistance of a uniform specimen of material with unit length and unit cross section.

symbol of resistance: R

unit: ohm (Ω)

$$\Omega = \frac{V}{A}$$

$R \sim l$

$R \sim 1/A$

resistance ( ) — $R = \rho \cdot \frac{l}{A}$ — length (m); cross-section (mm²); resistivity

depends on the matrial: $\rho = R \frac{A}{l}$

Electrical conductance

The electric conductance is the reciprocal value of the resistance. It shows how easily an object conducts electric current.

symbol of conductance: G

unit: siemens (S)

$$G = \frac{1}{R} \qquad 1\ S = \frac{1}{\Omega}$$

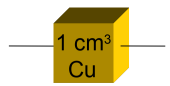
Electrical conductivity

The electric conductivity is the reciprocal value of the resistivity.

symbol of conductivity: σ

unit: siemens per metre (S/m)

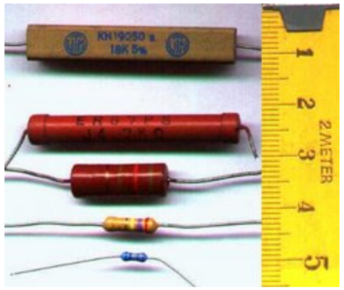
conductors	semiconductors	insulators
many free electrons per unit volume	few free charges per unit volume	no free charges per unit volume



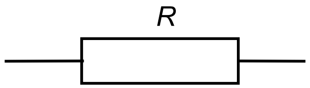
1 cm³ of copper contains 10^{23} free electrons

Resistors

resistors in electronics

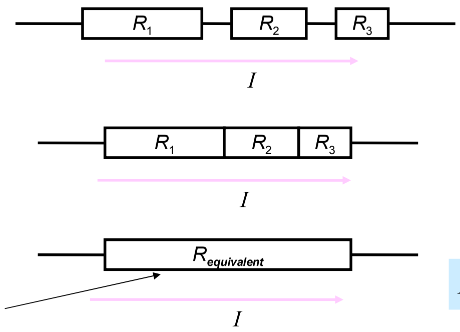


symbol of resistor



Connecting resistors in series

Resistances are connected in series if the same current flows through them.



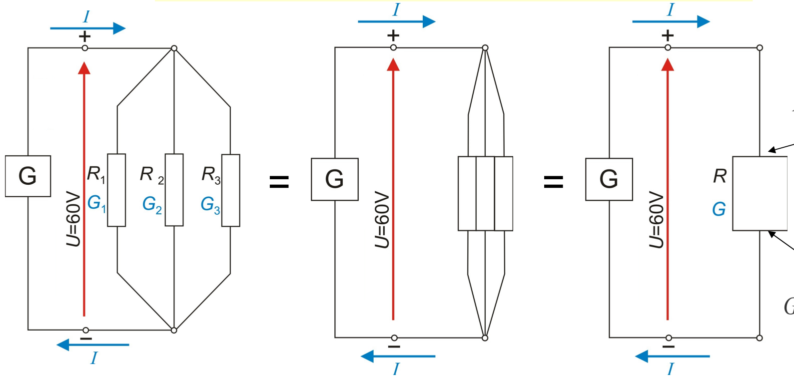
$$R=\rho\cdot\frac{l}{A}$$

$$R_{equivalent}=R_1+R_2+R_3$$

The resistance of the resistors connected in series adds up.

Connecting resistors in parallel

Resistances are connected in parallel if their ends are connected to the same voltage.



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

$$G=\frac{1}{\rho}\cdot\frac{A}{l}$$

The conductance of the resistors connected in parallel adds up.

$$G_1+G_2+G_3=G_{equivalent} \longrightarrow \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}=\frac{1}{R_{\text{equivalent}}}$$