Electricity

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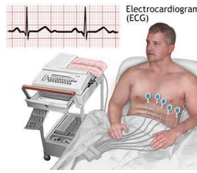
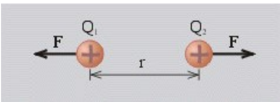


Application of Electricity in Medical and Pharmaceutical Field

Electric charge

q [C] *Coulomb*

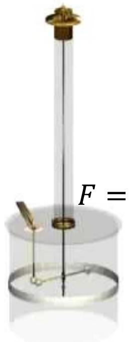
Elementary charge: $e = 1{,}6 \cdot 10^{-19}\mathrm{C}$ → $q_{p^+} = e$, $q_{e^-} = -e$



Coulomb's Law:

$$F = k\frac{q_1 q_2}{r^2}$$

$$(k = 9 \cdot 10^9 \frac{Nm^2}{C^2})$$



$$F = \gamma \frac{m_1 m_2}{r^2}$$

3

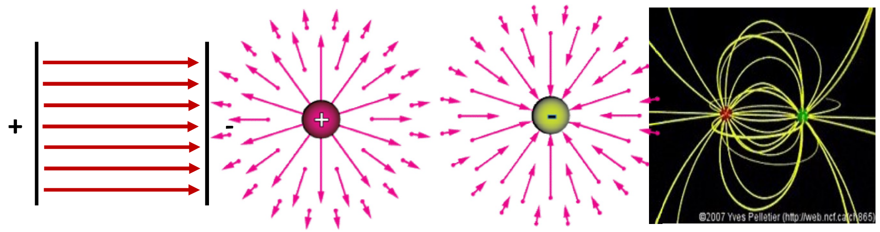
$\frac{}{s^2}$)

What is the ratio of the electric force to the gravitational force between a proton and an electron separated by 5.3 x 10^{-11} m (the radius of a hydrogen atom)? Mass of proton : $1{,}67 \times 10^{-27}$ kg; mass of electron: $9{,}1 \times 10^{-31}$ kg

$\gamma = 6{,}67 \cdot 10^{-1}$ $\frac{m^3}{kg \cdot s^2}$; k=$9 \cdot 10^9 \frac{Nm^2}{C^2}$

A metallic sphere has a charge of +4.0 nC. A negatively charged rod has a charge of -6.0 nC. When the rod touches the sphere, 8.2×10^9 electrons are transferred. What are the charges of the sphere and the rod now?

Electric Field

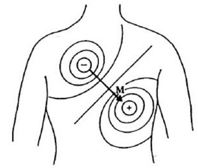


homogeneous *inhomogeneous* *Electric dipole*

e.Electric Dipole Moment:

$$p = q \cdot d$$

Debye: 1D = $3{,}34 \cdot 10^{-30}$ C·m



Electric Field

Electric field strength :

$$E = \frac{F}{q} \qquad \text{[N/C] vagy [V/m]}$$

$$E = k\frac{Q}{r^2}$$

Voltage :

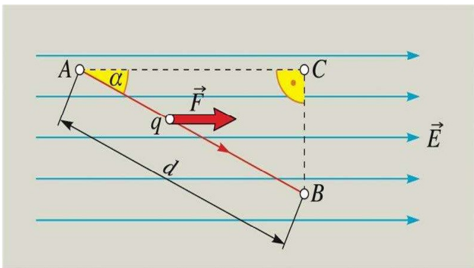
$$U_{21} = U = \frac{W}{q} \qquad \text{[V] } \textit{Volt}$$

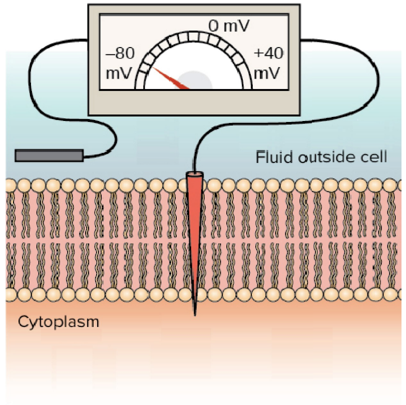
Electric potential :

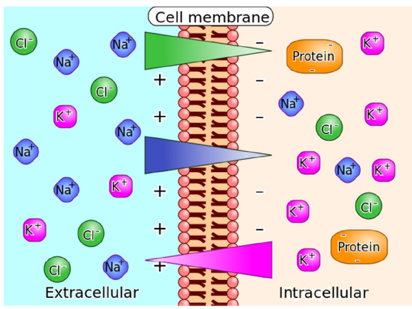
$$\varphi_i = U_{i0} \qquad \text{[V] } \textit{Volt}$$

$$\downarrow$$

$$U_{21} = U = \varphi_2 - \varphi_1$$



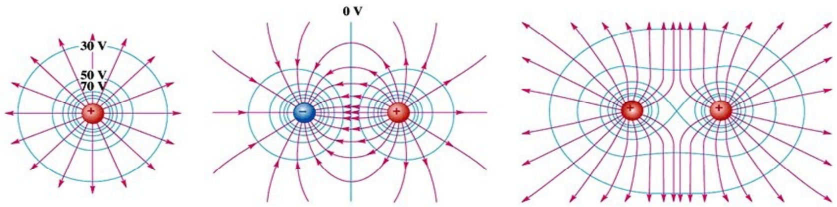


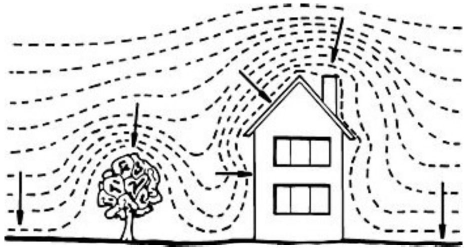


resting voltage
resting potential difference

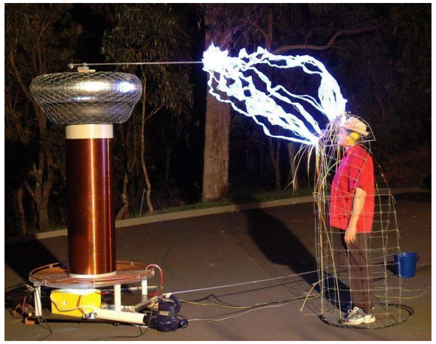
Electric Field

Equipotential surface:

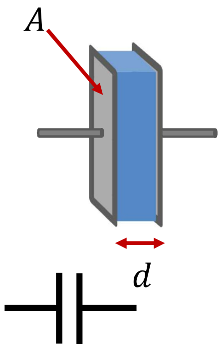




Faraday cage



Capacitor



electric field strength: $E = \frac{U}{d}$ [V/m]

capacitance: $C = \frac{q}{U}$ [F] *Farad*

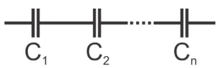
$$C = \epsilon_0 \epsilon_r \frac{A}{d}$$

The electric energy stored in the capacitor: $W = \frac{1}{2}\frac{q^2}{C} = \frac{1}{2} C \cdot U^2$

Connecting capacitors

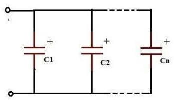
In series:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$$

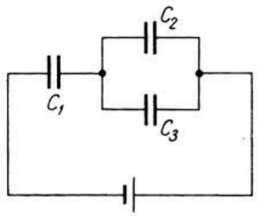


In parallel:

$$C = C_1 + C_2 + \cdots$$



Three capacitor are connected according to figure. C1= 1μF, C2=2μF, C3=3μF. Voltage of the battery is 12 V. Calculate the charges of each capacitors!



Electric current


André-Marie Ampère
1775-1836

electric current:

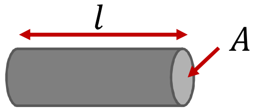
$$I = \frac{\Delta q}{\Delta t} \qquad [\text{A}]\ \textit{Amper}$$

Electric current


Georg Simon Ohm
1789-1854

Ohm's Law: $U = R \cdot I$

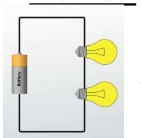
Electric resistance: $R = \frac{U}{I}$ [Ω] *Ohm*



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

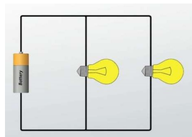
Connecting resistors

in series:



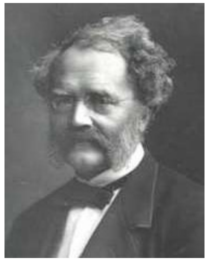
$$R = R_1 + R_2 + \cdots$$

in parallel:



$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$$

Electric current


Ernst Werner von Siemens
1816-1892

Electric conductance:

$$G = \frac{1}{R} \qquad [\text{S}]\ \textit{Siemens}$$

$$G = \frac{1}{R} = \frac{1}{\rho}\frac{A}{l} = \sigma \frac{A}{l}$$

Electric current

Work of electric current (Joule heating):

$W = U \cdot I \cdot t$ [J] *Joule*

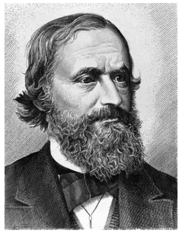
$U = R \cdot I$

$$W = R \cdot I^2 \cdot t = \frac{U^2}{R} t$$

Electric power:

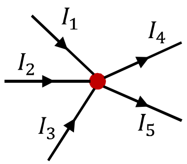
$$P = \frac{W}{t} = U \cdot I = R \cdot I^2 = \frac{U^2}{R} \qquad [\text{W}]\ \text{Watt}$$

Electric current



Gustav Robert Kirchhoff
1824-1887

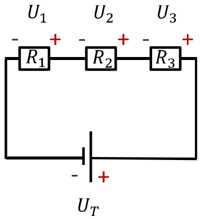
Kirchhoff's I. Law(junction law):



as a result of conservation of electric charge, the currents flowing into a junction are equal to the currents flowing out of that junction. In other words, in a branched (parallelly connected) circuit current is partitioned between the branches.

$$I_1 + I_2 + I_3 = I_4 + I_5$$

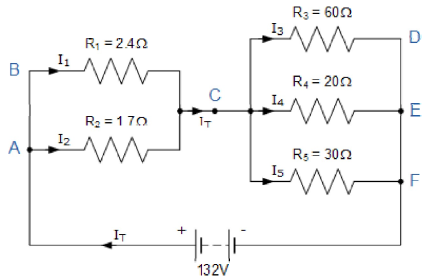
Kirchhoff's II. Law(Loop law):



as a result of conservation of energy, the directed sum (i.e., considering the signs) of voltages of electrical components along a loop within an electrical circuit is zero. In other words, within a loop (e.g., serially-connected circuit) voltage is partitioned between the electric components (e.g., resistances, capacitors, etc.)

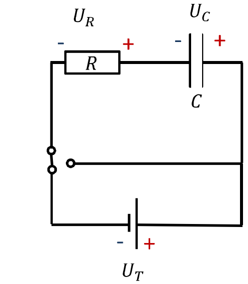
$$U_1 + U_2 + U_3 = U_T$$

Calculate the individual currents flowing through each resistor branch!

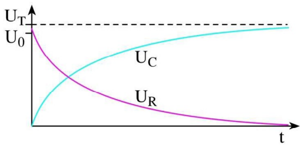


Electric current: RC circuit (in series)

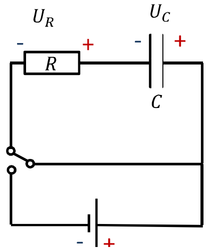
Charging the RC circuit

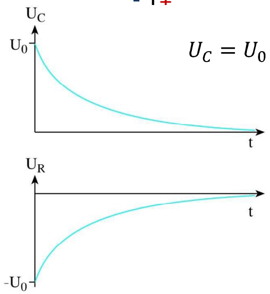


$$U_C = U_T \cdot \left(1 - e^{-\frac{t}{RC}}\right)$$



Discharging the RC circuit

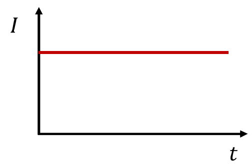




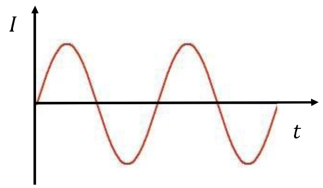
$$U_C = U_0 \cdot e^{-\frac{t}{RC}}$$

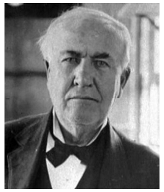
Electric current

Direct current, DC

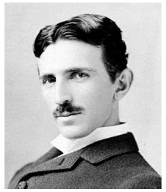


Alternating current, AC

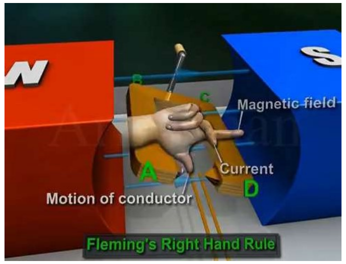


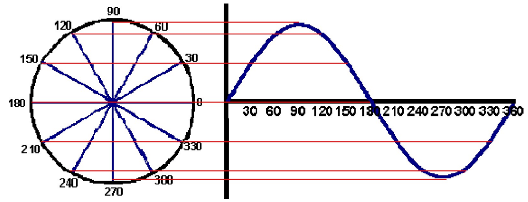


Thomas Alva Edison
1847-1931



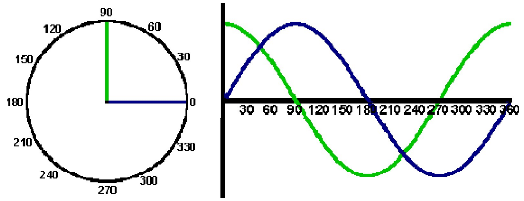
Nikola Tesla
1856-1943





$$I = I_{max} \cdot \sin \omega t$$

$$U = U_{max} \cdot \sin(\omega t + \varphi)$$



$$I_{eff} = \frac{I_{max}}{\sqrt{2}}$$

$$U_{eff} = \frac{U_{max}}{\sqrt{2}}$$

Electric current

Capacitor in an AC circuit

Capacitive reactance: $X_C = \dfrac{1}{\omega \cdot C}$ [Ω] *Ohm*

Impedance: If an AC circuit contains both resistors and capacitors, the total "resistance" of the whole circuit is called impedance.

Z [Ω] *Ohm*

In series RC circuit:

$$Z^2 = R^2 + X_C{}^2$$

In parallel RC circuit:

$$\left(\frac{1}{Z}\right)^2 = \left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C}\right)^2$$

A rheumatism patient receives iontophoretic therapy (administration of ionic pharmaceutical by means of direct current). The voltage is 40 V, the resistance of the treated body part is 12 500 Ω. a) What is the electric current flowing through the treated area? b) What amount of electric charge flows through the treated area in a 10-minute treatment? c) How many drug molecules enter the body during this period if they are in the form of monovalent ions? Give the amount of molecules in moles, too

The cross-section area of the copper wire of a 20-m-long extension lead is 1.5 mm 2 . The resistivity of copper is 1.78·10–8 Ωm. Find a) the resistance of the wire, b) the conductance of the wire, and c) the conductivity of copper.

During one of the biophysics labs we fill a graduated cylinder (height: 6 cm, cross section area: 2 cm 2) with a salt solution of 12 mS/m conductivity. Determine a) the conductance, b) the resistivity, and c) the resistance of the solution in the cylinder.

The domestic mains power in Europe oscillates according to the function: U = 325 V · sin(314 s –1 · t). Find: a) the peak value of the voltage, b) the effective (RMS) value of the voltage, c) the angular frequency of the AC, and d) its frequency.

An AC characterized by the U = 34 V · sin(6283 s –1 · t) function is connected to a 500 nF capacitor. Find a) the peak voltage, b) the effective voltage, and c) the capacitive reactance of the capacitor

The capacitance of the capacitor in a defibrillator is 50 µF. We charge it to a rather high voltage, 5000 V before intervention. at) What is the charge of the capacitor? b) What is the energy stored in the capacitor?

The resistance of the tungsten filament in a traditional light bulb at the operating temperature is 529 Ω. We connect the bulb to the mains power which has an effective voltage of 230 V. a) What heat is produced in the light bulb during a day? b) What is the power of the bulb?

A simplified representation of a defibrillator would be an RC circuit. The capacitor used in the device (C = 20 µF) was charged before treatment to a rather high voltage, 5 kV. Then it is attached to the chest using two so-called paddle electrodes. The capacitor discharges through the chest as a resistor (R = 1200 Ω). a) What is the energy stored in the charged capacitor? b) What is the electric current flowing through the body in the very beginning of discharging? c) What is the time constant of the RC circuit that is created during the intervention? d) What is the voltage of the capacitor 0.1 s after beginning the intervention? e) In what time does the voltage of the capacitor decrease to the thousandth, i.e. to 5 V

A body with q = 0.1 C charge is uniformly moved in a homogeneous electric field (E = 1 200 N/C) parallel to the field lines from position #1 to position #2. a) What force acts on the body? b) What work is done during the movement? c) What is the voltage between the two positions?

In an X-ray tube 80 kV voltage is accelerating an electron from the cathode toward the anode of the tube. a) What is the accelerating work done by the field? b) This work will appear in the form of the kinetic energy of the electron. What is the speed of the electron if its mass is considered constant (m = 9.11·10–31 kg), i.e., we neglect the relativistic mass increase?

Thank you!