

ELECTRICITY

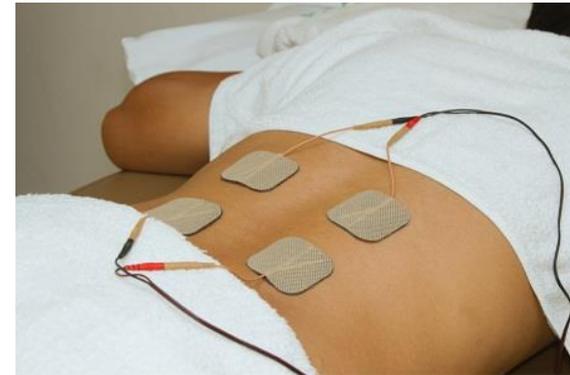
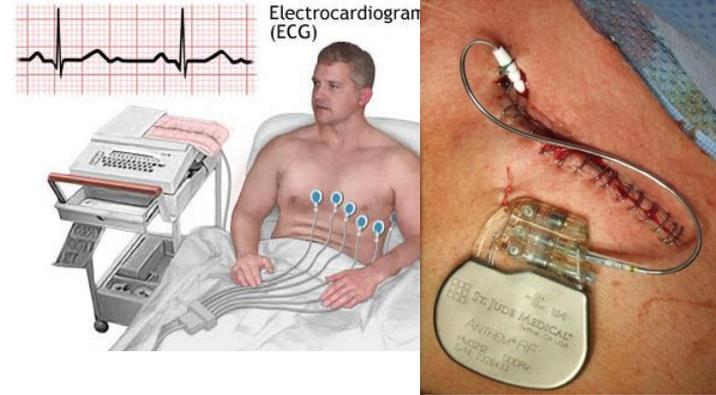
2023.09.22

Dr. Nikoletta Kósa

Department of Biophysics and Radiation Biology



SEMMELWEIS
UNIVERSITY 1769



Application of Electricity in Medical and Pharmaceutical Field

ECG

PRINCIPLES OF ELECTROCARDIOGRAPHY

PULSE GENERATOR

GENERATION OF ELECTRIC PULSES, COUNTING OF PULSES

restored ECG

implanted pacemaker

pacing leads (electrodes)

BINARY COUNTER ARRAY

light is on $1 \cdot 2^3 = 8$ $1 \cdot 2^2 = 4$ $1 \cdot 2^1 = 2$ $1 \cdot 2^0 = 1$
 light is off $0 \cdot 2^3 = 0$ $0 \cdot 2^2 = 0$ $0 \cdot 2^1 = 0$ $0 \cdot 2^0 = 0$

$0 \cdot 2^3 + 1 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0 = 5$

COULTER COUNTER

ELECTRONIC COUNTING OF THE CORPUSCULAR ELEMENTS OF BLOOD

Wallace Coulter
1913 - 1998

AMPLIFIER

CHARACTERISTICS OF THE ELECTRONIC AMPLIFIER

intracellular voltage

ECG (electrocardiogram)

PPG (phonocardiogram)

EEG (electroencephalogram)

EMG (electromyogram)

voltage amplitude, U_{eff} (V)

frequency, f (Hz)

triode
vacuum tube triode 1875-1961

transistor
1947-1961

operational amplifier (op-amp)
1923-2008

SKIN IMPEDANCE

DETERMINATION OF SKIN IMPEDANCE

current amplitude of the stimulus, I (mA)

duration of the stimulus, t (ms)

short and strong stimulus

long and weak stimulus

SENSATION

NO SENSATION

STIMULUS THRESHOLD

rheobase (r)

2x rheobase ($2r$)

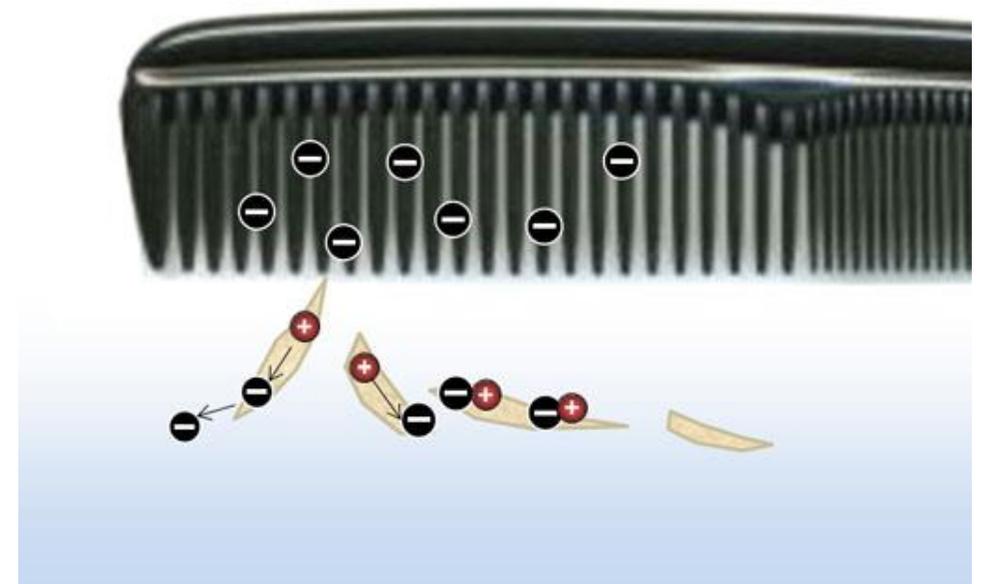
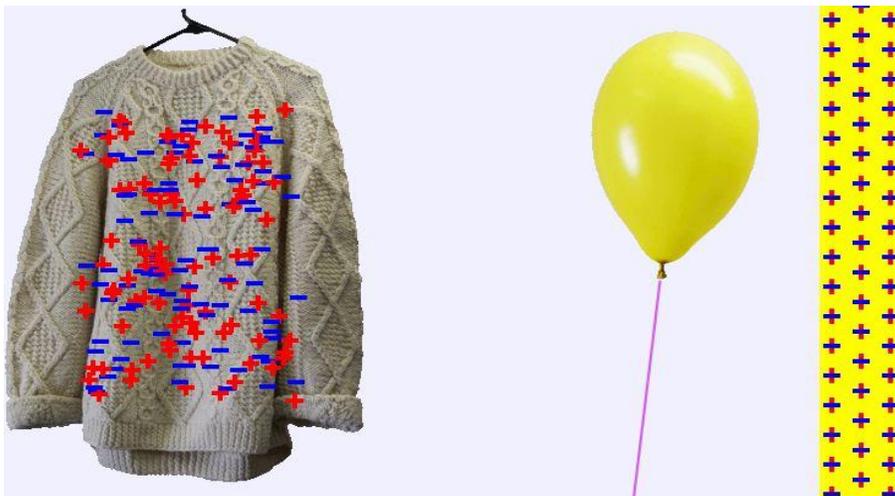
chronaxie (t)

body fat % measurement

Giovanni Galvani 1737-1804

Gustav Robert Kohlrausch 1804-1887

Electrostatics Effects



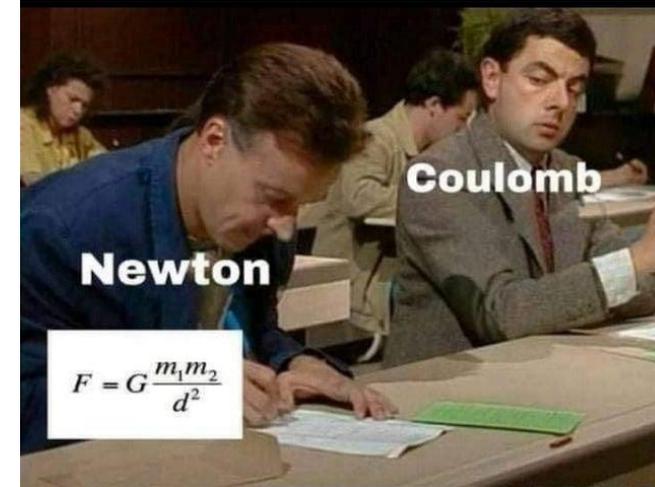
Electric charge

q [C] Coulomb

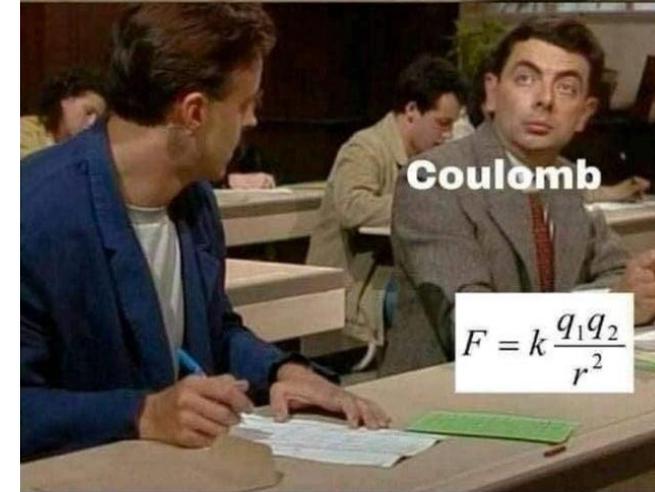
Elementary charge : $e = 1,6 \cdot 10^{-19} \text{C}$

$$q_{p^+} = e$$

$$q_{e^-} = -e$$



$$F = G \frac{m_1 m_2}{d^2}$$



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

Coulomb's Law :

Newton's Law of Universal Gravitation:

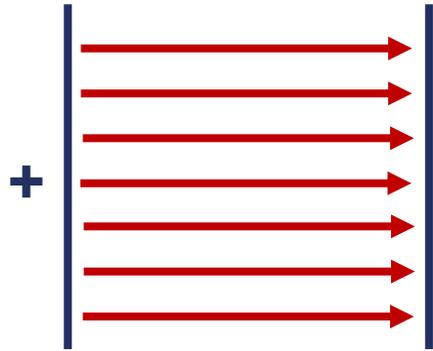
$$(k = 9 \cdot 10^9 \frac{\text{Nm}^2}{\text{C}^2})$$

$$(\gamma = 6,67 \cdot 10^{-11} \frac{\text{m}^3}{\text{kg} \cdot \text{s}^2})$$

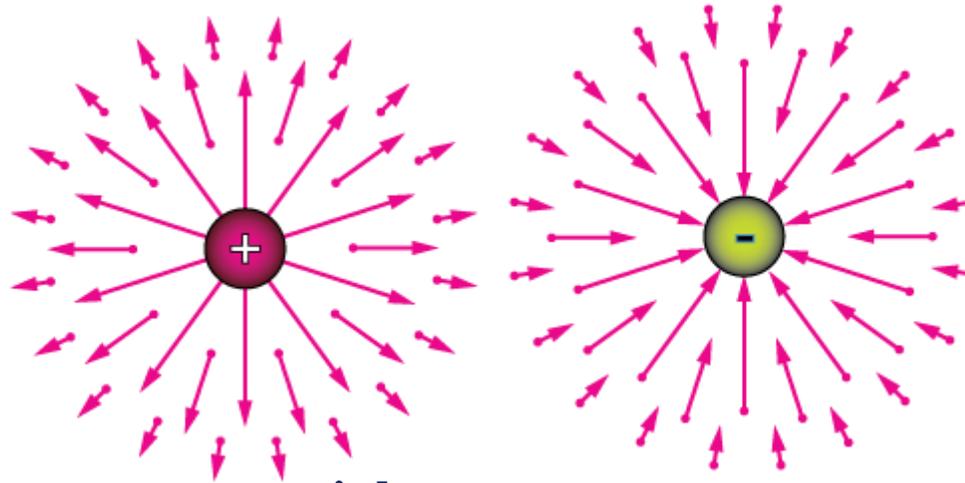
A metallic sphere has a charge of $+4.0 \text{ nC}$. A negatively charged rod has a charge of -6.0 nC . When the rod touches the sphere, 8.2×10^9 electrons are transferred. What are the charges of the sphere and the rod now?

Two pointlike charges are given, one of them is carrying twice as much charge as the other one. The distance between them is 10 cm and the force acting between them is 15 mN . Determine the value of the charges!

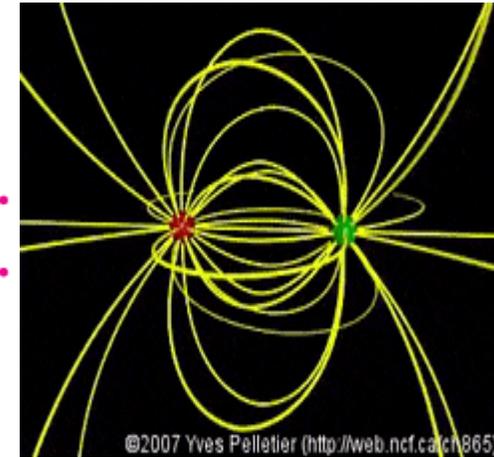
Electric Field



homogeneous



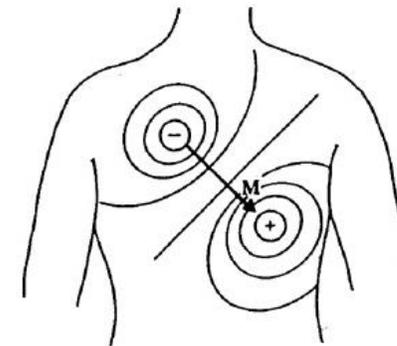
inhomogeneous



Electric dipole

Electric Dipole Moment:

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

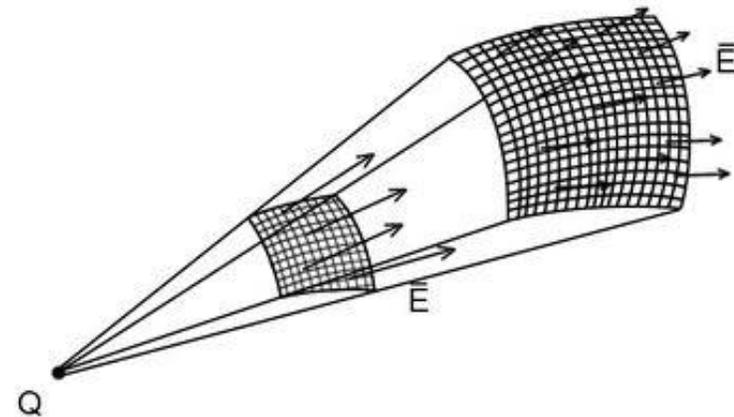
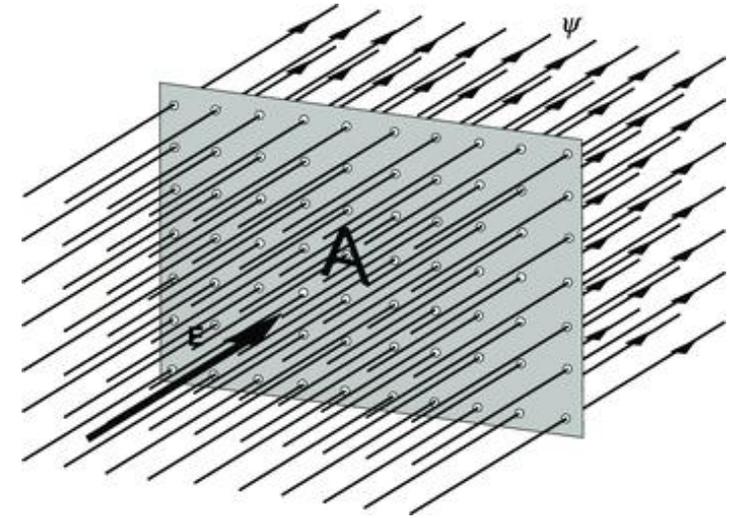


Electric Field

Electric field strength :

Electric Flux:

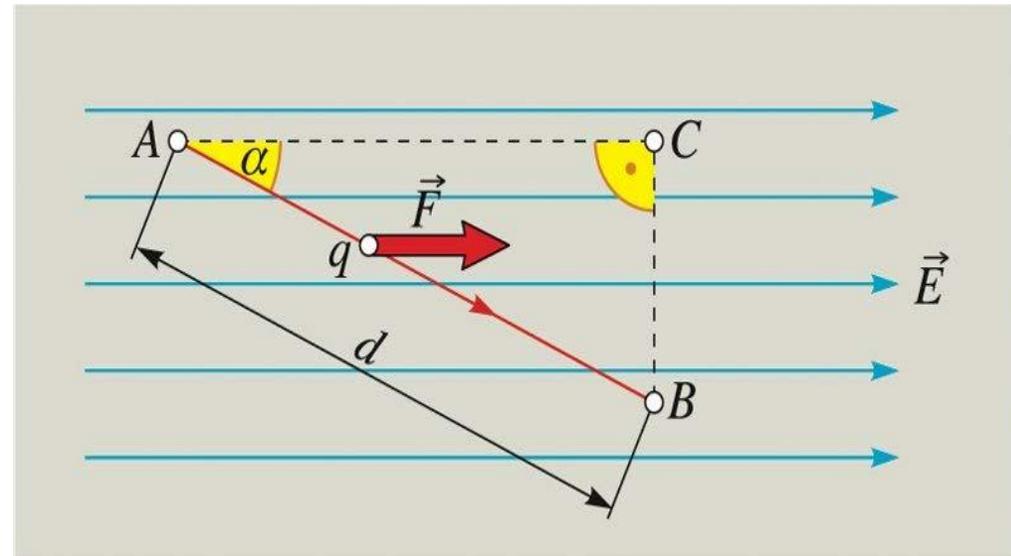
Superposition of electric fields:

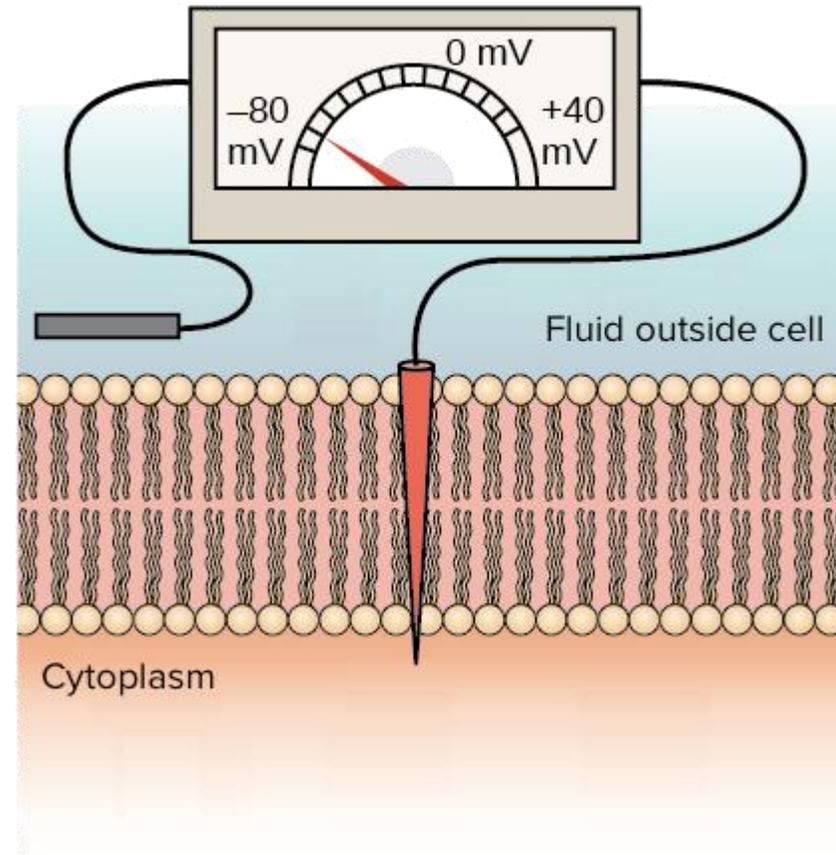
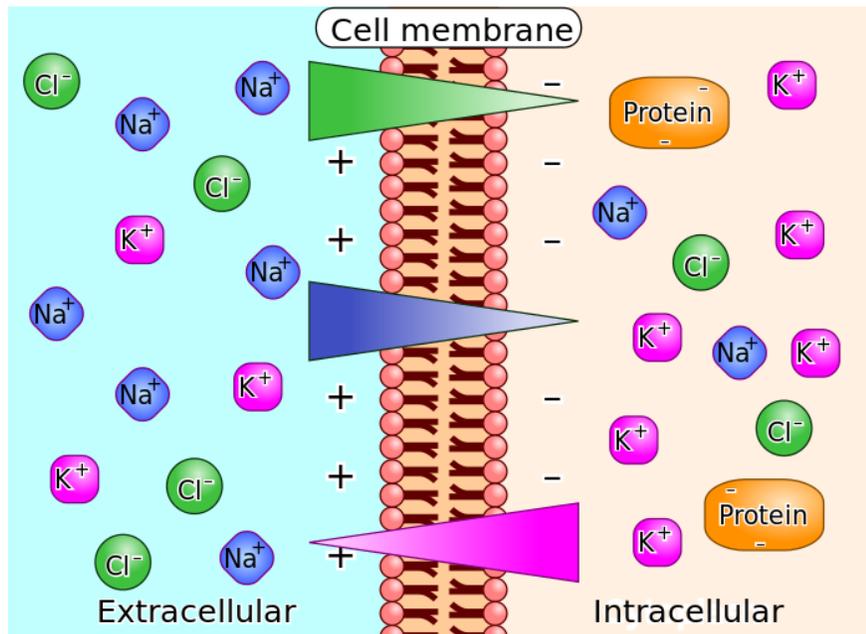


Electric Field

Voltage :

Electric potential :

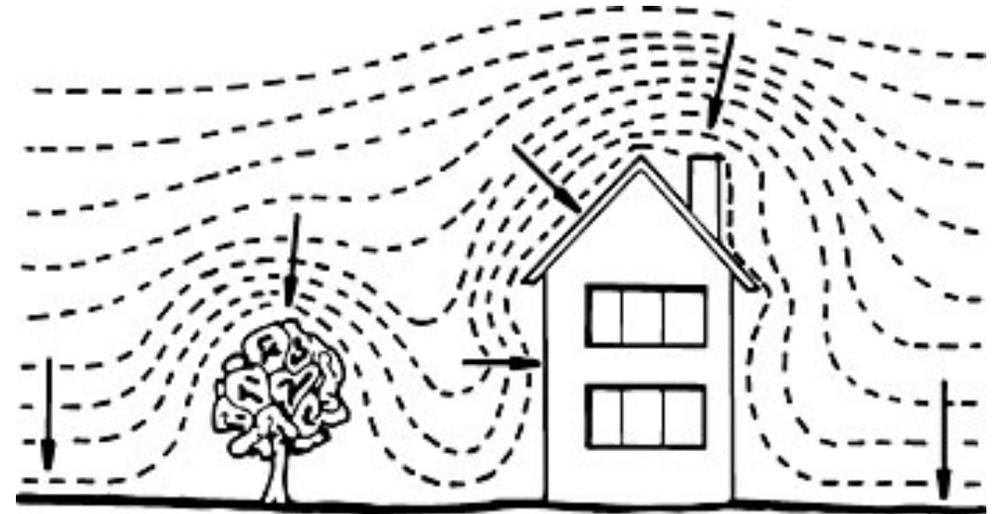
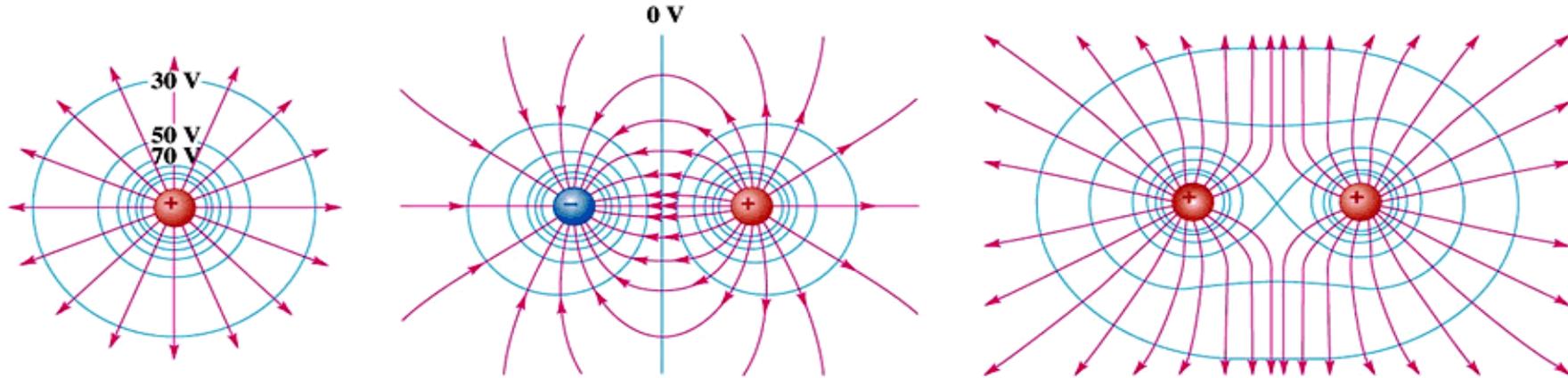




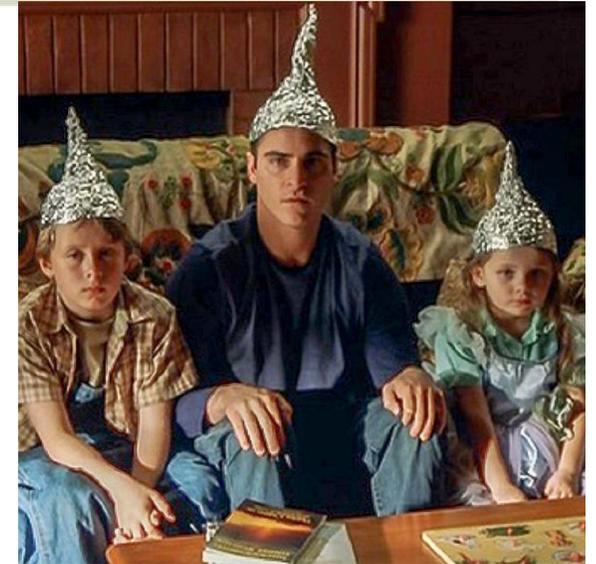
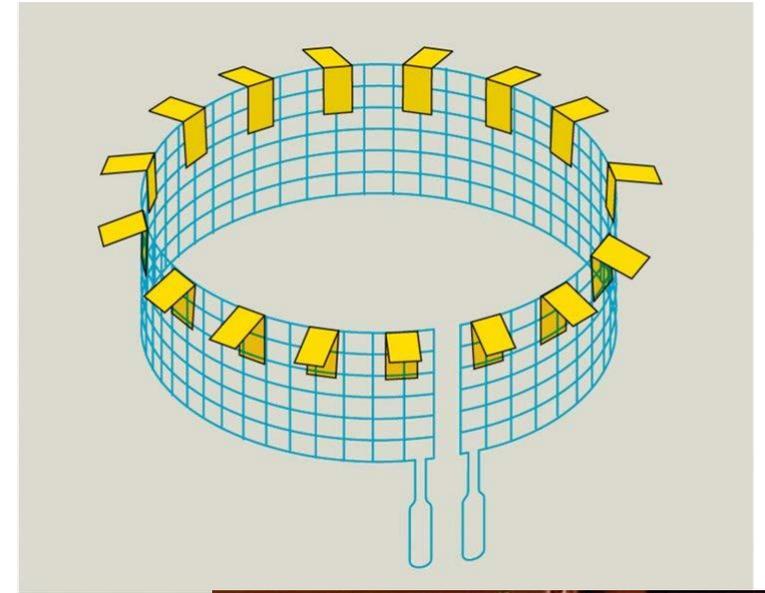
resting voltage
resting potential difference

Electric Field

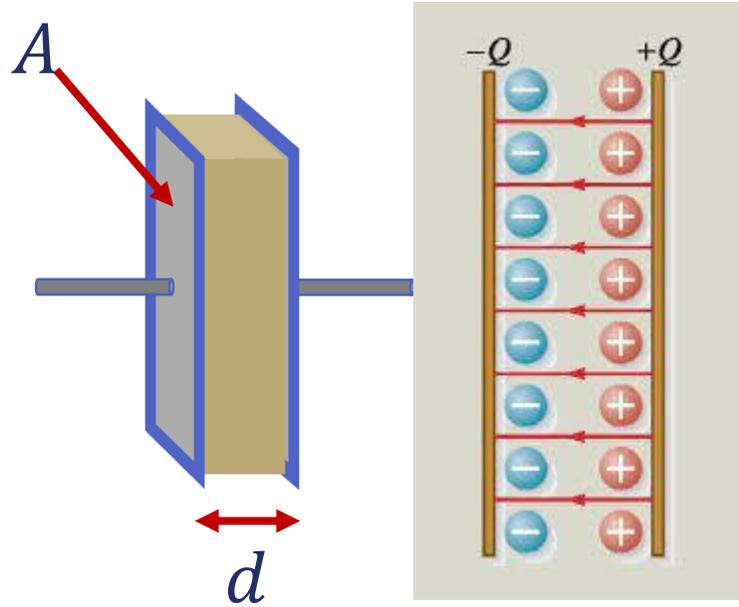
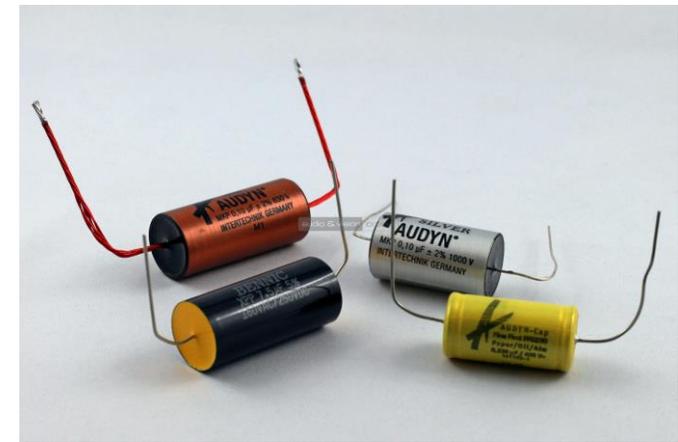
Equipotential surface:



Faraday cage



Capacitor



electric field strength:

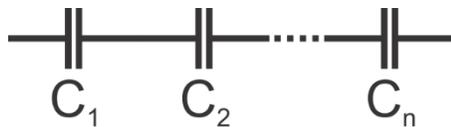
capacitance:

The electric energy stored in the capacitor:

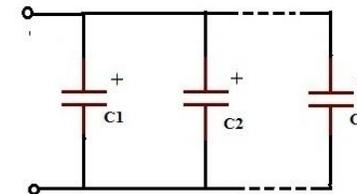


Connecting capacitors

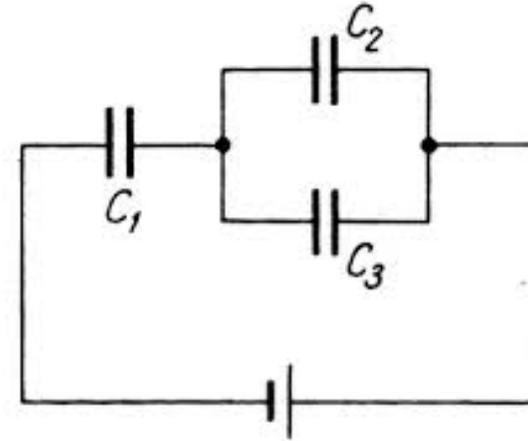
In series:



In parallel:



Three capacitors are connected according to figure. $C_1 = 1\mu\text{F}$, $C_2 = 2\mu\text{F}$, $C_3 = 3\mu\text{F}$. Voltage of the battery is 12 V. Calculate the charges of each capacitor!



Electric current



**André-Marie
Ampère
1775-1836**

electric current:

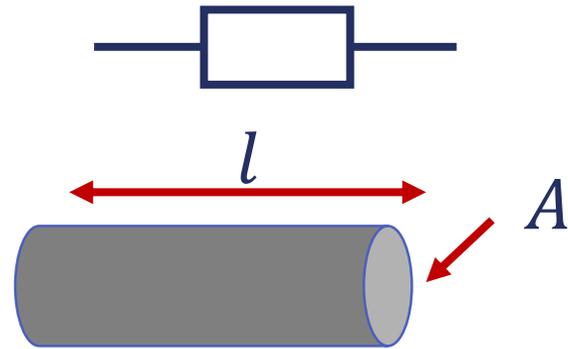


Georg Simon Ohm
1789-1854

Electric current

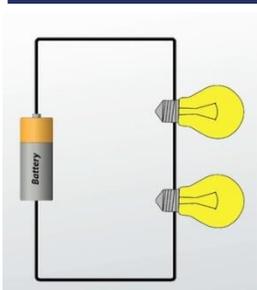
Ohm's Law:

Electric resistance:

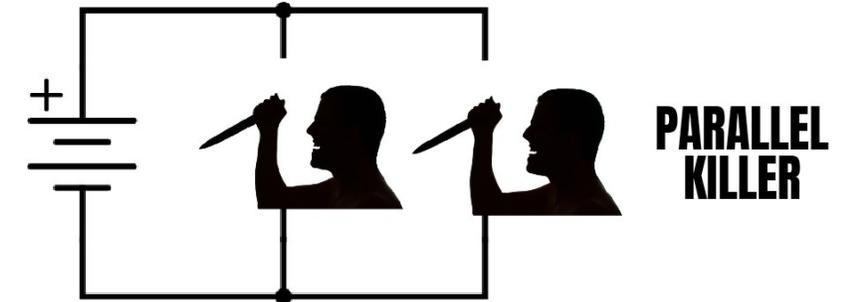
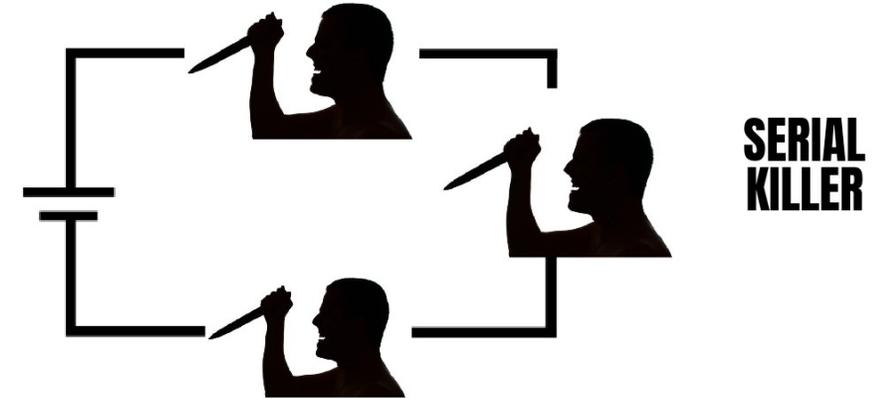
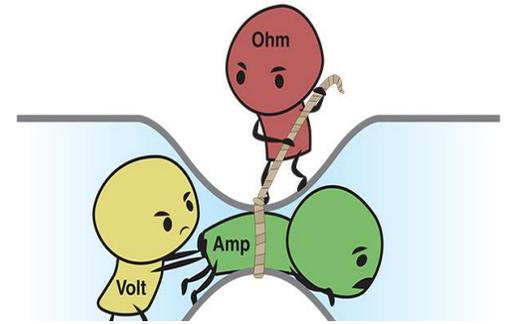
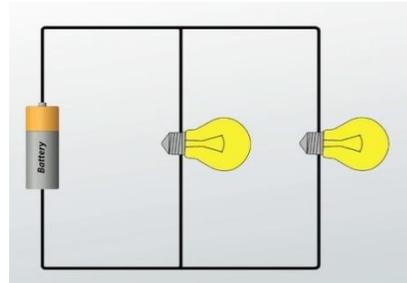


Connecting resistors

in series:



in parallel:



MADE WITH ELECTRICITY

Electric current

Electric conductance:



Ernst Werner von
Siemens
1816-1892



Electric current

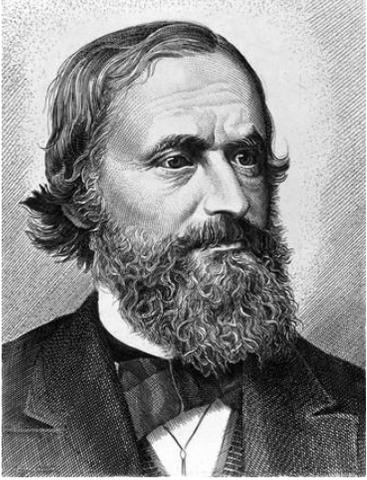


Work of electric current (Joule heating):



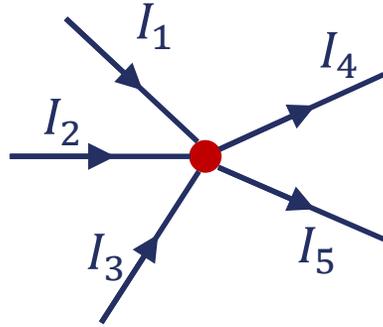
Electric power:

Electric current



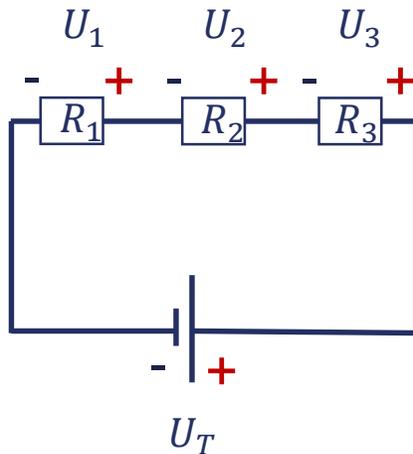
Gustav Robert
Kirchhoff
1824-1887

Kirchhoff's I. Law (junction law):



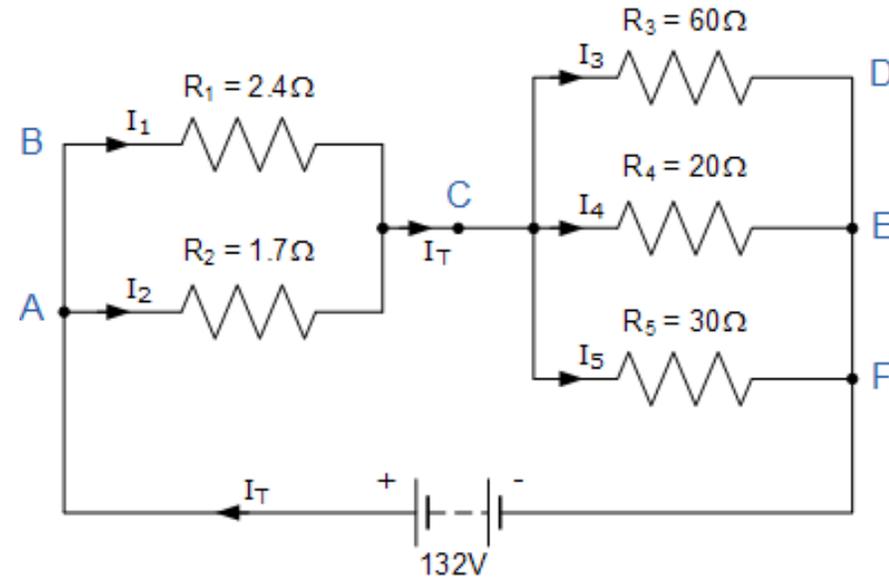
as a result of conservation of electric charge, the currents flowing into a junction are equal to the currents flowing out of that junction. In other words, in a branched (parallelly connected) circuit current is partitioned between the branches.

Kirchhoff's II. Law (Loop law):



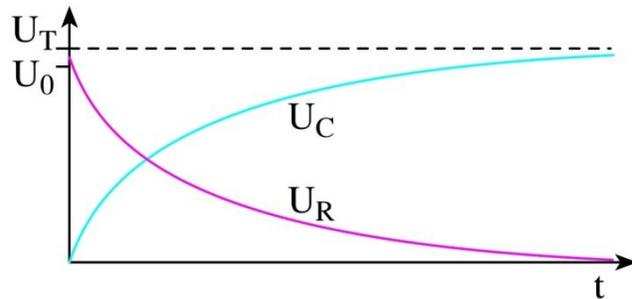
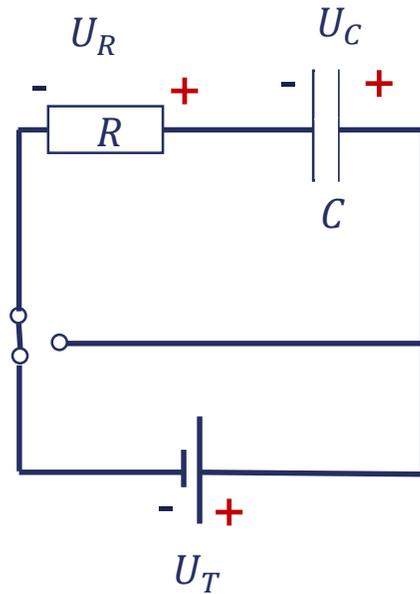
as a result of conservation of energy, the directed sum (i.e., considering the signs) of voltages of electrical components along a loop within an electrical circuit is zero. In other words, within a loop (e.g., serially-connected circuit) voltage is partitioned between the electric components (e.g.,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

Calculate the individual currents flowing through each resistor branch!

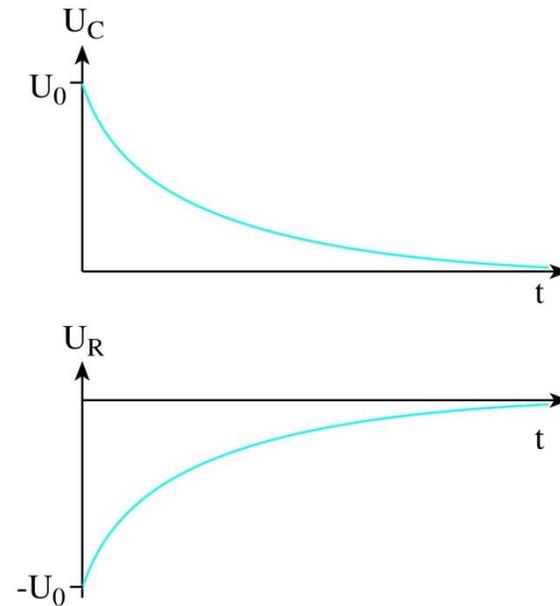
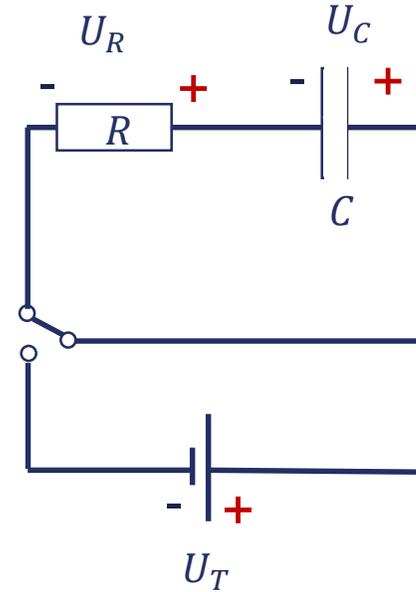


Electric current: RC circuit (in series)

Charging the RC circuit

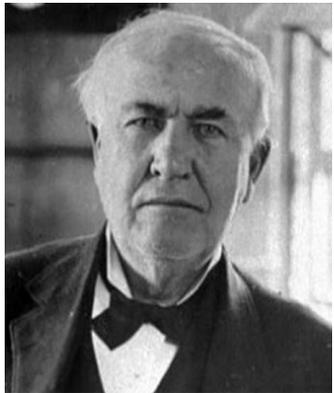
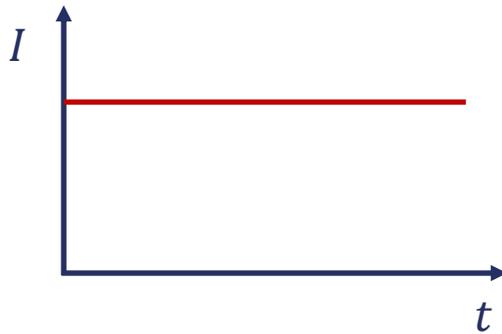


Discharging the RC circuit



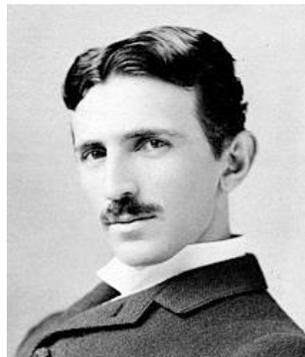
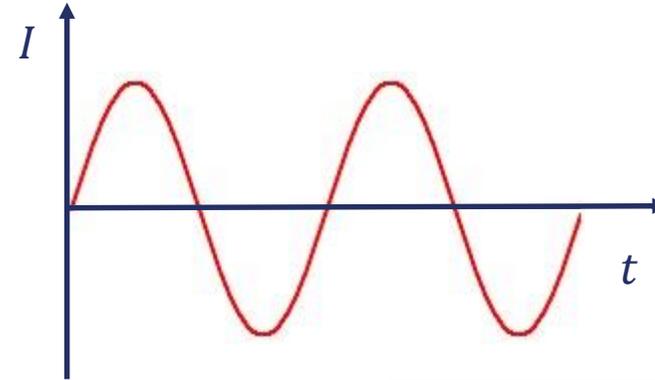
Electric current

Direct current, DC

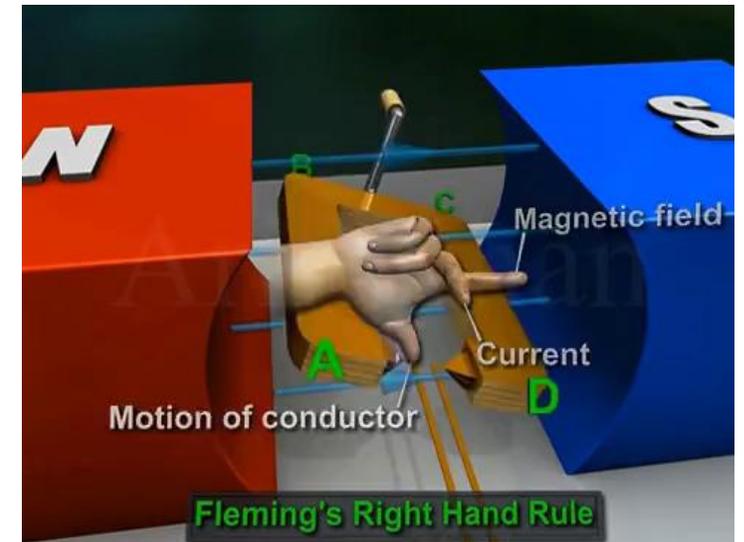


Thomas Alva
Edison
1847-1931

Alternating current, AC



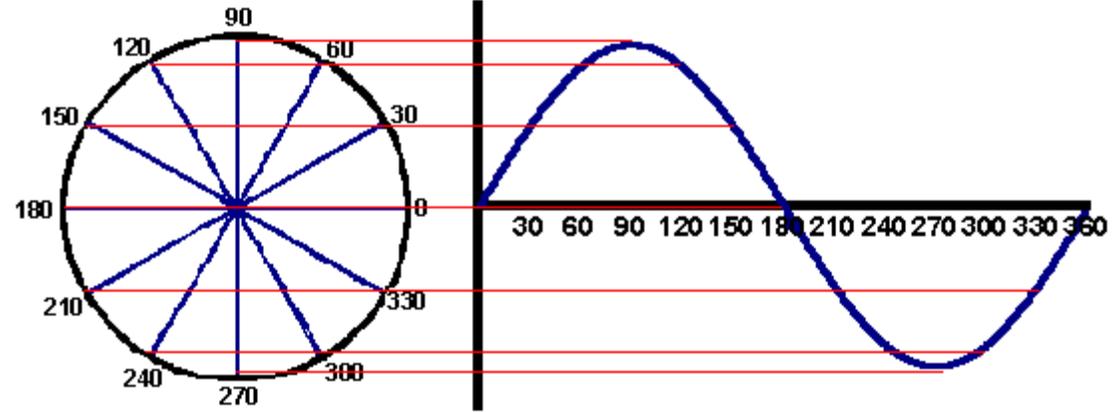
Nikola Tesla
1856-1943



Fleming's Right Hand Rule

Find the capacity that can be used with $10\text{M}\Omega$ resistance to construct an RC circuit with a time constant of 1s. Calculate the percentage of the initial voltage remaining in this RC circuit after discharging for 2s.

The time constant of an RC circuit is 0,6s. What voltage will the capacitor be charged to after 1s, if the source voltage is 100 V? How long will it take for the capacitor to discharge from the calculated voltage by half?



Electric current

Capacitor in an AC circuit

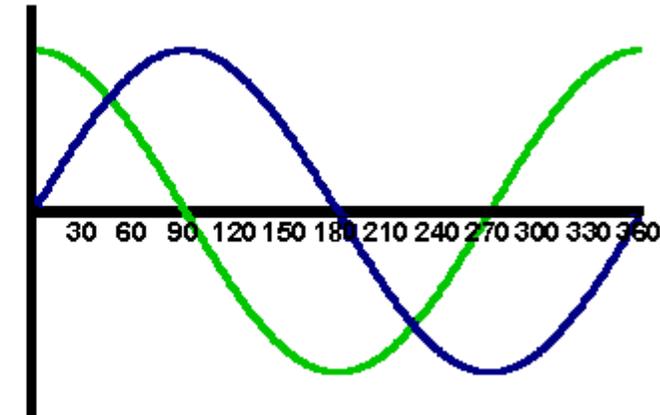
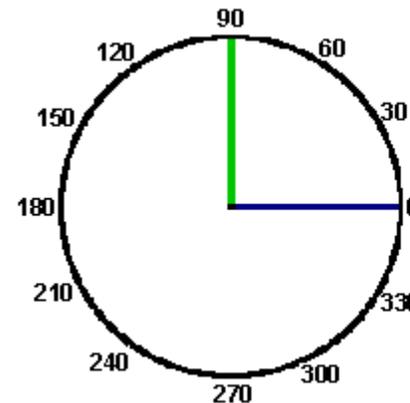
Capacitive reactance:

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

$$Z \text{ } [\Omega] \text{ Ohm}$$

In series RC circuit:

In parallel RC circuit:



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

What is the ratio of the electric force to the gravitational force between a proton and an electron separated by 53 pm (the radius of a hydrogen atom)? Mass of proton : $1,67 \times 10^{-27}$ kg; mass of electron: $9,1 \times 10^{-31}$ kg

$$\gamma = 6,67 \cdot 10^{-11} \frac{m^3}{kg \cdot s^2}; k=9 \cdot 10^9 \frac{Nm^2}{C^2}$$

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 $1.78 \cdot 10^{-8} \text{ } \Omega\text{m}$. 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: $U = 325 \text{ V} \cdot \sin(314 \text{ s}^{-1} \cdot t)$. 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 $U = 34 \text{ V} \cdot \sin(6283 \text{ s}^{-1} \cdot t)$ 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. a) 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 529Ω . 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 ($C = 20 \mu\text{F}$) 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 ($R = 1200 \Omega$). 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 $q = 0.1 \text{ C}$ charge is uniformly moved in a homogeneous electric field ($E = 1\,200 \text{ N/C}$) 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 ($m = 9.11 \cdot 10^{-31} \text{ kg}$), i.e., we neglect the relativistic mass increase?



kosa.nikolett@semmelweis.hu

Thank you!

