Biothermal physics

Eight lecture

Bioelectricity

Part I

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Third Stage

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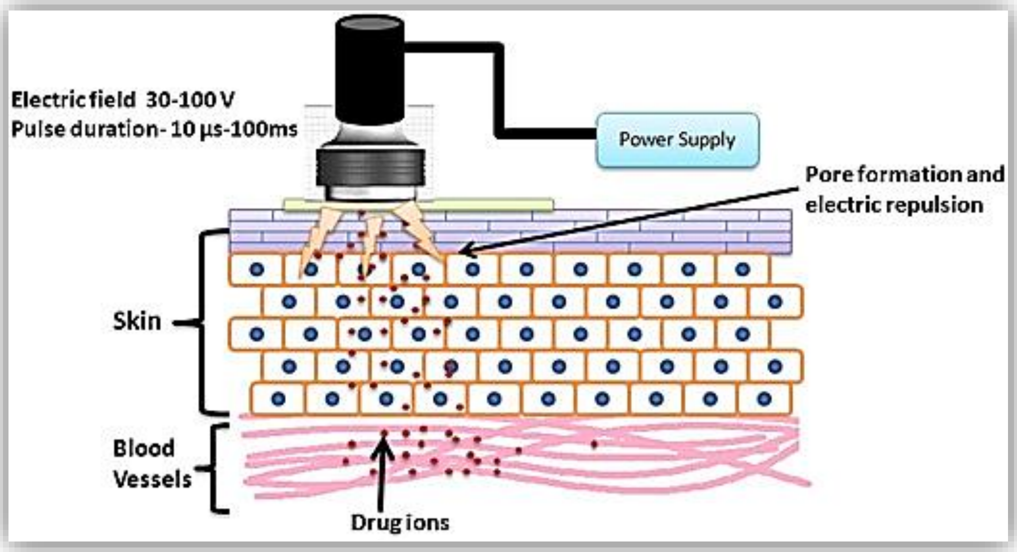
Introduction

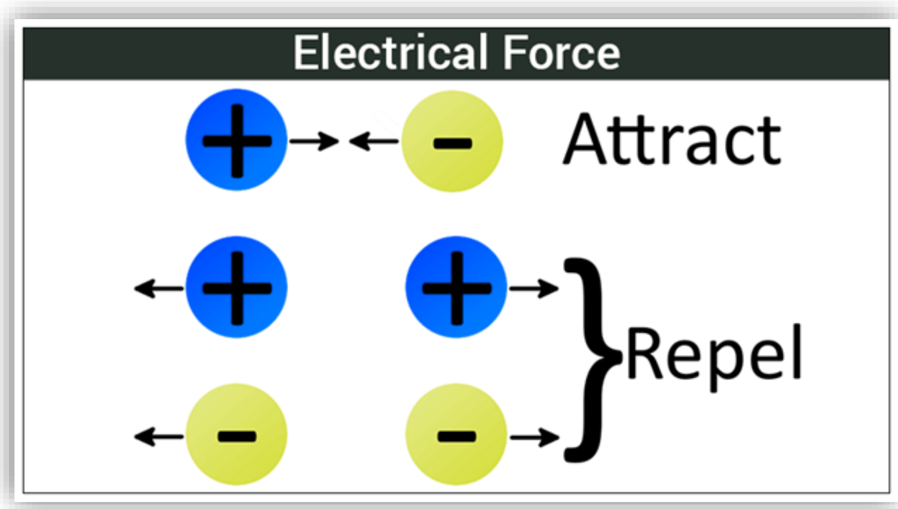
- **Bioelectricity** typically refers to the electromagnetic energy produced by living organisms.
- Such energy is usually manifested as ***ionic currents*** at ***nerves*** or ***muscles*** due to the propagation of the so called ***action potentials***.
- **Bioelectricity** also refers to the study of the interaction of externally applied electromagnetic energy with living organisms, as it is the case of the electroporation phenomenon**.**
- **Electroporation** is defined as a technique to increase cell membrane permeability to hydrophilic molecules under an applied electric field.



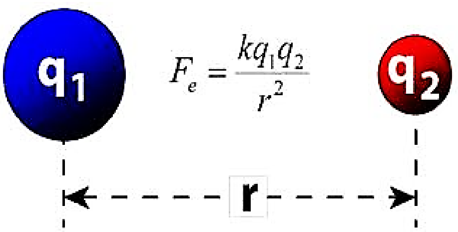
Overview of basic electricity concepts

- ***Electric charge (Q)***: is the fundamental property of subatomic particles that determines their electromagnetic interaction.
- ***The unit used to express the amount of charge*** is the ***coulomb*** (C)
- The charge of a ***proton*** is $+1.602 \times 10^{-19}$ C.
- The charge of an ***electron*** = -1.602×10^{-19} C.

- ***The electric charge of larger particles***, such as ***ions*** or ***molecules***, is an integer multiple of the elementary charge.
- Particles with charges with the ***same sign repel one another***, whereas ***opposite sign charged particles attract***.

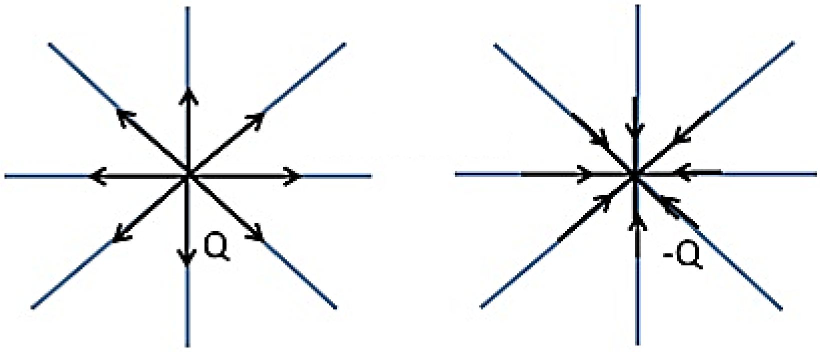


- ***Electric force*** The attractive or repulsive interaction between any two charged objects.
- The magnitude of this force ***is proportional to the product of their charges and the inverse square of the distance between them***. ***This state of Coulomb's law***



- ***The electric field (E)***: at a given point expresses the force that would be exerted on a positive charge of 1 coulomb placed at that point.
- The electric field is ***a vector*** (i.e. ***magnitude*** and ***direction***).

- ✓ Each charged particle creates an electric field which is proportional to its charge, inverse to the square of the distance and that points towards, or against, the particle depending on the sign of the charge.



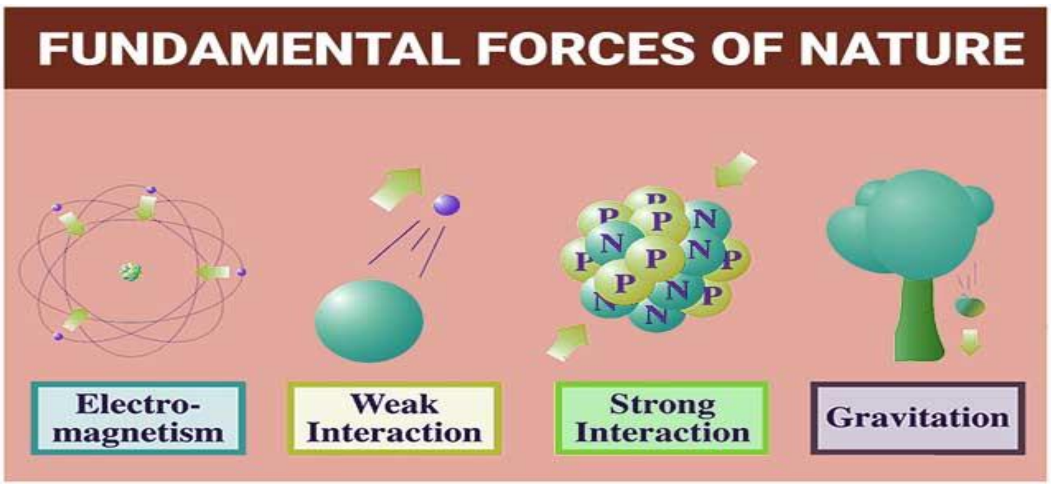
$$E(r) = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}\hat{\mathbf{r}}$$

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r^2}\hat{\mathbf{r}}$$

$$F(r) = q\,E(r)$$

Electric field due to charge Q and -Q

- ✓ ***The electric field concept*** comes from the fact that at any point the electric field is calculated as the summation of the electric fields created by each one of the charged particles independently.
- ✓ ***Moving electric charges*** generate ***magnetic fields*** and alternating magnetic fields cause electric charges to move.
- ✓ The ***velocity*** and ***trajectory*** of moving electric charges are affected by magnetic fields which in turn are effect by the moving electric charges.
- ✓ As a matter of fact, ***electric forces*** and ***magnetic forces*** are both manifestations of the ***electromagnetic*** force, which is one of the four fundamental forces identified in nature.



- ***Voltage*:** is defined as a difference in energy values due to the electric field.
- When the electric field is constant through the trajectory A-B (e.g. in an infinitesimal trajectory) then the ***voltage equals the electric field times the distance***.
- For that reason, ***the electric field (E) units are V/m***.
- The direction of E indicates in which direction the maximum drop in voltage is produced and the magnitude of E represents the value of this voltage drop.
- If an electric path exists between two points with different voltages, then free electric charges will move from the high energy position to the low energy position.
- ***The electric current*** value indicates the flow of electric charge through the cross-section of the electric path in a second.
- A lot of materials exhibit a ***linear relationship*** between the ***electric current*** and the ***voltage difference***. This relationship is known as the ***Ohm's law*** and the constant that relates both parameters is ***the resistance***:

Resistance symbol

$$R = \frac{V}{I}$$

- where R is the resistance (units: ohms, Ω), V is the voltage difference (units: volts, V) and I is the current that flows through the resistance (units: amperes, A).
- The inverse of the resistance (G = 1/R = I/V) is called ***conductance*** and is expressed in Siemens, S.
- It is important to note that ***power is dissipated as heat at any conductor.*** This phenomenon is known as ***Joule heating*** and it is also referred to as

ohmic heating or ***resistive heating*** because of its relationship with the Ohm's law:

$$P_{dissipated} = VI = I^2 R = \frac{V^2}{R} = V^2 G$$

- ***Current density*** (J, units: A/m^2) which is the electric current per unit area of cross section.
- It is also possible to define the "resistance" of each infinitesimal portion of a conductive medium: the ***resistivity*** (ρ; "rho") of a material at a specific point can be formally defined as:

$$\rho = \frac{\mathbf{E}}{\mathbf{J}}$$

- The resistivity can also be defined as:

$$\rho = R \frac{S}{L}$$

- where R is the resistance that a cylinder of the material (S is the cross-sectional area of cylinder and L is its length) exhibits between its opposite flat surfaces.
- Therefore, the units for the resistivity are $\Omega.m$ $(= \Omega.m^2/m)$.
- ***The inverse of the resistivity*** is the ***conductivity*** (σ = 1/ρ) and it is expressed in S/m (Siemens/meter).
- The dissipated power due to Joule heating at unitary volume, that is, the ***dissipated power density*** (units are ***watts/cubic meter***), can now be written:

$$p_{dissipated} = \frac{|\mathbf{E}|^2}{\rho} = \sigma |\mathbf{E}|^2$$

- ***Example: for Joule heating***

  1. If a pulse of 1000 V/cm (100,000 V/m) is applied to a living tissue and conductivity for tissues is about 1.5 S/m.

The dissipated power density $P_{dissipated} = \sigma \,|E|^2 = 15\times10^9$ W/m^3

2. If the pulse is 100 microseconds (μs) long, then the dissipated energy density (energy = U = power × time) will be 1.5 ×106 J/m^3 (joules/cubic meter).

3.If we assume that the thermal properties of the tissue are equal to those of liquid water and that no heat is lost by radiation, diffusion or convection, then the temperature rise (ΔT) due to the pulse would be:

$$\Delta T = \frac{U}{c\,d} = 0.36 \text{ K}$$

where c is the specific heat capacity (c_{water} = 4.184 J/ (g.K), joules/ (grams × kelvin)) and d is the mass density (d_{water} = 0.997×106 g/m^3).