Medical physics

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Physics of Electrical and Magnetic Properties

- Electric and magnetic fields are closely coupled in many areas of physics

- electromagnetic waves

❖ Magnetic fields appear when current flows

Review of Electrical Properties

Coulomb's Law

$$E = \frac{kq}{r^2}$$

The potential of that charge is:

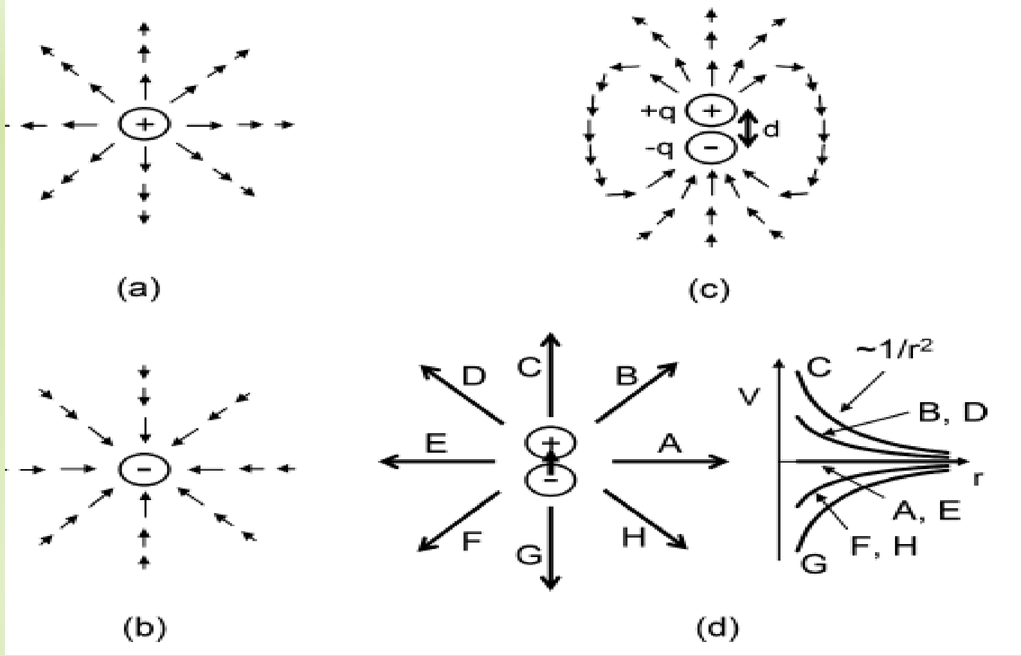
$$V = \frac{kq}{r}$$

$$\Delta V = V_b - V_a = -\int_{r_a}^{r_b} \mathbf{E} \cdot d\mathbf{r}.$$

$$\mathbf{E} = -\nabla V$$

$$E = -\frac{dV}{dx}.$$

Electric dipole moment



- there are two charges q and −q in vacuum separated, say a distance d
- the expression for the potential can be simplified to give
- Where P = qd is the electric dipole moment vector, which has magnitude P = qd and points in the d direction. If the angle between the dipole vector P and distance vector r is θ, then this equation becomes

$$V = \frac{kP\cos\theta}{r^2}.$$

moving particle

- let us consider a moving particle with charge q
- the current, $I = dq/dt$
- current density $J = I/A$

This conservation of current (and charge) is known as Kirchhoff's 1st Law

$$\sum_n I_n = 0.$$

THE RESISTANCE

- The resistance is an extensive property that depends on the intensive property resistivity ρ of the material, and the cross-sectional area A and length L of the structure.

$$R = \frac{\rho L}{A}.$$

- For a cylinder with radius a, we have A = πa2 and R = ρL/πa2. More generally, for a structure with uniform cross-section, the resistance R is proportional to length and we can define a resistance per unit length the conductivity is

$$\sigma = 1/\rho$$

The Electrical Conduction through Blood and Tissues

- The conductivity σ of a solution is the sum of the contributions to the current flow for each ion

$$\sigma = \sum_i n_i \Lambda_{0,i}.$$

tissue	resistivity
cerebrospinal fluid	0.650
blood plasma	0.7
whole blood	1.6 (Hct = 45%)
skeletal muscle	
– longitudinal	1.25–3.45
– transverse	6.75–18.0
liver	7
lung	
– inspired	17.0
– expired	8.0
neural tissue (as in brain)	
– gray matter	2.8
– white matter	6.8
fat	20
bone	>40
skin	
– wet	10^5
– dry	10^7

this contribution is proportional to the concentration n_i for that ion, with a proportionality constant $A_{0,i}$ which is the molar conductance at infinite dilution for several common ions. The resistance of a path can be determined using:

In the body

- charged ions, such as Na^{+}, K^{+}, Ca^{2+}, Cl^{-}, and negatively-charged proteins, are the important carriers of charge

- Electrons are the charge carriers in most man-made electronic circuits

- A voltage or potential difference V can also develop between two structures, one with a charge +q and the other with charge −q, because of the electric fields that run from one to the other. This voltage is

$$V = \frac{q}{C},$$

Electrical Conduction through Blood and Tissues

- When voltage is applied across a materical ⟶ a current flows because electrons move under the influence of an electric field

- When a voltage is applied ⟶ across a solution containing positive and negative ions current flows because both ions move under the influence of the electric field

- The conductivity σ of a solution is the sum of the contributions to the current flow for each ion.

$$\sigma = \sum_i n_i \Lambda_{0,i}.$$

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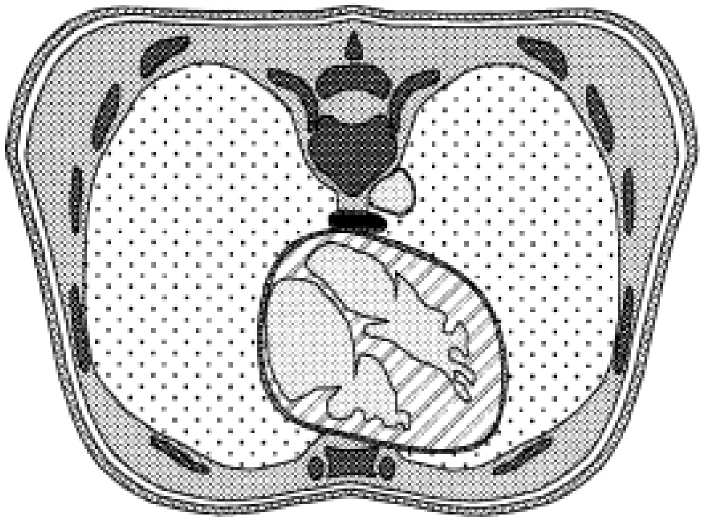


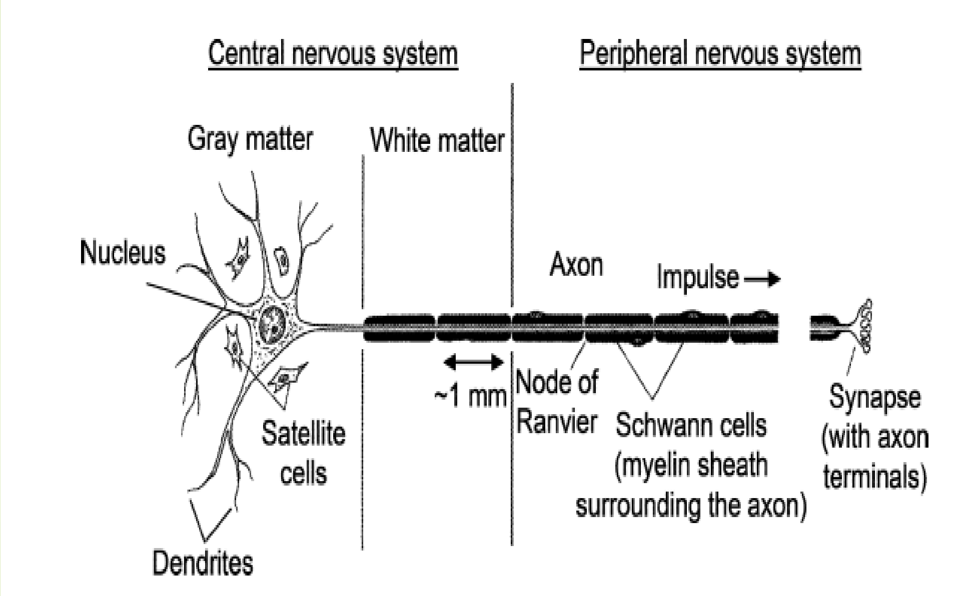
Tissue	Resistivity [Ω m]
Blood	1.6
Heart muscle	2.5 (parallel to fibers)
	5.6 (normal to fibers)
Skeletal muscle	1.9 (parallel to fibers)
	13.2 (normal to fibers)
Lungs	20
Fat	25
Bone	177

THE NERVOUS SYSTEM

- The most remarkable use of electrical phenomena in living organisms is found in the nervous system

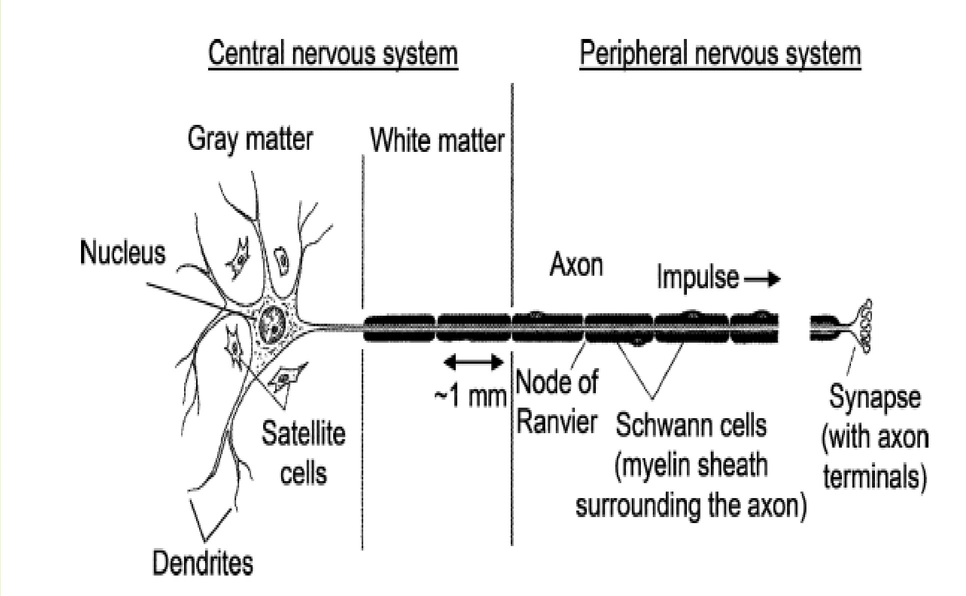
- Specialized cells called *neurons* form a complex network within the body which receives, processes, and transmits information from one part of the body to another.

- When a neuron receives an appropriate stimulus, it produces electrical pulses that are propagated along its cable like structure.



THE NERVOUS SYSTEM

- The neurons, which are the basic units of the nervous system, can be divided into three classes: *sensory* neurons, *motor* neurons, and *interneurons*



- 1-**The sensory neurons** :receive stimuli from sensory organs. Depending on their specialized functions, the sensory neurons convey messages about factors such as heat, light, pressure, muscle tension
- 2-**The motor neurons** carry messages that control the muscle cells
- 3-**The interneurons** transmit information between neurons

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THE NERVOUS SYSTEM

- The ability of the neuron to transmit messages is due to the special electrical characteristics of the axon.

- Most of the data about the electrical and chemical properties of the axon is obtained by inserting small needle like probes into the axon. With such probes it is possible to measure currents flowing in the axon and to sample its chemical composition.

- Such experiments are usually difficult as the diameter of most axons is very small. Even the largest axons in the human nervous system have a diameter of only about 20 μm(20×10^{-4} cm).

Electrical Signals in the Brain

- Electrical signals are important as in other parts of the body, such as the electroencephalograms (EEGs) of brain waves

- The EEG signal is irregular, but it has identifiable rhythmic patterns:

- alpha waves (frequency of 8–13 Hz; awake, restful state)
- beta waves (14–25 Hz; alert wakefulness, extra activation, tension)
- theta waves (4–7 Hz, mostly in children, also adults with emotional stress and with many brain disorders),
- delta waves (<3.5 Hz; deep sleep)

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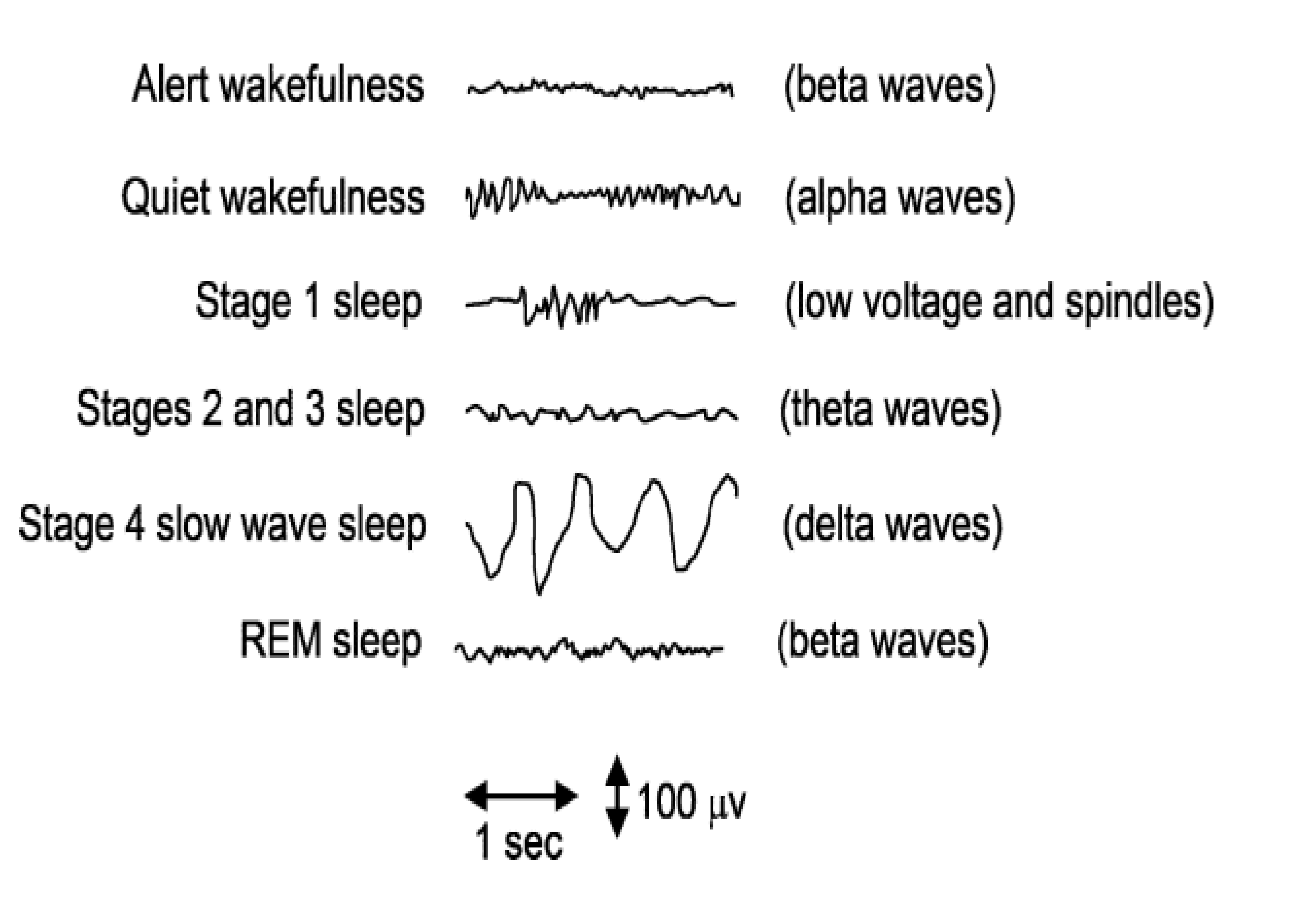

Effect of currents (in mA) on the human body (for about 1 s).

Electrical Signals in the Brain

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effect	DC	AC (60 Hz)
slight sensation at contact point	0.6	0.3
perception threshold	3.5	0.7
shock		
– not painful, no loss of muscular control	6	1.2
– painful, no loss of muscular control	41	6
– painful, let-go threshold	51	10.5
– painful, severe effects: muscular contractions, breathing difficulty	60	15
– possible ventricular fibrillation (loss of normal heart rhythm)	500	100

l values are approximate.

Electrical Signals in the Brain

- The Biot-Savart Law determines the magnetic field from currents. Consider a continuous current I flowing along the infinitely long z-axis. Using the Biot- Savart Law, one can show that a distance R away the magnetic field B has magnitude
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$$B = \frac{\mu_0 I}{2\pi R}$$


Thank you