# An Electrical Model of Propagation of Signals in the Nerve Axon

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*Abstract* - **Nowadays with the projects going on in prosthesis technology becomes more important. It's necessary to use Electromyogram (EMG) in the process of replacing a lost limb. The nerve impulses to be sent to the ghost of that limb can be detected and this then transferred to the prosthesis.**

**The present lab work is designed to give the student knowledge about the nerve system and the conduction process. This knowledge will be utilized during the measurement of nerve propagation speed, and the display and evaluation of the resulting data. While doing the lab, the student will also get practice in various aspects of general signal acquisition**.

## INTRODUCTION

Since the experiment focuses on detecting nerve impulses, it would be convenient to explain the function of the nerve system, and later, go through the single nerve impulse. The nerve cell may be divided on the basis of its structure and function into three
main parts[1]:

- the cell "body", also called the soma
- numerous short processes of the "soma", called the "dendrites"
- the single long nerve fiber, the "axon"

The short processes of the cell body, the dendrites, receive impulses from other cells and transfer them to the cell body. The long nerve fiber, the "axon", transfers the signal from the cell body to another nerve or to a muscle cell. Mammalian axons are usually about 1-20 μm in diameter. Some axons in larger animals may be several meters in length. The axon may be covered with an insulating layer called the "myelin sheath", which is formed by "Schwann cells" (Fig. 1).

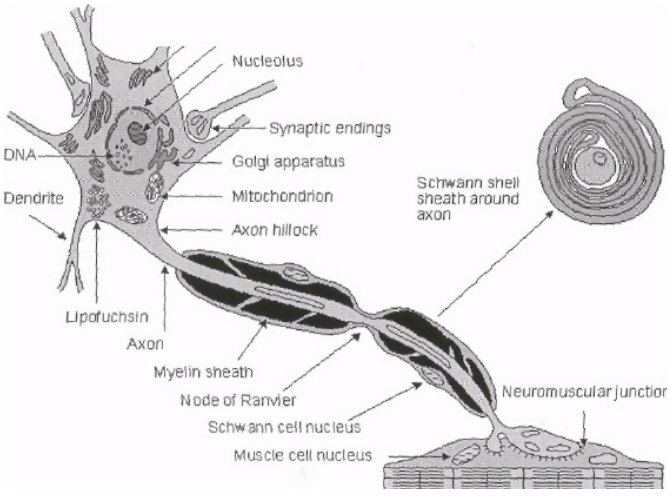


Fig. 1 - The major components of neuron

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The membrane voltage Vm(transmembrane voltage) of an excitable cell is defined as the potential at the inner surface $C_J$ relative to that at the outer $C_i$ surface of the membrane, i.e. Vm = Cj - $C_i$. If a nerve cell is stimulated, the transmembrane voltage necessarily changes. After stimulation the membrane voltage returns to its original resting value. If the excitatory stimulus is strong enough, the transmembrane potential reaches the threshold, and the membrane produces a characteristic electric impulse, the nerve impulse. This potential response follows a characteristic form regardless of the strength of the transthreshold stimulus. The response of the membrane to various stimuli of changing strength can be find on Fig. 2

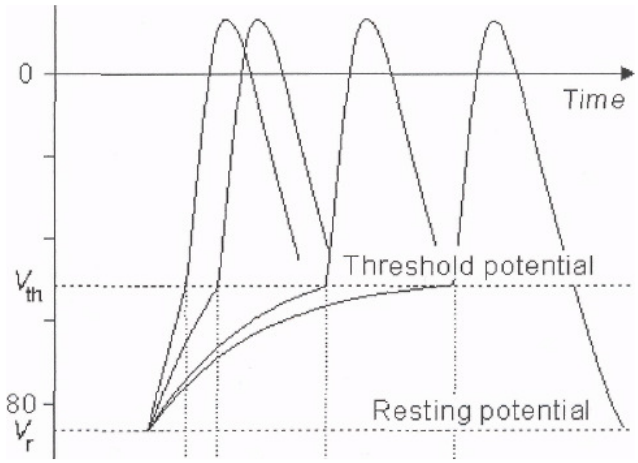


Fig. 2 - The response of the membrane to various stimuli of changing strength

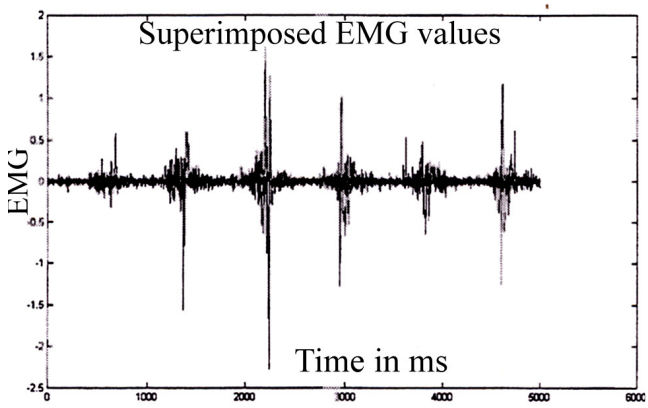


Fig. 3 EMG of a resting biceps, stimulated occasionally, and the contraction moments.

When measuring, if there is no forced contraction of the muscle, a signal resembling white noise is seen. When the target muscle is stimulated, in this case with the use of a

electrical stimulator, the seen signal should be more distinctive[3].

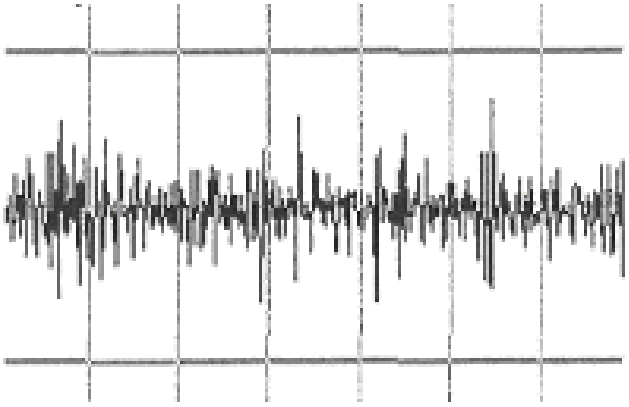

Fig. 4a

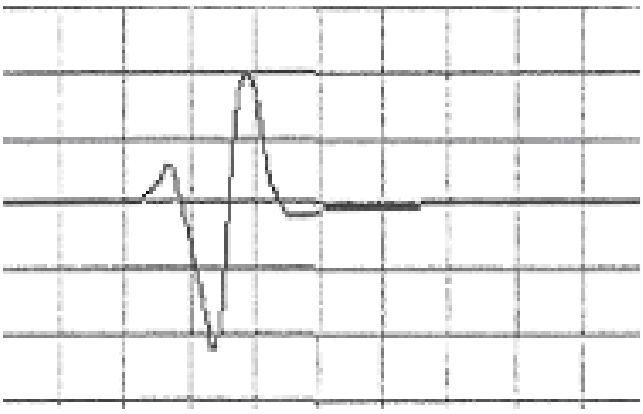

Fig. 4b

Fig. 4. A muscle group at constant contraction (4a), and the EMG of one contraction of a muscle fiber (4b).

The spikes occur when the right arm makes a contraction can be seen on Fig.3. The activity in the muscle can easily be seen, compared to the times of rest. The first one (Fig.4.a) is a contracted muscle, which seems like nose, having many components in different frequencies, seemingly random[4]. The picture (Fig.4b) shows the EMG taken from a single fiber, where a clear signal can be obtained.fig.4a Fig.4b It's well known[2] that the concentration of sodium ions (Na+) is about 10 times higher outside the membrane than inside, whereas the concentration of the potassium (K+) ions is about 30 times higher inside as compared to outside. When the membrane is stimulated so that the transmembrane potential rises about 20 mV and reaches the threshold - that is, when the membrane voltage changes from -70 mV to about -50 mV (these are illustrative and common numerical values) - the sodium and potassium ionic permeabilities of the membrane change. The sodium ion permeability increases very rapidly at first, allowing sodium ions to flow from outside to inside, making the inside more positive. The inside reaches a potential of about +20 mV. After that, the more slowly increasing potassium ion permeability allows potassium ions to flow from inside to outside, thus returning the intracellular potential to its resting value. The maximum excursion of the membrane voltage during activation is about

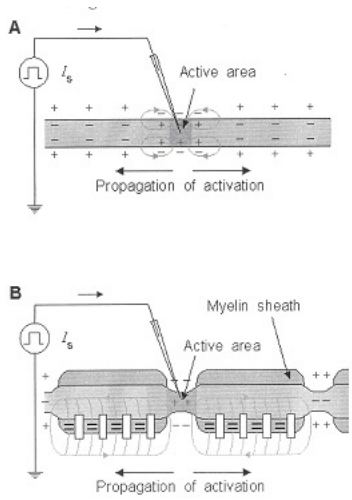


Fig.5
**A - Continuous conduction of a nerve impulse in a nerve axon in an unmyelinated axon**
**B - Saltatory conduction of a nerve impulse in a nerve axon in a myelinated axon.**

100 mV; the duration of the nerve impulse is around 1 ms. While at rest, following activation, the Na-K pump restores the ion concentrations inside and outside the membrane to their original values. The activation propagates in an axon as anunattenuated nerve impulse.[3]. The potential difference between excited and unexcited regions of an axon would cause small currents, now called "local circuit currents", to flow between them in such a direction that they stimulate the unexcited region. Although excitatory inputs may be seen in the dendrites and/or soma, activation originates normally only in the soma. Activation in the form of the nerve impulse (action potential) is first seen in the root of the axon - the initial segment of the axon, often called the "axon hillock". From there it propagates along the axon. If excitation is initiated artificially somewhere along the axon, propagation then takes place in both directions from the stimulus site. The conduction velocity depends on the electric properties and the geometry of the axon. An important physical property of the membrane is the change in sodium conductance due to activation.[4] The higher the maximum value achieved by the sodium conductance, the higher the maximum value of the sodium ion current and the higher the rate of change in the membrane voltage. The result is a higher gradient of voltage, increased local currents, faster excitation, and increased conduction velocity. The decrease in the threshold potential facilitates the triggering of the activation process. The velocity also depends on the resistivity of the medium inside and outside the membrane since these also affect the depolarization time constant [4]. The smaller the resistance, the smaller the time constant and the faster the conduction velocity. The temperature greatly affects the time constant of the sodium conductance; a decrease in temperature decreases the conduction velocity. A myelinated axon (surrounded by the myelin sheath) can produce a nerve impulse only at the nodes of Ranvier. The fig.5 shows propagation of signals. In these axons the nerve impulse propagates from one node to another, as illustrated in Fig. 5B. Such a propagation is called saltatory conduction In unmyelinated axo the conduction is continuous and slower on Fig. 5A.

The membrane capacitance per unit length of a myelinated axon is much smaller than in an unmyelinated axon. Therefore, the myelin sheath increases the conduction

velocity. The resistance of the axoplasm per unit length is inversely proportional to the cross-sectional area of the axon and thus to the square of the diameter. The membrane capacitance per unit length is directly proportional to the diameter. Because the time constant formed from the product controls the nodal transmembrane potential, It is reasonable to suppose that the velocity would be inversely proportional to the time constant. On this basis the conduction velocity of the myelinated axon should be directly proportional to the diameter of the axon. Some experimental investigations were done in the cases of different diameters of the axons (different parts of the bodies and different animals) The experimental results can be find on the fig.6 as points. The conduction velocity in myelinated axon has the approximate value shown:

$$v = 6d$$

where

v= velocity of the nerve impulse [m/s]

d= axon diameter [μm]

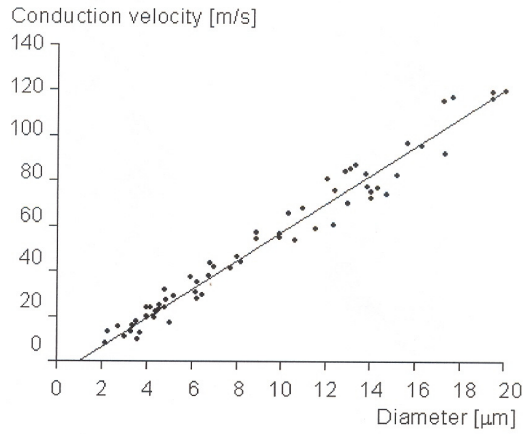


**Figure 6 - Experimentally determined conduction velocity of a nerve in a mammalian myelinated axon as a function of the diameter.**

Fig. 6. Experimentally determined conduction velocity of a nerve impulse in a mammalian myelinated axon as a function of the diameter.

## CONCLUSION

1.The method for investigation of EMG, presented in the paper, is designed to give the student know-ledge about the nerve pulses and the conduction process.

2. An electrical model of propagation of signals in the nerve axon is described in the paper.

3. Experimentally determined conduction velocity of a nerve impulse in a mammalian myelinated axon as a function of the diameter was obtained in the process of investigation.

## REFERENCES:

[1] http://www.lucs.lu.se/arthand/,

[2] http://uc.rutgers.edu/news/science/arthand2.html

[3] rhttp://www.medicine.mcgill.ca/physio/vlabonline/cnslab/cnstheory.htm1

[4] rhttp://web.media. mit.edu/~marrin/CIM.htm1