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On biological signaling

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Abstract: Presently, nerve pulse propagation is understood to take place by electric action pulses. The theoretical description is given by the Hodgkin-Huxley model. Recently, an alternative model was proclaimed, where signaling is carried out by acoustic solitons. The solitons are built by a local phase transition in the lyotropic liquid crystal (LLC) of a biologic membrane. We argue that the crystal structure arranging hydrogen bonds at the membrane surface do not allow such an acoustic soliton model. The bound water is a component of the LLC and the assumed phase transition represents a negative entropy step.

Keywords: biological signaling, biophysics, bound water at liquid crystals, mechano properties of membranes.

Until now, biological signaling is assumed to be performed by electric potential pulses, which propagate along interacting neurons on membranes. A biological electrical signal is shown in Figure 1. The pulse has a peak voltage of about 100 mV and a time length of about 2 ms. This voltage is produced by ion pumps, which are separated differently corresponding to the potential Sodium (Na^+) and Potassium (K^+) ions across the membrane surface. This model of action potential was introduced by Hodgkin and Huxley in 1952 [1].

The photons of the electric field pulses are coupled with the membrane molecules to so-called polaritons. They determine the dielectric response of electromagnetic waves.

The biological membrane is a lyotropic liquid-crystal (LLC). That means the fluid and the gel crystal like structures take place only in a liquid, which in most cases is the biological membrane's water. One of the dominant human membrane molecules is Dimyristoyl-glycerol-phosphorylcholine (DMPC), which is sketched in Figure 2 [3].

The transition temperature from the gel to the liquid phase is below the human body temperature, it is about 20 °C [4]. Human being's cell membranes are always in the liquid phase

The periodic structure of both phases is correlated with the hydrogen bonds of the water layers on top of the polar headgroups of the lipids [3, 4]. The energy of a hydrogen bond is ≈ 130 meV in the case of phospholipids [4].

Up to 15 H_2O molecules/lipids are bound at the membrane surface in order to build the LLC structures [3, 4]. The LLC of a double layer DMPC membrane is sketched in Figure 3.

However, up to 45 water molecules per lipid molecule can get bound to the membranes, structuring the phases of the LLC [4]. A loss of the bound water is the reason for the freezing and the dryness effects of creatures and plants.

Recently, Heimburg [6–8] has developed a signaling soliton model due to a phase transition from the fluid to the gel state. Such a soliton of some ms duration would reduce the diameter of an axon membrane >1 nm [10–13]. The size change in both axial and radial directions might influence the interaction at the synapses between two adjacent nerve cells. Above we speculated that such a phase transition is effective in the case of cryogenic anesthesia, i. e., local cooling tissue. A phase transition can cause a breakdown of the signal transport due to a size mismatch of the synapses in the fluid/gel transition of the membrane. The size reduction takes place in radial as well in the axial directions by more than 25%. This may explain the anesthetic elimination of pain by cryogenics therapy. Local cooling could depress the freezing point of the LLC and thus cause the membrane phase transition from the fluid to the gel state. Obviously, the gel phase does not produce and transmit signals.

As mentioned above, this liquid to gel transition of the membrane's molecules was suggested to be the basis for the biological signal in opposition to the ion model of Hodgkin and Huxley. Especially, Heimburg [6–9] is vehemently claiming that the signal is formed by an acoustic soliton in the gel phase. This process would represent a local transition to the lower entropy of the gel phase and would result in a negative entropy step and also a reconstruction of the hydrogen bonds geometry at this part of the membrane. However, in Heimburg's model the bound water has been never considered. The hydrogen bonds are in charge of both, the fluid and the gel phase structures. Figure 3 displays the arrangement in the gel phase [3, 4].

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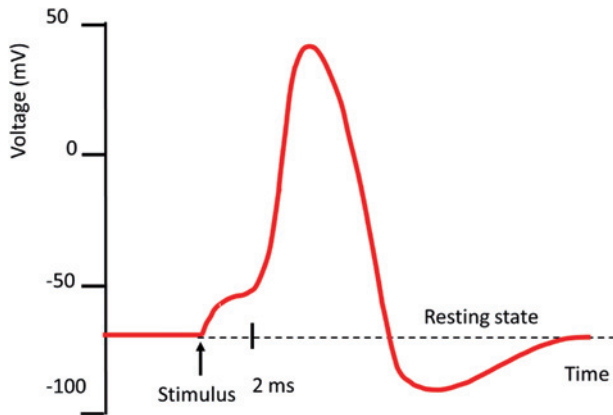


Figure 1: Membrane potential as measured e. g., along human and plant's [2] nerve circuits.

In addition, the synapsis connection of the adjacent neurons would display a mismatch. Such a mismatch of adjacent dendrites represents an interruption or at least a geometrical discontinuity due to the large number of molecules performing a signal soliton in the gel phase.

The medium of a membrane is not a pure elastic one, as mentioned above, the medium is based on polaritons. The ions and the molecules are coupled as polaritons.

Their characteristics are measured by their dielectric properties, and estimating the size of the soliton [4, 5] should be taken into account.

As already stated above the water molecules near the membrane surface perform hydrogen bonds with the head group of the phospholipids [3]. The hydration geometry is part of the molecular arrangement. Its interaction energy and its geometrical structures are different in the two phases of the LLC and has to be taken into considerations.

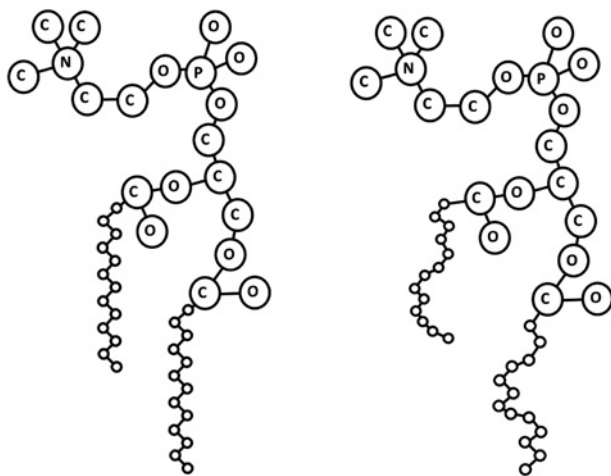


Figure 2: The all-trans (left) and the trans-gauche (right) hydrocarbon chains of a DMPC molecule.

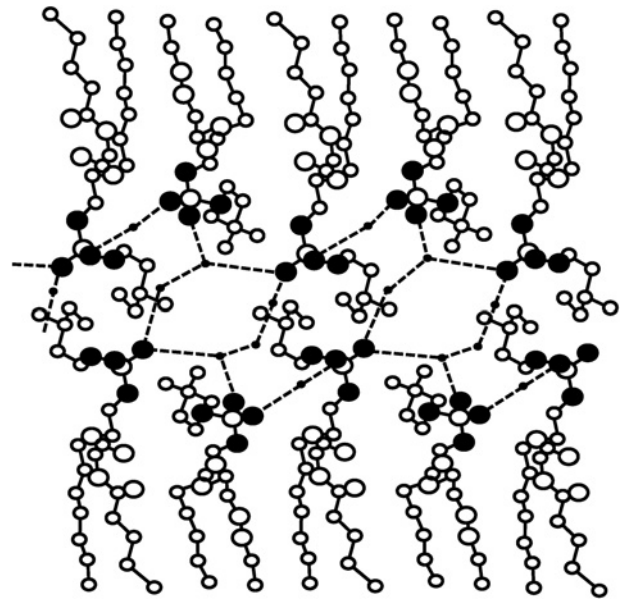


Figure 3: Shows an example of arranging the DMPC LLC head groups by hydrogen bonds. The dotted lines represent the hydrogen bonds between two DMPC bilayers in the gel phase [3, 4]. The large black points are oxygen, the small ones are hydrogen atoms. Obviously, the hydrogen bonds are in charge of the liquid crystal arrangement [3].

For a membrane molecule the activation energy of the bound water in the fluid phase was found to be 475 meV [4].

The generation of solitons as signal carriers should take the hydrogen bonds at the phase transition and the geometrical mismatch at the synapses into account. The ends of the axons are expected to have a considerable amount of glycolipids [14].

Achim Enders studied the dielectric influence of a number of gaseous anesthetics at the membrane surface. He observed a coupling with the bound water at the membrane surface for all the investigated chemically different anesthetics [14].



Figure 4: Sketch of the gel (left) below the melting point and the fluid phase (right) of the DMPC LLC. The head groups of the molecules are represented by the black oval.

Incidentally, Erwin Schrödinger introduced a negative entropy in order to explain *What Is Life?* [15]. However, he thought this hypothesis to be the reason for the general stability of life and not to form a gel state for the action potential.

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