The Axon: Restructuring Waves and Electrical Currents

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ABSTRACT

An article "**The Brain, Reimagined**," by Douglas Fox (Sci. Am., v.27, No 3, Fall 2018) concerns work by physicists T. Heimburg and A.D. Jackson, who argue that signals in neurons are conveyed by mechanical waves of expansion and contraction of the cell membrane rather than by electrical spikes, or action potentials, as described by the Huxley-Hodgkin theory. But the chief provisions of this theory are firmly established.

Hypothesis on the honeycomb structure of the lipid biomembrane by Dr. R.-H.N. Mikelsaar makes it possible to remove the contradictions between these two concepts.

These authors Thomas Heimburg and Andrew D. Jackson from the Niels Bohr Institute in Copenhagen discovered that when a nerve signal is transmitted in the axon's membrane he is accompanied by a shock wave that travels down the axon [T. Heimburg, A.D. Jackson, Proc. Nat. Acad. Sci. 102, 9790 (2005)]. Their main statement: **As the wave front advances, it squeezes the lipid molecules, briefly changing them from fluid to liquid crystalline, making them bulge and release heat. As the wave passes, the molecules revert back to fluid form, narrowing and reabsorbing the heat**.

But the chief provisions of the Huxley-Hodgkin theory are firmly established, so it is necessary not to discard it, but to supplement it. And the Mikelsaar conjecture allows us to make such a synthesis.

`A Hypothesis on the Structure of the Biomembrane Lipid Bilayer` of Dr. R.-H.N. Mikelsaar (Tartu University, Estonia) about the honeycomb-like structure of the lipid biomembrane was published in a scientific journal `Molecular Crystals and Liquid Crystals`, Vol. 152, pp. 229—257 (1987)

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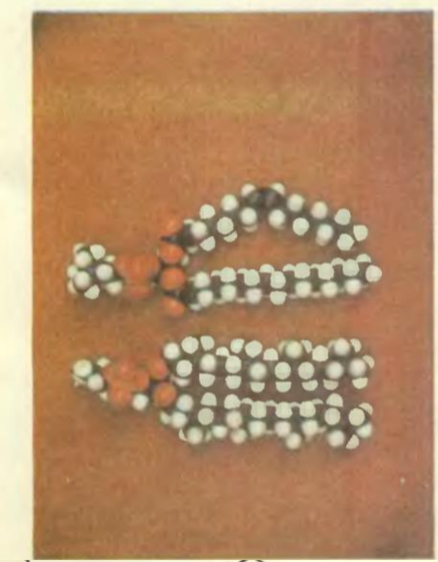
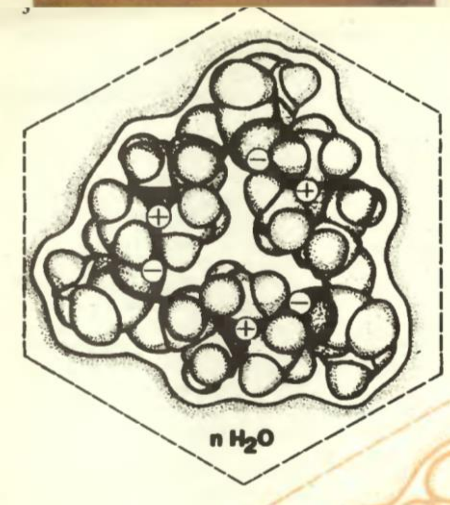
Then he published an article in the Soviet popular science magazine "Chemistry and Life" (1990, No. 4 in Russian).

I briefly once again outline the essence of the Mikelsaar hypothesis and will give illustrations (which I did not do in my previous notes on this topic; I took them from the article in "Chemistry and Life").

Working (= playing) with Tartu plastic atomic-molecular space-filling models (made under his leadership) Dr. Mikelsaar discovered that the three phospholipid (six lipid tails) molecules can form a right hexagonal prism. Every prism is closed above by `a hat` of three polar groups (heads of lipids) — they are bound by electrostatic interactions. According to Mikelsaar`s hypothesis, **such hexagonal trimeric units cover all the surface of the membrane** — it looks like the floor of a room with the parquet hexagonal tiles. And it is similar to a honeycomb.

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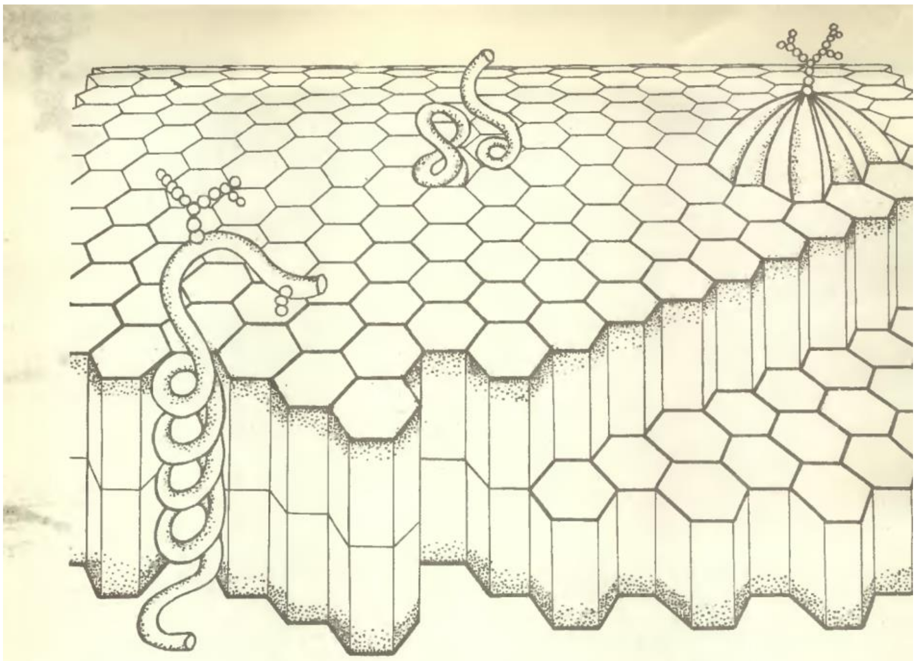
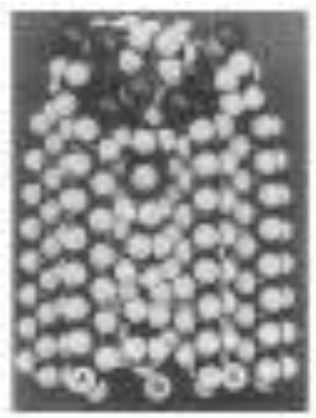
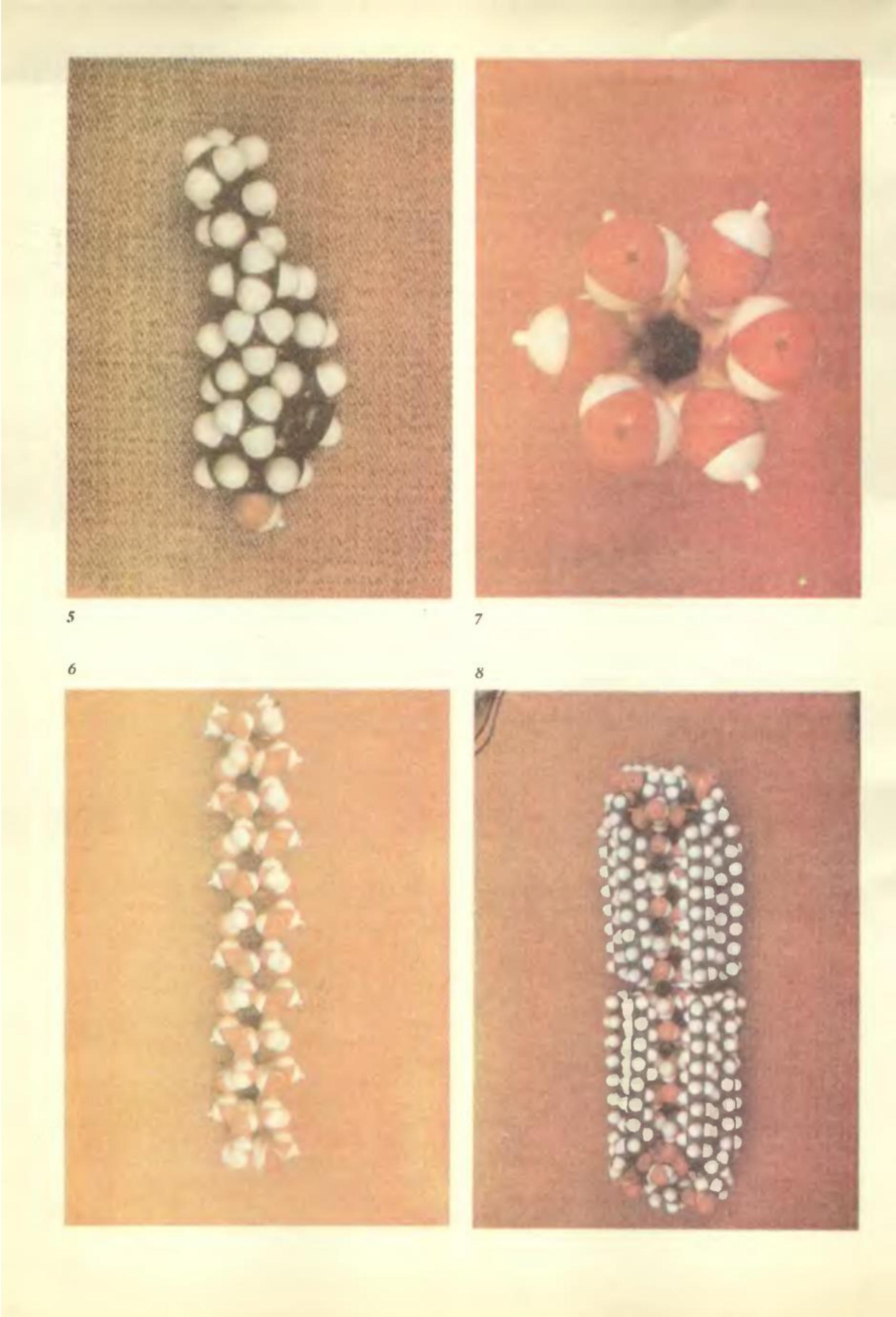


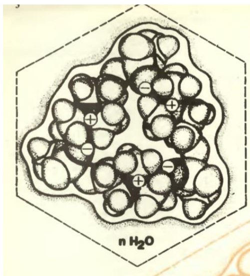
But inside prisms, there are cavities which must be filled with some substance. It turned out that the three molecules of cholesterol perfectly fit it (in the photo on the left); however, the quantity of this steroid in the lipid layer can vary and be not enough to fill all prisms. In this case, the prisms can contain **--** and this is a clue point **-- tubes of structured (ice-like) water** (they are named *shafts*); thus, so-called a hydrophobic lipid membrane may contain significant amounts of water. It is important that in the hydrophobic environment of lipid tails, this water (shafts) will freeze not at zero by Celsius but at a higher temperature, possibly physiological temperature. Ice`s melting will cause greater mobility of lipids, and that`s **the physical meaning of the membrane phase transition** (it is known, the high amount of cholesterol diminishes phase transition, now it becomes clear, why: the absence of water – the absence of transition).

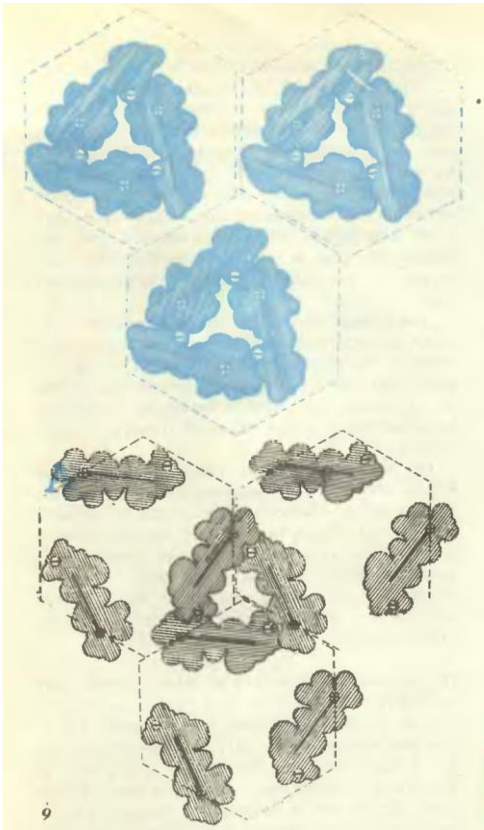




A very interesting opportunity this honeycomb model opens for the molecular mechanism of **nerve impulses**. There is opinion (Ichiji Tasaki), that Na^+ flow through the membrane occurs not by using special protein channels, but directly through the lipid bilayer, which changes its state under the action of a potential jump. The proposed model implements this idea.

It is established that the initiation of sodium current into the axon is accompanied by the shift of charged atomic groups (gate current). One can imagine such a picture: at the potential jump on the membrane polar heads of lipids will rise, turn at a certain angle and fall into new positions, forming connections with the heads of neighboring prisms; in this membrane`s domain, the highly ordered quasi-crystalline state will arise (neighboring prisms bind to each other). The gates (caps) open and each prism will become a channel for sodium ions — the geometry of the holes at the top will allow Na^+ (but not K^+) to pass through:





With this **trigger switching**, a phase transition will take place in the water which was fluid in the shafts – it will turn into ice. The membrane width will increase (because lipid tails will straighten), and its area will decrease. In this case, heat will be released: the water has frozen (when returning to its previous state, the membrane will absorb this heat).

This means that all the effects that T. Heimburg and A. D. Jackson observed are easily explained on the basis of Mikelsaar model. The whole picture becomes clear: the potential jump causes a trigger effect and a flow of sodium ions will rush through the membrane. This will cause a potential jump in the adjacent section of the membrane, and so on -- structural changes and electrical impulse mutually support each other. There are no contradictions between them.

It can be assumed that this model will also clarify the old riddle about the mechanism of action of general anesthetics. It is possible that anesthetic molecules, penetrating into the lipid layer, distort its structure, due to which trigger switching does not occur.

"*To advance our understanding of how nervous systems operate it is important to develop comprehensive models where electrical, chemical, and mechanical energies are not compartmentalized from one another, but rather cooperate in a synergistic manner to regulate neuronal excitability and signaling. By starting to consider the interplay between electrical, chemical, and mechanical energy, new paradigms for understanding and studying the biophysics of neural systems will advance our comprehension of brain function*" (Mueller and Tyler, 2014, p. 3).

Considered while hypothetical trigger switching of lipid heads is a completely new effect, which is associated precisely with the honeycomb-like structure of the membrane (again, hypothetical so far). Now the task is to confirm or refute Mikelsaar hypothesis.

See also our paper `The Honeycomb-like Biomembrane and Bioprotonics` https://vixra.org/author/lev_i_verkhovsky