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Review Article

Nobel Prizes on the Border of Medicine and Natural Sciences: Elective Discipline for Students of Higher Medical Institutions

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Abstract

In the present article we discuss the structure of the elective course "Modern problems of biophysics: Nobel Prizes for outstanding achievements of natural sciences in medicine" which is taught in the Department of Medical and Biological Physics and Informatics of the Bogomolets National Medical University. Here we present the topics of lectures that are assisted by practical classes where we discuss important achievements of the natural sciences that help us to understand better, how human organism operates.

Keywords: *Medical Physics; Biological Physics; Nobel Prizes; Grid Cells in the Brain; Synergetics; Perception; Synaptic Transmission*

Introduction

Coverage of current issues of biophysics, physiology and medicine is an important aspect of training future medical professionals. «Modern problems of biophysics: Nobel Prizes for outstanding achievements of natural sciences in medicine» is an elective course taught at the Department of Medical and Biological Physics and Informatics of the Bogomolets National Medical University. The most interesting issues of biophysics, physiology and medicine are discussed on lectures and practical classes of this discipline, namely, those for which the Nobel Prizes were awarded. The main goal is to interest the students and to form a natural-scientific picture of the world in them, where medicine is integrated into the system of natural sciences.

Basic structure of the elective course «Modern problems of biophysics: Nobel Prizes for outstanding achievements of natural sciences in medicine»

Thus, the topic of the first lecture of the course is "Fundamentals of synergetics: integration processes "medicine - natural sciences"". Here, among others [1], we discuss the achievements of John O'Keefe, May-Britt and Edward Moser [2], who received the Nobel Prize in Physiology and Medicine in 2014 for the discovery of the so-called "place" and "grid" brain cells responsible for the system of human and animal orientation in space. Having also studied mathematics, statistics and programming at a professional level, Edward Moser offered an explanation of the origin of grid cells in the brain, surprising in its scientific insight. The main idea of this explanation was to use the analogy of hexagonal structures of grid cells in the brain of humans and animals [3-7] and the vortex structure in type II superconductors, being discovered earlier in the so-called vortices by Alexei Abrikosov, 2003 Nobel laureate in Physics [8].

Recently, one of the authors of this article proposed a somewhat different approach to explaining the appearance of hexagons near the bifurcation (critical) points [9]. This approach is conceptually close to the one mentioned above, since it also uses modern achievements in the physics of phase transitions. In particular, the expression for free energy of order-parameter fluctuations called the Ginzburg-Landau Hamiltonian [10], both were Nobel Prize winners in Physics - Lev Landau in 1962 and Vitaly Ginzburg in 2003. Note that the order parameter is the main quantity describing the symmetry of the system under study, while fluctuations are random deviations of any quantity (say, the density or the temperature) from its average values. At the same time, these two approaches to explaining the basic cause of the emergence of hexagonal structures in the grid cells system have significant differences.

The later approach takes into account such specific and important features of the processes occurring in the brain:

(a) The interaction of neurons which has both an electrical and biochemical nature of the processes of generation and propagation of the action potential (AP), in other words, "the firing AP" [1,2];

(b) Use of the thermodynamic theory of chemically reacting systems developed by Theophile de Donder [11] and Ilya Prigogine [12], 1977 Nobel laureate in Chemistry, according to which the coordinate (degree of completeness) should play the role of the order parameter, and the affinity being the conjugated (in the thermodynamic sense) quantity for the chemically reacting system (see also [9,13]);

(c) Application of synergetic methods [14-16] to trasfer Hermann Haken's results, obtained for a physical system of hexagonal Benard cells arising in a viscous fluid with vertical temperature gradients near the boundary of hydrodynamic stability when the Rayleigh number reaches its critical value, to a seemingly completely different neurophysiological system of grid cells in the brain.

The final difference is related to the universality classes uniting systems of different nature that have the same behavior near bifurcation (critical) points (see, for example, a review article [16]). Most likely, the biochemically reacting system of neurons in the brain belongs (unlike type II superconductors) to the same class of universality as the real fluid near the liquid-vapor critical point. The three-dimensional (3D) Ising model in an external magnetic field belongs to the same class of universality. All three above-mentioned systems are different in nature, but are characterized by the same critical behavior near their phase transition (bifurcation) points, namely: 1) they have the same dimension $n = 1$ of the scalar order parameter, 2) they have the same spatial dimension $D = 3$, 3) they have a short-range intermolecular potential, and 4) they are described by the Ginzburg-Landau Hamiltonian being identical in their functional form with odd (cubic) nonlinear term in the order parameter.

Next, we discuss the physical basis of the processes of perception and processing of information by the organs of sight, hearing and smell. Namely, works on the diopter of the eye by Alvar Gulstrand; discoveries related to the primary physiological and chemical visual processes in the eye by Ragnar Granit, Holden Hartline, Georg Wald, as well as discoveries concerning the principles of information processing in the visual system by David Hunter Hubel and Thorsten Wiesel [6] are discussed. With regard to hearing, we pay attention to the discovery of the physical mechanisms of perception of stimuli by the cochlea by Georg von Bekeshi. We also study the principles of organization of the olfactory system and the study of olfactory receptors by Richard Excel and Linda Buck [7].

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Next, we discuss the process of synaptic transmission, which has several important stages: the delivery of vesicles into the presynaptic region, the excitation of a nerve impulse and its transmission along the neuron. James Rothman, Randy Shekman, Thomas Sudhoff were awarded the Nobel Prize in Physiology and Medicine in 2013 for discovering the mechanisms of regulation of vesicle delivery, the main transport system of our cells [20,21]. The Nobel Prize in Physiology and Medicine for discoveries concerning ionic mechanisms of excitation and inhibition in the peripheral and central regions of the nerve cell membrane was given to John Eccles, Alan Hodgkin, Andrew Fielding Huxley [22,23] in 1963. Also, Arvid Carlsson, Paul Greenhard, Eric Kendel became Nobel laureates in Physiology and Medicine in 2000 for discoveries concerning signaling in the nervous system [24,25].

Conclusion

We summarize our course by discussing and modeling the process of synaptic transmission, because the problem of intercellular interaction is as important for living nature as the problem of intermolecular interaction for inanimate nature. Indeed, intercellular interaction is an extremely important process for the normal functioning of the living being, which allows to coordinate the work of a very large population of cells. It should be noted that the process of intercellular interaction underlies the process of thinking - perhaps the most important difference between living and inanimate nature [26-28].

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