PHYSICS AND THE BRAIN

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The brain is the most complicated system known to man (excluding larger systems that contain one or more brains such as a family). Consisting of atoms and molecules, the brain appears to be governed by known laws of physics and by nothing else. The description of cerebral function involves phenomena on a wide range of time and length scales, from atoms to neurons, from cortical interactions to social networks.

We know a lot and with great confidence and accuracy about the structure of the brain, how ions diffuse, how electrical signals are generated and transmitted, and how the brain uses energy and synthesizes proteins and other substances, but a full explanation will include also concepts such as evolution, maturation, and deterioration of the brain, perception, thinking, learning, memory, sleep, consciousness, mind. A very large body of knowledge of these phenomena has been accumulated but the central question of how the brain processes information remains to be answered properly. Some phenomena such as consciousness may even require additions or modifications to the presently accepted laws of physics.

Considering the brain as a dynamical system in a suitable phase space provides an example of how concepts from physics can be used in neuroscience. For this end, we may introduce the concept of firing vector, the components of which are the firing frequencies of neurons. Three claims will be made: 1) the firing vector describes the instantaneous information-processing state of the brain (This description can be easily refined so that it incorporates the precise timing of action potentials), 2) conscious and other states corresponding to meanings or representations may correspond to regions in the firing-vector space, and 3) MEG and EEG, being linearly related to primary current distributions in the brain, measure projections of the firing vector. We notice immediately what TMS does in this framework: it kicks the brain into a new state. This allows us to interpret the observation that electrical and magnetic stimulation of the brain may change the content of conscious experience (*e.g.*, it may alleviate intractable pain): brain stimulation may move the firing vector away from a particular mental state.

In addition to helping to improve solutions to the bioelectromagnetic inverse problem, full-brain models may lead to insights and new understanding of how the brain works. In this context, furthermore, we need to improve our understanding of several fundamental, related questions: What is information in a physical system? How is information coded in the brain? How does the network process information? How does the brain learn? These are clearly areas where a physicist's or a mathematician's skills and ingenuity may be extremely valuable.