VITALISTIC AND MECHANISTIC CONCEPTS IN THE HISTORY OF BIOELECTROMAGNETICS

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INTRODUCTION

A number of actual discussions in bioelectromagnetics and biophoton research can be shown to form part of an argument between two schools that has been going on since about three hundred years. The discussion between vitalistic and mechanistic thinking in bioelectromagnetics has started with the opening of this field of inquiry in the 16th century. However, in every epoch it has taken another form according to contemporary conceptual frameworks and scientific terminologies.

DEFINITION AND ORIGINS OF VITALISM AND MECHANISM

Vitalistic theories hold that life can only be explained from laws intrinsic to living organisms, basically different from those of anorganic life, while mechanistic (or "reductionist") theories attempt explanation on the basis of the theory of anorganic nature, i.e. exclusively from the basic assumptions of physics and chemistry (Ungerer, 1965, 1966). From the point of view of the history of science, the controversy between vitalism and mechanism is largely that between field and particle theories (Jammer, 1980/81). The vitalists postulate some connecting principle or force, without which the world and its parts could not interact and hold together; especially, its action is seen to explain the peculiarity of living organisms. In this connection, the notion of coherence was already used by the stoicists (300 B.C.-200 A.C.) to denote the dynamical continuum of the "pneuma" as such a principle.

VITALISTIC NOTIONS IN EARLY ELECTRICAL SCIENCE AND NEUROLOGY

For many centuries, this role was mainly assigned to the "ether" in one or another form -- by Descartes, among others --, but as soon as electricity and magnetism became subjects of investigation, these forces, long seen as expressions of the ether, were as often identified with this vital force. When in the 16th century the nervous system was anatomically identified, the ancient concept of "animal spirits", or a "vital fluid", probably inherited from prehistoric times and much used in antiquity, also reemerged in the discourse on the causes of muscular contraction and nerve conduction (Bischof, 1994a). By 1751 the identification of animal spirits with electricity was common; Robert Whytt, one of the founders of neurology, a vitalist who saw a "sentient principle" at work in the nerves, derided the tendency of many contemporaries to ascribe about everything to the work of electricity. His Swiss opponent Albrecht von Haller adopted the concept of "irritability" -- the property of living matter to react to stimulation or "irritation" -- from Francis Glisson and showed experimentally that contraction is produced by the nerves and initiated by a stimulus. Electrical stimulation of muscle-nerve preparations soon became a standard procedure in the physiological laboratories of the time. Haller, however, cautioned that the electrical stimulability of living tissue only showed electricity was a powerful stimulus but did not necessarily prove that it was also the cause of contraction. He concluded one could not at the moment decide on the identity of electricity and animal spirits.

THE GALVANI-VOLTA CONTROVERSY

The most known protagonists of the argument between vitalistic vs. mechanistic views in bioelectromagnetics certainly are the Italians Luigi Galvani and Alessandro Volta (Hoff, 1936; Pera, 1992). When in 1759 Galvani graduated in medicine at Bologna, Hallerian irritability was strongly discussed. By 1780 he was experimenting with electrical stimulation. By then a number of reports on electric fishes had strengthened the possibility of a link between the nerve fluid and electricity. In 1774 Henry Cavendish had shown that the shock delivered by electric fish was due to an electric current generated by them. Galvani's famous experiments on frog-leg preparations, designed to decide on the existence of an "animal electricity", consisted in three series (Hoff, 1936). In the first series he repeated the accidental finding of strong contractions of the usual frog muscle-nerve preparation in which legs and feet were attached to a stump of the vertebral column by the sciatic nerves, when the nerve was touched by a scalpel and simultaneously sparks were drawn from the electric machine across the room. With this, he not only had shown muscle contraction by electric stimulation, but also discovered the action of electromagnetic (EM) waves at a distance.

The second series of experiments that is mostly referred to certainly was the least suitable one to prove the existence of animal electricity. Having noticed that frog preparations hung by copper hooks from the iron railing of a balcony contracted, Galvani began to investigate the conditions under which this occurred. He not only checked if thunderstorms might be responsible for the contractions (which they were not), but also used different combinations of metals, which all gave contractions, but of different intensities, depending on the metals used. Poor conductors did not cause any reaction.

Until 1786, Galvani considered the contractions in the second series of experiments to be caused by "metal electricity", but later changed his mind and assumed that the animal electricity stored in the tissue triggered the contraction upon contact with the metal. The publication of his results in the treatise *De viribus electricitatis* (1791) made Galvani famous and led many to believe that the "nerve fluids" had been identified. But his interpretation was not shared by everyone. His main opponent was Alessandro Volta, who after having successfully replicated Galvani's experiments went on to demonstrate that the contraction caused by metals was due to stimulation of the muscle or nerve by the minute currents generated by the contact of dissimular metals. To Volta's conclusion that therefore animal electricity did not exist Galvani responded with a third series of experiments made without any metals, definitely proving the existence of an animal electricity. The same frog preparation was held by one foot while the other foot was made to touch the vertebral column. In that condition, or when the vertebral column was made to fall on the thigh, the muscles contracted vigourously. In spite of the evidence, Volta stuck to his rejection of animal electricity, trying to explain the effect as a result of heterogenous tissues which he maintained were producing the currents.

This argument was refuted by the young Alexander von Humboldt who was not satisfied by Volta's interpretation. In a series of brillant experiments, Humboldt repeated Volta's and Galvani's experiments and extended them. In his publication of 1797 he concluded that Galvani had in fact discovered two different phenomena, both genuine: bimetallic electricity and intrinsic animal electricity. In the 1830's Galvani's observations were confirmed and extended with the new static galvanometer by Leopoldo Nobili and Carlo Matteucci.

THE RISE OF SCIENTIFIC MEDICINE AND THE "FINAL OVERCOMING" OF VITALISM

However, in spite of these results Volta's view that the origin of bioelectric currents lies in the chemical changes taking place in some "biological pile" was to have a much greater influence than Galvani's; it helped to draw increasing attention to the chemical aspects of bioelectricity. It was the "Berlin school" of the medical faculty at the Humboldt University where modern experimental electrophysiology was developed in the 1840's and 1850's, that undertook to dethrone vitalism and to build the first real stronghold for mechanistic bioelectromagnetics. The founder of this school, physiologist Johannes von Müller, still had his roots in the "Naturphilosophie" of romantic medicine and thus in vitalism. He believed in an 'organic vital force which controls and regulates life functions according to the same chemical and physical laws that govern all of nature'. His pupil Emil Du Bois-Reymond, in his youth a friend of the now old Alexander von Humboldt, got the commission to replicate Matteucci's experiments. From now on Du Bois-Reymond, a most meticulous experimenter who set himself high standards of experimental technique, devoted himself to electrophysiology and transformed it from a collection of disparate observations to an important branch of science. Together with Hermann von Helmholtz, he belonged to a group of brilliant young physicists and physiologists who set out to apply physical principles and methods of measurements to physiological problems. In their research programme of 1847 they had declared reductionism and rejection of the vitalism of "Naturphilosophie" as a basis of their philosophy. Du Bois-Reymond himself developed most of the methods and apparatus needed to eliminate errors in measurement and avoid the difficulties that had riddled his predecessors in the field. In 1842 he used his new galvanometer to reproduce Matteucci's "injury current" in muscle, and then studied the "action currents" accompanying normal and tetanic (prolonged) muscular contraction. Even more significant were his many findings on nerve physiology. In 1843 he discovered the resting current in nerves, the polarization at the points of entry and exit during the passage of direct current through a nerve, and most importantly, in 1849, he demonstrated that the passage of the nerve impulse could be detected electrically. The precise measurement of its velocity was accomplished in 1850 by Helmholtz. Using a ballistic galvanometer, he found the same value as measured today, 25 to 30 m/sec at room temperature. This showed that the passage of the nerve impulse was much slower than the flow of electric current along a wire, so that the conviction arose that it was an entirely different phenomenon.

Du Bois-Reymond was a declared anti-vitalist and one of the most prominent adversaries of the famous vitalist Baron Karl von Reichenbach, with whom he carried on a violent controversy on the latter's "odic force". In his "*Investigations on Animal Electricity*" he wrote 1848 under the impression of his discovery of nervous conduction: "...the existence of a vital force is out of the question; the sudden emergence of such a force is prrohibited by the law of the conservation of energy". However, vitalistic conceptions had been his point of depart for the establishment of the existence of nerve electricity, and he also laid the foundations for the investigation of the ancient problem of a connecting principle in the organism by scientific methods. Together with Claude Bernard, he was the first to point to the energetic peculiarity of the processes in living organisms as being "open systems" in dynamical equilibrium. Bernard took a similar intermediary stance between vitalism and mechanism and maintained in his *"Introduction to the Study of Experimental Medicine"* (1865) that all phenomena in living systems followed the same laws as those of the anorganic world and that a vital force did not exist; on the other haand he postulated in *"Lessons of Experimental Physiology"* (1855) that living systems were capable of self-regulating their "inner environment", a faculty later to be called "homeostasis".

However, a pupil of Du Bois-Reymond, Julius Bernstein, soon was to deliver a "final" blow to such vitalistic tendencies. He argued strongly for what he himself called the "mechanistic theory of life" (1890). His membrane theory of nerve excitation, first proposed in 1871 and fully developed in his *"Electrobiology"* (1912), was to become the paradigm of scientific medicine, and has contributed substantially to the demise of bioelectricity that was soon to follow. Based in his later development on Walther Nernst's work on the ionic diffusion of electrolytes in the 1880's, the theory assumed the membrane to be selectively permeable to potassium ions in the resting state and to suddenly and reversibly increase permeability to all ions when excited. The physical chemist Nernst who also developed molecular theories to explain electrical stimulation, was a pupil of Boltzmann and like him one of the pioneers of the modern atomistic/molecular approach to natural processes. Bernstein's basic idea that bioelectricity is the result of changes in the ionic distribution between cytoplasm and the extracellular medium subsequently was supported and extended by N.Rashevsky (1933), A.M.Monnier (1934), A.V.Hill (1936), K.S.Cole and A.J.Curtis (1939) and A.L.Hodgkin and A.F.Huxley (1952).

In 1874 Du Bois-Reymond had maintained that the nerve impulse simultaneously was transmitted by electrical as well as by chemical means. When microscopists found the synaptic gap between nerve and muscle, transmission across this gap that could not be explained by the Bernstein hypothesis remained the last domain of bioelectricity. But in 1921 Austrian physiologist Otto Loewi postulated that the transmission of the nerve impulse across the synaptic gap was chemical, setting neurophysiology definitely on a chemical path. With the work of two other scientists of the "Berlin school", the postulation of "receptor theory" and the introduction of chemotherapy by Paul Ehrlich in 1910, and Rudolf Virchow's "cellular pathology", the foundation for the new "scientific medicine" was laid. The methods and concepts of the Berlin school, and with it the mechanistic, molecular conception of life, through its incontested leadership soon was to be adapted worldwide and to become paradigmatic not only for physiology and medicine, but for modern science and worldview in general. In the

1880's some American pupils of Helmholtz established it in the United States where it spread from Johns Hopkins University and the Rockefeller Institute. In 1910 the Flexner Report solicited a general reform of medicine and science on the basis of experimental science, and by 1930 the reform was accomplished. The almost complete abolition of medical practices such as electrotherapy, phototherapy and homeopathy by that time shows the scientific climate in the first decades of the 20th century was not favorable to bioelectric research and vitalistic concepts.

THE MODERN REVIVAL OF VITALISTIC APPROACHES

The Nobel prizes to Otto Loewi in 1936 and in 1939 to Gerhard Domagk for the development of the first sulfonamides marks the time around 1940 as the period when the biochemical approach to life eclipsed all other approaches. In the 1950's it got its modern name of "molecular biology" from W.T.Astbury and P.Weiss (Weiss, 1970). In 1940 German electrophysiologist noted in his textbook that "electrophysiology in many questions of general importance does not seem to take the key position accorded to it uncontestedly twenty years ago. The weight of many electrical hypotheses of life processes decreases due to new knowledge on chemical and other processes" (Schaefer, 1940).

In the early 1920's Hans Spemann, Alexander Gurwitsch and Paul Weiss independently had postulated "morphogenetic fields" to explain certain properties of developing organisms. The concept derives from the work of German biologist and philosopher Hans Driesch, the founder of modern vitalism (Oppenheimer, 1972). Driesch was the first to point, in 1892, to the field properties of organisms, as a conclusion of his experiments with fertilized sea urchin eggs. He observed that in spite of perturbations of the normal course of the first cleavage each of the two blastomeres could form a whole larva, rather than a half one as expected. Driesch concluded that at this stage, the fate of the cell is not yet determined; it is a function of its geometrical position in the whole, and if this position is changed, the cell can form parts that it does not normally form during development. The ability of any part of a living organism to grow into a whole -- its faculty of regulation -- was a clear sign of field properties. While recognizing the field properties of organisms, in the 1890's Driesch came to believe in "entelechy" as a regulator of organic development - a vital force he considered to be indefinable in terms of physics and chemistry, and thus not experimentally verifiable. Alexander Gurwitsch, on the other hand, although clearly taking sides with vitalism, was determined to put the hypothesis of the biological field to the experimental test (Gurwitsch, 1915). He conceded that "the argumentation of Driesch (...) becomes at times somewhat metaphysical", but defended the "right to a practical vitalism, as a method of exact empirical investigation", and criticised the tendency of the mechanists "to efface any specific difference between the living and the non-living". "By isolating at random a feature of the living and comparing it with an inorganic model", he wrote, "one can indeed seem to show the identity of the two", and called this the "typical method of the ancient sophists". He also defended the right of the biologist to introduce what he called "the chief postulate of my own 'vitalism'", "spatial but immaterial factors of morphogenesis" in the form of morphogenetic fields, also called the "dynamical praeformation of the morphe" by him.

While Gurwitsch and many colleagues did not specify the exact nature of this biological field, others from the 1920's to the 1940's did advance EM field theories of life. Earlier proposals had been made by Rudolf Keller (Keller, 1918) and George W.Crile (Crile, 1926 and 1936). Elmer

J.Lund (Lund, 1947) concluded from decades of work on the bioelectric potentials of plants and animals that all polar systems are surrounded by and possess interpenetrating maintained electric fields generated by each one of the constituent polar cells in order to maintain electrical correlation within the system. He hypothesized that the fields constitute a primitive type of integrating mechanism that plays an important role in the spatial organization of metabolic processes and coordinates growth and possibly other processes. The hypothesis of Harold S.Burr and F.S.C.Northrop (Burr and Northrop, 1935), based on Burr's work on bioelectric potentials (Burr, 1972), is summarized in the following quote: "The pattern of organization of any biological system is established by a complex electro-dynamic field, which is in part determined by its atomic physico-chemical components and which in part determines the behaviour and orientation of those components. This field is electrical in the physical sense and by its properties it relates the entities of the biological system in a characteristic pattern and is itself in part a result of the existence of those entities. It determines and is determined by the components. More than establishing pattern, it must maintain pattern in the midst of a physico-chemical flux. Therefore, it must regulate and control living things, it must be the mechanism the outcome of whose activity is "wholeness", organization and continuity. The electro-dynamic field then is comparable to the entelechy of Driesch, the embryonic field of Spemann, the biological field of Weiss".

Georges Lakhovsky (Lakhovsky, 1963) postulated that each living being is simultaneously a broad band emitter and receptor of EM radiation, and that every cell of the organism is an electrical resonator. According to Lakhovsky, the chromosomes of the cell nucleus constitute oscillatory circuits and are surrounded by a weak EM field which interacts with the ambient EM fields. Perturbations of the natural frequency of the cell can induce illness; they may be caused by changes in the composition of the medium in the cell, by the presence of bacteria or virus, which are supposed to emit their own EM fields, or by unusual fluctuations of solar or cosmic radiation.

However, the times were not favorable for EM theories of life for several decades. The introduction of Child's concept of physiological gradients (Child, 1915) into biological field theory seems to have been prompted by the need to avoid either non-material (of the Gurwitsch type) or EM solutions to biological field concepts and to steer the latter safely into chemical waters. As Waddington writes, the more materialistically minded embryologists in the 1930's worried much about the question of the nature of the postulated embryological or morphogenetic fields. "Our feeling was that the field concept would only be useful scientifically if we had grounds for believing that we were talking of the distribution in space of one or a few potentially identifiable chemical substances" (Waddington, 1966). Waddington also notes that the "suggestions that interactions (between processes within the field) might be largely electrical in nature", such as Lund's, "nowadays seem to have receded into the background" compared to chemical interaction.

THE RISE OF MODERN CONCEPTS OF LIFE AND BIOELECTROMAGNETICS

World War II marks the threshold to a new era in theoretical biology and bioelectromagnetics. With the beginning of the war, a long-lasting controversy over the deleterious side effects of EM radiation seemed to come to a conclusion with the assumption that non-ionizing radiation had no biological effects. After the war, many new EM technologies, originally developed for military purposes, became available to research laboratories, among them the microwave technologies that followed from the development of the radar, the photoelectric multipliers now used in bioluminescence research, and the electric transistor. In the 1940's and 1950's also a number of theoretical concepts important for the formation of a new view of life which already had been proposed earlier started to be more widely accepted. Besides the two antagonistic standpoints of vitalism and mechanism attempts to overcome the ages-old dualism, as foreshadowed in the attitude of Bernard and Du Bois-Reymond, were now gaining wider importance (Ungerer, 1966). The epochal changes in physics in the first decades of the 20th century and new findings in biology, but even more importantly, new developments im epistemology, created a new situation in which the old antagonisms found a new form that seemed to open up, besides the decision for one of the two traditional forms of life explanation, the new possibility of an explanation from a governing law taken from biology.

In the 1920's and 1930's Vladimir I.Vernadsky described the planet as a living whole and postulated that the biosphere -- a term coined by him -- and individuals organism cannot be separated from each other; geological evolution is considerably influenced by organic life (Bailes, 1990). Everything in nature is intimately connected. He wrote in 1967: "The living organism of the biosphere now has to be studied empirically als a special body which cannot be reduced completely to known physical and chemical systems". He maintained to describe the phenomena of life on the basis of purely material and energetic characteristics was not sufficient, and predicted future scientists would extend the concept of living matter with additional factors besides energy and matter, such as information. He also pointed to the fact that organic life is tied up into highly sensitive regulation processes with EM fields in the environment, including sunlight.

The recognition of self-regulation (homeostasis) of organisms and parts thereof, as postulated by W.B.Cannon in 1932 (Cannon, 1932), as a fundamental peculiarity of organic life and its explanation by cybernetics and system theory helped much to bridge the chasm between vitalism and mechanism. The concept of living organisms as thermodynamically non-equilibrium, open systems, first proposed in the 1920's by Ervin Bauer (Bauer, 1920a, 1920b), Vernadsky and Alexander Gurwitsch (Bischof, 1994b), was mainly promoted in the 1930's and 1940's by Ludwig von Bertalanffy (Bertalanffy, 1940, 1949, 1950), and mathematically formalized by Ilya Prigogine and others (Prigogine, 1947, 1954). Other important early contributions were by Pascual Jordan (Jordan, 1938), who proposed that living organisms are able to amplify very weak signals, and by Schroedinger who maintained that the fact that living systems are able to preserve order and can get rid of entropy, based on their control by the highly ordered aperiodical crystal of DNA, shows that they do not evade the ordinary physical laws but at the same time follow other, hitherto unknown physical laws besides these (Schroedinger, 1944). In 1941 Albert Szent-Györgyi wrote that with the mechanistic approach in biochemistry somehow life was lost and only dead matter remained (Szent-Györgyi, 1941). "It seems that something important is missing without which no understanding is possible". He considered the missing element was electricity which had to be reintroduced into biology. The foundation of nonlinear optics by Alfred Kastler in the 1950's, the invention of masers and lasers in the 1960's, and the extension of the concepts of non-equilibricity and cooperativity from the molecular level into the domain of electromagnetics by Herbert Fröhlich (Fröhlich, 1968), including his work on coherence and Bose-condensation, finally established the theoretical bases for a modern EM theory of life that could combine molecular and field aspects.

The groundbreaking work of Alexander Presman, *"Electromagnetic Fields and Life"*, published in English in 1970, provided the first impetus and formulation for such a modern EM field theory for biology (Presman, 1970). Dedicated to the memory of Vernadsky, it first made known to the West, the results of the pioneering work of Soviet scientists on the biological effects of non-ionizing radiation, undertaken mainly in the 1960's. It made clear that the assumption that these frequencies had no influence on living systems was no longer tenable; with this the old controversy about the existence of non-thermal effects that had already occupied Tesla and d'Arsonval at the turn of the century was brought to a conclusion. Based on his review of the Russian and Western experimental work, Presman argued that environmental EM fields have played a central role in the evolution of life and also are involved in the regulation of the vital activity of organisms. He suggested that living beings behave as specialized and highly sensitive antenna systems for diverse parameters of weak fields of the order of the ambient natural fields. According to Presman, EM fields serve as mediators for the interconnection of the organism with the environment as well as for the communication between organisms, and EM fields produced by the organisms themselves are involved in the coordination and communication of physiological systems within living organisms. He also suggested that informational, as opposed to energetic, interactions play a significant, if not the main, role in EM biocommunication. Presman's book has had a great influence on subsequent work, not least because it had dared to formulate a holistic field hypothesis of life, thereby breaking the long-lasting taboo on "vitalistic" conceptions.

CONCLUSION

Upon close examination, the relationship between vitalistic and mechanistic thinking in the history of biology turns out to be not so much a dualistic one, but rather a living dialectic of two antagonists that very much profit from each other. It seems that the stimulating interaction of vitalism and mechanism has been a most necessary factor in the development of biological theory. The mechanistic approach provides the most necessary concreteness to the concepts of life. On the other hand, whenever mechanistic thinking tends to become sterile and sclerotic, vitalism is apt to breathe new life into it. Today, EM and field theories of life, always associated with vitalistic thinking, again are needed as a necessary complement to a biological thinking that has too closely focussed on molecular details and thereby lost view of the living organism as a whole.

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