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*EVIDENCE FOR THE EXISTENCE OF AN ELECTRO-DYNAMIC FIELD IN LIVING ORGANISMS**

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Read before the Academy, April 24, 1939

There are two major classical theories of modern science: particle physics and field physics. The chief difference between them was clearly stated by Clerk Maxwell in his initial paper on electro-magnetic theory. Particle physics, he writes, considers any phenomenon "as due to the mutual action of particles," "but we are proceeding on a different principle, and searching for the explanation of the phenomena, not in the currents alone but also in the surrounding medium"[1] or, to use the language of his third paper, "in the form of the relations of the motion of the parts."[2] In short, particle physics directs attention to the constituent particles, whereas field physics centers theory and experimentation upon the medium in which the system as a whole is imbedded and upon its structure.

Since the fundamental problem of biology is organization, it would appear that field physics is the more appropriate for its investigation. It was considerations similar to these, together with certain facts in experimental embryology,[3] which caused the writers in 1935 to propose the "electro-dynamic theory of life."[4] It was this theory in turn which guided Burr, Lane and Nims to the construction of the vacuum-tube microvoltmeter,[5] and which suggested the experimental investigations [6–18] and findings which it is the purpose of the remainder of this paper to summarize.

In biology, the complexity of the living system is so great that investigators have been content since the time of Aristotle to analyze and describe, in as much detail as possible, the nature of its component parts. However, every biologist knows that one of the most important problems is to describe quantitatively as well as qualitatively the relationships which are known to exist within cells and between them and their environment. To study this relatedness in the laboratory required that certain conditions be met. As pointed out by Lund in his brilliant and meticulous study of the bio-electric properties of the growing onion root tip, determination of the electrical properties of the living system can be carried out most advantageously by means of instruments which record only voltage differences independent of current and resistance. This condition precludes the use of nearly all standard instruments, save the quadrant electrometer or similar devices.

Using a vacuum-tube microvoltmeter with a high degree of sensitivity and excellent stability, it has been possible to explore the electrical properties of a wide variety of living forms undisturbed by changes in resistance in the organism and without disturbing in any significant way the inherent electrical properties of the thing measured.

This has been accomplished by designing an instrument which is essentially a vacuum-tube bridge. The input impedance is sufficiently high to draw a minimum of current from the system under measurement and is, therefore, independent of resistance changes in the measured system. Contact between the instrument and the living organism is made through silver-silver chloride electrodes immersed in physiological salt solution. Since these electrodes are non-polarizing and reversible, electrode artefacts are reduced to a minimum. The entire apparatus is shielded and grounded at appropriate points so that it can be said with a fair degree of certainty that the recorded deflections of the galvanometer spot give an accurate picture of the voltage differences in the living system.

Studies of the past five years have shown that in many vertebrates, as well as in plants and invertebrates, there is a relatively steady state voltage difference between any two points. These gradients are remarkably stable, are of considerable magnitude and are changed only by alterations in the fundamental biology of the organism. Moreover, in all the forms studied, the gradients are not chaotic but exist in a well-defined pattern which is characteristic of the species to which the animal belongs and is, to some extent, characteristic of the individual. In general, it may be said that growth and development, local injuries, the menstrual cycle and ovulation in the female, and the incidence of cancer profoundly affect voltage differences in what seem to be a unique manner.

Interesting as the above observations may be, it is more important to determine if the experimentally measured pattern of voltage differences determines in any fundamental sense the organization of the system. In this connection the physical chemist, Teorell,[19] has made an important observation. He has shown that a physical system undergoing chemical reactions produces active ions which pass through a membrane with different mobilities. This results in an electric field whose forces determine the distribution and motion of all the passive ions in the system. Thus, his theory, derived from Ostwald, Nernst and Planck, provides meaning both for the determination of the electric field by the active ions and the determination of the position and motion of the passive ions by the electric field. This, it is to be noted, is a special case that is in accord with the fundamental thesis of the electro-dynamic theory of life. It was said that, "the pattern or 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 behavior and orientation of those components."

It is not surprising, therefore, that voltage gradients between the head and tail of Amblystoma and chick embryos can be determined with considerable certainty not only when contact is made directly with the surface of the organism, but also when the electrodes are from $1^{1}/_{2}$ to 2 mm. away from the surface of the embryo. It will be seen at once that this is a striking confirmation of the field concept since the distribution of the chlorine ions in the physiological salt solution surrounding the embryo is determined by the field of the organism in such a manner that it is capable of being measured by a vacuum-tube microvoltmeter.

A further striking bit of confirmatory evidence is found in the phenomenon which may be observed in the salamander embryo when it is revolving between the tips of a pair of capillary electrodes as a result of ciliary action. As the head passes first under one electrode and then under the other, corresponding oscillations of the galvanometer occur. Under these conditions the embryo is acting as an AC generator of very low frequency. Such a phenomenon can only be explained, so far as it is possible to see at present, on the assumption that an electrical field exists in the embryo.

In the course of many hundreds of thousands of determinations of voltage differences in women, it has been shown that a very definite bio-electric correlate of the menstrual cycle exists. It may be said with a fair degree of assurance that usually once but sometimes twice in the menstrual cycle there is a sharp rise in voltage difference which lasts for approximately 24 hours. Furthermore, it can be shown that this rise is in all probability associated with ovulation. The findings make it reasonably certain that these bio-electric correlates of ovulation may occur at any time in the cycle. Moreover, there is no tendency for the appearance of a rhythm in the time of ovulation. In fact, cycles occasionally appear without a bio-electric ovulatory peak. Hence it may be said that it is impossible to predict the time of ovulation. All that can be done is to record the time when it occurs. These determinations have been made between the right and left index fingers. They, therefore, reflect changes in physiological activity which are concentrated in the main in the generative tract. However, these changes are so profound as to produce undoubted alterations in the field of the whole organism. Explanation of the phenomenon on the basis of ionic transport or changes in the local chemistry is difficult. The phenomenon is relatively easy to understand, however, if an electro-dynamic field of the whole organism is assumed, the over-all properties of which may be altered by changes in local constituent factors.

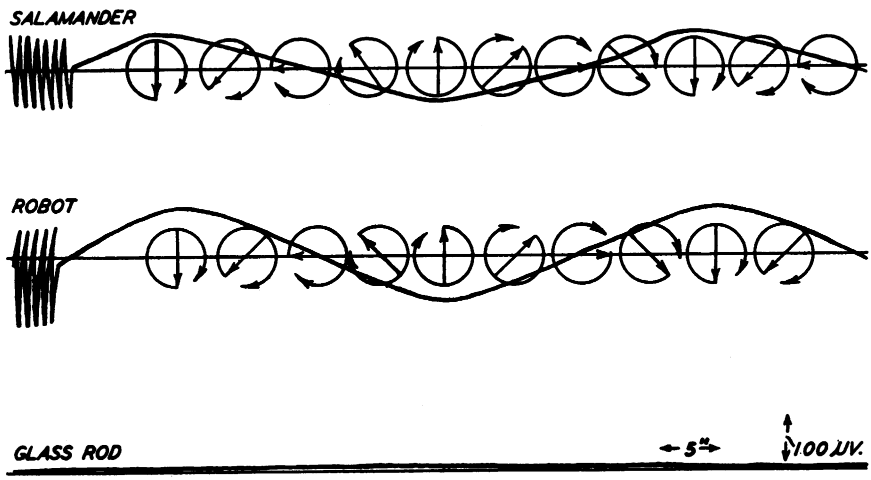

FIGURE 1

A tracing of three graphs from a recording galvanometer and a microvoltmeter demonstrating the similarity between the electrical field in a salamander and a copper-solder robot when each is rotated. Below, the complete absence of any such phenomenon when the glass rod is rotated.

In the same way, registration of the exact time of ovulation in the rabbit and in man, as confirmed by Reboul and Davis[20] and Rock,[21] may be assumed to be a field phenomenon, inasmuch as the measurements were made not directly on the ovary but between the symphysis and the vagina. Here it has been shown as a result of direct observation, that the bio-electric correlate of ovulation is coincident with the liberation of the ovum from the follicle, even though pickup electrodes are centimeters distant.

During an extensive study of the bio-electric correlates of cancer in mice, it was noted that in young mice a marked rise in voltage gradients across the chest occurred from two to three weeks before the new growth could be detected by palpation. This rise was independent of the locus in the organism of the new growth. Apparently rapidly growing masses of cells, too small for direct observation, produce local bio-electric changes in the organism which effect the field properties of the whole system in such a manner as to make it possible to record the changed voltage gradients across the chest.

It seems clear from the above that an understanding of a wide variety of bio-electric phenomena in the living organism can best be reached by the assumption of an electro-dynamic field in the organism.

* Aided by a grant from the Josiah Macy, Jr., Foundation.

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