It is recommended that the stations be so located, if possible that the greater part of the work of securing and measuring the films may be done by local scientists. On the other hand, it is recommended that the installation of the apparatus be supervised by those who have devised it and had experience with it. It is recommended that all the details of securing the records, measuring the films, and making the calculations be entirely homogeneous and under the supervision of those who have already perfected them.

Committee of the American Section of the International Geophysical Union on Earth Tides,

A. A. MICHELSON, *Chairman*,
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T. C. CHAMBERLIN

SPECIAL ARTICLES

RESEMBLANCES BETWEEN THE PROPERTIES OF SURFACE-FILMS IN PASSIVE METALS AND IN PROTOPLASM. I

IN my recent comparison of protoplasmic transmission with the transmission of activation in passive metals.[1] I reviewed evidence indicating that in both cases the effect is dependent upon the properties of the thin film of impermeable or protective material formed or deposited at the interface between the metal, or the protoplasm, and the adjoining electrolyte solution. In the passive metal the composition and physical properties of this thin layer are such that it is very readily and rapidly altered or removed by the electrochemical action of the local circuits which appear wherever the film is locally interrupted or its permeability increased beyond a certain limit. The originally continuous and homogeneous film (of oxide or oxygen compound) may thus be removed by electrolytic reduction at the local cathode; a new local circuit is then automatically formed at the boundary between this reduced or activated region (where metallic iron is exposed) and the film-covered or passive area beyond, which forms the cathode of the circuit; a similar process is there repeated; and in this manner the active state is propagated over the whole surface of the metal. Similarly in the living system, *e. g.*, nerve-axone (according to the local action theory of protoplasmic transmission), the surface-film or plasma-membrane is locally altered or interrupted in an analogous manner by the action of the local bioelectric circuit formed between the region of excitation and the resting region beyond; at this latter region, where the current (positive stream) of the circuit passes from the protoplasmic surface to the medium, it produces, primarily through some local process of electrolysis, a change—the critical or excitatory change—in the structure and electromotor properties of the surface-film, this change being apparently associated with an interruption of continuity or increased permeability; a new circuit then arises at the boundary between this newly altered or activated area and the adjacent still unaltered area; and by a repetition of this process at each new active-resting boundary as it is formed, a wave of chemical and physical alteration, associated with a local electrical circuit, travels over the surface of the irritable element. This wave constitutes the excitation-wave, or nerve impulse in the case of the nerve-axone. Since by its very nature this wave is always associated with a local electric current, it produces the effects of electrical stimulation wherever it extends, hence also in the irritable structure, *e. g.*, muscle-cell, at which the axone terminates.

This theory postulates an essential similarity in physicochemical properties and constitution between the surface-films of passive metals and the protoplasmic surface-films or plasma-membranes of the irritable living cells or cell-structures. Certain general resemblances are apparent: both types of film are water-insoluble, are formed by chemical alteration (typically involving oxidation) of the surface-layer of the metal or protoplasm, are impermeable or difficultly permeable to the electrolytes of the adjoining solution, and are subject to ready alteration under the influence of electric currents formed by local action. In consequence of this latter condition such films are often unstable and subject to com-

[1] SCIENCE, N. S., 1918, Vol. 48, p. 51; *cf.* also my general article on "Protoplasmic Transmission," *Scientific Monthly*, 1919, Vol. 8, pp. 456, 552.

plete and rapid dissolution as a result of slight local mechanical and chemical alteration; any interruption of continuity sets up a local circuit and initiates a process of dissolution which may be propagated over the whole surface and result in the complete destruction of the film; many living cells (*e. g.*, blood corpuscles) are thus unstable, as is also the passive state of a metal like iron in most solutions. Accordingly, unless the film is automatically restored whenever it is interrupted, the state of passivity in a metal, such as iron, or of continued life in a living cell, is temporary and never lasts long. A special peculiarity of such systems, however, is that when the passive metal is immersed in a suitable oxidizing solution, or the living cell in its normal medium, the continuity of the film is preserved by an automatic regulatory process of the type just indicated; and under such conditions the passive or the living condition may be a highly stable one. Automatic reversion to the passive or resting condition is in fact the rule in metals or in irritable elements under certain conditions. This peculiarity is an especially important one from the physiological standpoint, and its basis will be further considered below.

If, as the local action theory of stimulation would imply, the control of protoplasmic processes is largely dependent upon the peculiar properties and behavior of surface-films of this type, it is clear that the general physics and chemistry of such films must be a matter of fundamental interest for general physiology. Although the films formed upon metallic surfaces are obviously widely different in their chemical composition from those enclosing irritable living elements like muscle-cells or nerve-fibers, they nevertheless exhibit in their general physical properties, conditions of formation and behavior many close resemblances to the latter. And it is just those properties which both types of film possess in common that determine the most characteristic features of their behavior, in particular their "irritability" and their power of transmitting chemical influence to a distance. These are the properties which are of most general physiological interest, and they are dependent upon simple conditions of a general kind, which are in no way peculiar to living protoplasm but are present in varying degree at all boundary-surfaces across which the transfer of electricity in association with chemical change (electrolysis) can take place.

The surface-film of passive iron is especially suitable for study from the above point of view because of the readiness with which it is formed and its marked sensitivity to mechanical and electrical influences; in these and other respects it exhibits a behavior closely analogous to that of the protoplasmic surface-films of irritable cells and cell-elements. The experiments about to be described have aimed at determining the degree to which these analogies extend to other peculiarities of behavior, and in particular whether definite correspondences exist in regard to the influence of electrolytes and surface-active organic compounds upon the stability and other properties of the film. Both of these classes of compounds have a well-known and characteristic influence on protoplasmic irritability, a property which is undoubtedly dependent upon the state of the surface-films or plasma-membranes of the irritable elements.

Self-conserving Properties of the Film.—An automatic power of repair is a highly characteristic property of protoplasmic surface-films; slight wounds or interruptions of the cell-surface are repaired; more extensive injury frequently leads to a rapid breakdown of the entire cell. The normal return of a living irritable element to the resting state after stimulation, or cell-division, or other change associated with alteration of the plasma-membrane, appears to depend mainly upon this ability to reform the surface-film. In irritable tissues (muscle, nerve) the time required for this restorative process apparently corresponds with the temporarily insensitive or "refractory" period immediately following excitation, whose duration (as is well known to physiologists) is in general briefer the more rapid the response of the tissue to excitation. Rapid response and rapid recovery are thus constantly associated properties of an irritable tissue. A similar automatic restoration of the passivating surface-film after activation takes place in an iron wire immersed in a strongly oxidizing solution like concentrated nitric acid, and is similarly associated with a return of the original sensitive or *quasi*-irritable properties of the film; this recovery is also attended with a certain delay, analogous to the refractory period of the protoplasmic system. In this automatic return of passivity both the general oxidizing action of the solution and the electrochemical oxidizing influence at the local anodic regions of the metallic surface are factors.

Iron wires which have previously been rendered passive will frequently retain their passivity for an indefinite time, if left undisturbed, in solutions whose oxidizing powers are insufficient to impart passivity to already active wires. This is the case, for example, in solutions of nitric acid of less than 1.2 s.g.; in such solutions passivity remains unaltered for an indefinite time, provided the continuity of the surface-film is not interrupted (by mechanical or other means) over a sufficiently great area. But activity, once it is established, is permanent and the metal dissolves in the acid. As a rule, extensive scraping or vigorous jarring is required to activate mechanically a passive iron wire immersed in 1.2 HNO_3, although different specimens of iron vary in sensitivity. Apparently if the total area of metallic surface which is thus freed from film and exposed to the direct action of the acid is less than a certain critical minimum, the local anodic action quickly reforms the film, and the wire as a whole continues to exhibit passivity. Hence a single scratch with a glass rod may be ineffective, while if several scratches are made simultaneously or close together the total or summated effect may be sufficient for activation. This behavior throws light upon the general nature of summation-effects in film-covered systems of this class, which include living protoplasm as well as passive iron. Destruction of a sufficient area of surface-film is followed by a rapidly propagated wave of activity which destroys the whole film and renders the whole metal active. Thus the physiological distinction between the "local change" and the "propagated disturbance" in irritable tissues, familiar to physiologists from the work of Keith Lucas and others, is exemplified in the behavior of such wires. Any alteration of the film affecting less than a certain critical area fails to propagate itself and involve the whole surface. Apparently the ratio $\frac{\text{active area}}{\text{passive area}}$ must exceed a certain critical minimum if the activating effect is to gain the predominance and involve the whole surface of the metal; otherwise the entire surface resumes the passive state. Local conditions of either passivity or activity are equally capable of spreading; and the final state of the system as a whole depends upon whether the one or the other condition gains the upper hand. The tendency to revert to passivity after local disturbance varies in different metals and in different specimens of the same metal; for example, in nickel (in 1.2 HNO_3) it is much greater than in iron. Hence the local state of the surface at any time is determined by the relative intensity of the two opposed processes, one of which tends to form and the other to destroy the surface-film. A similar statement holds true of the protoplasmic systems; in the maintenance of any living structure constructive or "anabolic" processes are continually at work, which compensate or offset the continually acting destructive processes; this applies to the surface-film as well as to other protoplasmic structures.

Another simple observation, continually repeated in these experiments, indicates still further the active or self-regulating character of the process by which the surface-film of passive iron is preserved intact in an oxidizing solution (*e. g.*, 1.20 HNO_3) in spite of minor disturbances or local alterations in the film. All solutions of chlorides rapidly destroy passivity, at a rate which is approximately proportional to the concentration of the Cl-ions; usually in the wires used in the following experiments an exposure of 8 or 10 seconds to *m*/1200 NaCl or KCl is required to render a passive wire reactive to 1.20 HNO_3. When, however, such a wire is exposed to the salt solution for less than this critical period, *e. g.*, for 6 seconds, and is then dipped momentarily in 1.20 HNO_3, washed in distilled water, and again placed in the salt solution, it is found that the time now required for activation is not shorter but is essentially the same as before, *i. e.*, 8 to 10 seconds. Evidently the brief exposure to the acid has restored the partly altered film to its original condition. But if the process of alteration in salt solution is allowed to pass the critical stage (with, *e. g.*, 10 seconds exposure) before transfer to the acid, the latter has no passivating action, and the wire continues to react until completely dissolved. This observation shows that the progressive modification which the film undergoes in the salt solution is of a kind which is rapidly and completely reversible if the metal is returned to the acid before a certain critical stage is reached; but after this stage is once passed the whole film breaks down when the wire is replaced in acid and the iron is no longer protected against solution. This behavior resembles that of living cells after transfer from a balanced salt-solution like sea water to a toxic solution like pure $m/2$ NaCl, as shown (*e. g.*) in Osterhout's experiments with *Laminaria;* the cells undergo a progressively injurious modification associated with an alteration in the properties of the plasma-membranes, shown by increasing permeability; this change may be reversed by transfer to the original medium before, but not after, the modification has reached a certain critical stage. Thus the characteristic power, normally possessed by the living plasma-membrane, of preserving intact its continuity and semipermeability is simulated in a general manner by the behavior of the surface-film of passive iron in dilute nitric acid.

The action of salt-solutions upon those surface-films (influence of nature and concentration of salts, relative rates of action of different salts, antagonisms) will be described more fully in the second part of this article.

Ralph S. Lillie

SOCIETIES AND ACADEMIES

THE NORTH CAROLINA ACADEMY OF SCIENCE

The annual meeting of the North Carolina Academy of Science was held at Trinity College, Durham, on May 2 and 3.

The presidential address was given by Dr. E. W. Gudger on "On an extraordinary method of fishing—the use of remora for catching fish and turtles."

The following papers were presented:

Undamped electrical oscillations: C. W. Edwards.
A portable printing outfit for the ecologist: Z. P. Metcalf.
Sanitation in the south: Thorndike Saville.
Some generic distinctions in sponges: H. V. Wilson.
A magnetic paradox: F. N. Edgerton, Jr.
Vegetation in the closing of ponds with special reference to the Kamaplain ponds of Wexford county, Michigan: Collier Cobb and H. D. House.
Preliminary studies of the reproduction rate of Copepoda: Fannie E. Vann.
Deposits of volcanic ash: John E. Smith (by title).
Asymmetry in the formation of the nervous system in the frog embryo: Blackwell Markham.
Recent mosquito control work in North Carolina: R. W. Leiby.
Reptilian folklore: C. S. Brimley.
New or little known diatoms from Beaufort, North Carolina: J. J. Wolfe.
Some notes on Protozoa:
(a) *Occurrence of Tintinnus serratus Kofoid in Chesapeake Bay.*
(b) *Arcella excavata nov. sp.:* Bert Cunningham.
The ovary of the Gaff-topsail catfish, Felichthys felis: E. W. Gudger.
The seventeen-year locust in North Carolina in 1917: Z. P. Metcalf.
Our rats, mice and shrews: C. S. Brimley.
The high frequency electric furnace: F. N. Egerton, Jr.
The felsites of Mount Collier: John E. Smith (by title).
The inland waterway from Boston to Beaufort: Collier Cobb.
(a) *A new parasitic blue-green alga.*
(b) *Comparison of Rhododendron catawbiense with a form occurring at Chapel Hill:* W. C. Cooker.
Locating invisible objects: C. C. Hatley.

Bert Cunningham,
Secretary

SCIENCE

A Weekly Journal devoted to the Advancement of Science, publishing the official notices and proceedings of the American Association for the Advancement of Science

Published every Friday by

THE SCIENCE PRESS

LANCASTER, PA. GARRISON, N. Y.

NEW YORK, N. Y.

Entered in the post-office at Lancaster, Pa., as second class matter