Demonstration of 'Abolition of Action Potentials' and 'Subthreshold Responses' in the Cobalt Electrode System

ICHIJI TASAKI

From the Laboratory of Neurophysiology, National Institute of Neurological Diseases and Blindness, National Institutes of Health, Bethesda, Maryland

ABSTRACT

TASAKI, ICHIJI. *Demonstration of 'abolition of action potentials' and 'subthreshold responses' in the cobalt electrode system.* Am. J. Physiol. 190(3): 575–577. 1957.—In a model of the nerve membrane consisting of a cobalt wire immersed in a solution of HCl and C_rO_3, 'abolition of action potentials,' 'subthreshold responses' and the 'impedance loss during activity' have been demonstrated. These observations are considered to support the 'two-stable state hypothesis' of nerve excitation.

IT HAS BEEN pointed out by many physicists and physiologists that in a metal wire immersed in concentrated acid solution a phenomon can be demonstrated which resembles the process of conduction of impulses along the nerve fiber (1–4 and others). The electrochemistry of this propagation of activation wave in the metal wire nerve model has been worked out by Bonhoeffer (4), Franck (5), Yamagiwa (6, 7) and others. It was shown that the production of the action potential in the metal wire is based on transition between the state in which the metal surface is covered by an oxide layer and the bare state.

Quite recently, a phenomenon termed as 'abolition of an action potential' was found in the nerve fiber of the toad and of the squid (8, 9). The action potential developed by a single node of Ranvier of the toad or by a squid giant axon treated with TEA can be terminated abruptly by passing a strong pulse of inward current through the membrane. A similar phenomenon has been known for some time in action potential of the cardiac muscle (10). To explain this phenomenon of abolition, it has been suggested that the surface membrane of the nerve fiber or the muscle has two stable states and that initiation and abolition of action potentials represent transitions between the two states (8, 9).

The purpose of the present investigation is to show that a phenomenon similar to the 'abolition of an action potential' can be demonstrated in the inanimate system consisting of a metal covered by an oxide layer. In the present investigation, a piece of cobalt immersed in a solution of hydrochloric acid and chromiun trioxide (11) was used, simply because this system has shorter 'refractory periods' than the ordinary iron wire model. Records of 'subthreshold responses' and of 'impedance loss during activity' have been taken in this connection.

These observations presented in this paper do not, of course, attest to the validity of the two-stable state hypothesis in the nerve fiber. But, they serve as an indirect support of the hypothesis, by assuring that this hypothesis does not conflict with our present-day knowledge of electrochemistry.

OBSERVATIONS

Figure 1 shows the experimental setup used to demonstrate abolition of action potential in the cobalt-electrode system. A piece of cobalt wire (about 1 mm in diameter and covered by a glass tubing except for about 5 mm at the tip) was immersed in a 2 N HCl solution in a glass beaker. A 1 M solution of C_rO_3 was then gradually poured into the beaker. It was seen that the potential difference between the platinum wire and the grounded cobalt wire in the beaker started to fluctuate when the concentration of C_rO_3 in the beaker reached a certain level. The time course of the potential

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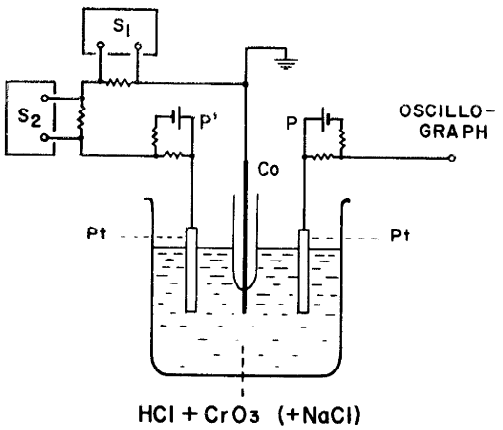

FIG. 1. Experimental setup used to demonstrate 'abolition of the action potential' and 'subthreshold responses' in the cobalt-electrode system. *Co*, cobalt wire of about 1 mm in diameter enclosed partly in a glass tubing. *Pt*, platinum wire for recording potential variations (*right*) and for applying current pulses to the cobalt wire (*left*). S_1 and S_2, stimulus isolation unit (Grass). *P* and *P'*, 3-volt batteries and potential dividers for compensating the potential difference between the platinum and cobalt wire.

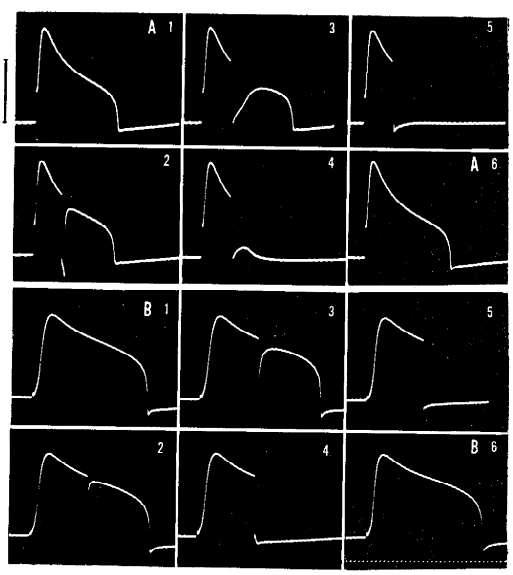

FIG. 2. Demonstration of 'abolition of action potentials' in the cobalt-electrode system. Composition of the fluid in which the electrodes were immersed was a mixture of 1 part of 2 N HCl solution and a nearly equal part of 1 M CrO_3 solution with a small amount of NaCl. Intensity of the polarizing current and the time allowed for corrosion of the cobalt wire were slightly different when the two sets of photographs, *A* and *B*, were taken. Voltage calibration, 100 mv; the deflection was upward when the potential of the platinum electrode went up. Time markers 60 cps. Intensity of the abolishing current pulse was increased successively in between *record 2* and *5*.

variation resembled spontaneous discharges of impulses in excitable tissues.

Through a second electrode of platinum immersed in the fluid, rectangular current pulses pulses (1–10 msec. in duration and 10–100 ma in intensity) were applied to the cobalt wire at a regular interval of 2–3 seconds. It was possible to synchronize the response to these periodic stimuli. By varying the ratio (CrO_3)/(HCl) and also by adjusting the polarizing

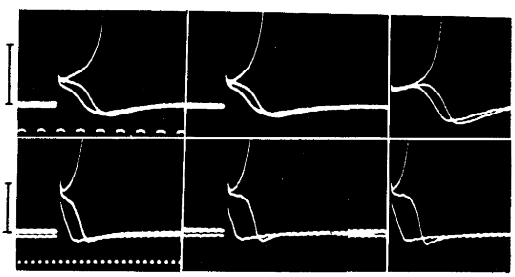

FIG. 3. Demonstration of 'subthreshold responses' in the cobalt-electrode system. Three photographs in each row were taken from one electrode at nearly constant intensity of stimulus. Three sweeps were superimposed in each photograph. Note the marked variability in the rate of decay of the electrode potential. 'Action potential' of the system was similar to those in fig. 2*B*.

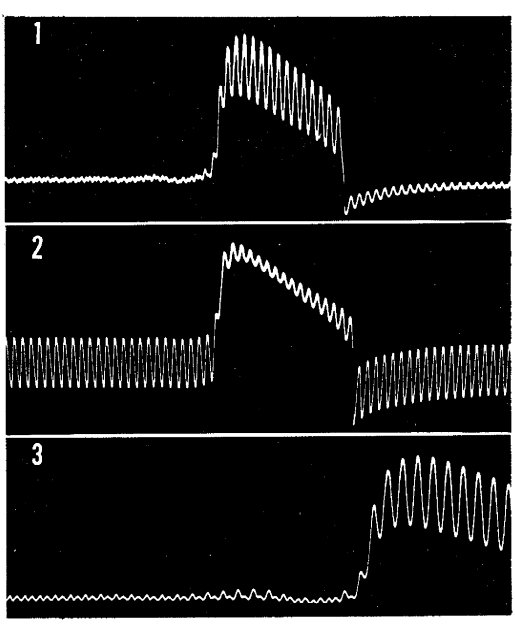

FIG. 4. Demonstration of 'impedance loss during activity' in the cobalt-electrode system. An a.c. Wheatstone bridge was used to reduce the amplitude of the a.c. component before the start of a 'response' (*top* and *bottom*) or during 'activity' (*middle*). *Bottom record* was taken at higher film speed.

current through the cobalt wire, responses which resembled action potentials of the nerve fiber in their time course were obtained (fig. 2). The time allowed for corrosion to raise the concentration of cobalt in the solution was another factor affecting the shape of the observed responses.

During the course of the action potential, a strong current pulse was applied to bring the potential difference toward the resting level. It was easy to show that the portion of the action potential following the pulse was eliminated when the pulse intensity reached a certain level. When the pulse was not strong enough, the recorded potential returned after the end of the pulse toward the level which might have been reached if no abolishing pulse had been applied. A less intense current was needed to abolish the action potential in the later phase than in the earlier phase. These findings are similar to those reported on the nerve fiber (8, 9).

It was found possible to abolish action potentials in the iron wire immersed in nitric acid in all-or-none-manner.

Records of subthreshold responses presented in figure 3 were obtained with the experimental setup of figure 1. The intensity of the stimulating pulses from the stimulus isolation unit was adjusted to threshold and was kept constant. Due to a spontaneous alteration in the state of the surface of the cobalt wire, a shock sometimes brought about a potential change which decayed very rapidly after the end of the pulse. In other cases, a shock of the same intensity generated a slowly decaying potential variation or sometimes a full sized response. These potential variations, are very similar to those known in the nerve fiber (8, 12).

The membrane impedance during activity in the cobalt model was observed by connecting a platinum wire and a cobalt electrode to the unknown arm of an alternating current Wheatstone bridge. The ratio arms consisted of two ohmic resistors, 10 and 100 ohms. The third arm was made of a resistor of about 5000 ohms (variable) with a parallel condensor of about 0.1 microfarad (variable). The frequency of the bridge a.c. was 25–30 cps. Responses were induced spontaneously.

The bridge output was led directly to the oscillograph; no attempt was made to separate the a.c. and d.c. components in the output by the use of an electric filter.

The records presented in figure 4 resemble those obtained from the nerve fiber (13, 14). In the last record, the doubling of the frequency of the a.c. which has been demonstrated by Franck and Lüdering (15) previously, is seen. The phenomenon of frequency doubling has not been demonstrated in the nerve fiber. It seems worthwhile, however, to look for this phenomenon in the squid axon and in the frog nerve fiber.

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REFERENCES

1. HEATHCOTE, H. L. *Ztchr. Physik. Chemic.* 37: 368, 1902.
2. HEATHCOTE, H. L. *J. Soc. Chem. Ind.* 26: 899, 1907.
3. LILLIE, R. S. *Biol. Rev.* 11: 181, 1936.
4. BONHOEFFER, K. F. *J. Gen. Physiol.* 32: 69, 1948.
5. FRANCK, U. F. *Progress in Biophysics* 6: 172, 1955.
6. YAMAGIWA, K. *Jap. Med. J.* 1: 390, 1948.
7. YAMIGIWA, K. *Jap. Med. J.* 2: 217, 1949.
8. TASAKI, I. *J. Gen. Physiol.* 39: 377, 1956.
9. TASAKI, I. AND S. HAGIWARA. *J. Gen. Physiol.* 40: 859. 1957.
10. WEIDMANN, S. *J. Physiol.* 115: 227, 1951.
11. FRANCK, U. F. AND L. MEUNIER. *Ztschr. Naturforsch* 8b: 396, 1953.
12. HODGKIN, A. L. *Proc. Roy. Soc., London, s. B.* 126: 87, 1938.
13. COLE, K. S. AND H. J. CURTIS. *J. Gen. Physiol.* 22: 649, 1939.
14. TASAKI, I. *Nervous Transmission.* Springfield: Thomas, 1953, pp. 55–58.
15. FRANCK, U. F. AND H. LÜDERING. Diplomarbeit, Göttingen, 1953.