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Circuit Transmission and Interference of Activation Waves in Passive Iron Wire.

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The pure commercial soft iron wire known as Armco,* when rendered passive in nitric acid of 70-80 v. %† transmits activity in the usual manner whenever the wire is activated locally by any means, such as scraping with glass or touching with zinc. The resulting activity in such strong acid is temporary, each area of the wire becoming active in its turn as the state of activity spreads, and then reverting to the passive state. Both the transmission and the repassivation are electrochemical processes; any area on becoming active forms the anode of a local electric couple, the adjoining passive area forming the cathode; the latter is then automatically activated through the destruction of the passivating surface film by electrochemical reduction; and by repetition of this process the state of activity spreads rapidly over the whole wire. The reversal or repassivation is a result of the reformation of the surface film by oxidation of the exposed metal; in strong acid (above 60 v.%) the reaction of the metal with the acid is self-limiting, by reason of the electrochemical oxidation which follows automatically in any area of metal as it becomes active and therefore anodal. This oxidation reforms the film and passivates the metal. Accordingly, in strong acid the reaction at any point of the wire lasts for only a brief time, which is the briefer the stronger the acid, *e. g.*, a small fraction of a second in fully recovered Armco wires in 80 v.% HNO_3 at 20°.

When a passive Armco wire in strong acid is touched with zinc at any point a restricted area or "wave" of activity, indicated by a darkening of the metallic surface and a slight effervescence, is seen to pass along the wire in both directions from the contact. The velocity and length of this wave vary with the concentration of acid, the temperature and the interval since the previous activation. In HNO_3 of 78 to 80 v.% at 15°, under the conditions described below, the wave retains an approximately constant length of 12 to 15 cm. and travels at *ca.* 15 cm. per second. During the time (*ca.* 1 second) occupied by the reaction at each point the surface film is successively broken down by cathodic reduction and reformed by

* American Rolling Mill Co. The carbon content is given as less than 0.1%.
† Volumes of acid (C. P. HNO_3 of sp. gr. 1.42) in 100 volumes of solution.

anodic oxidation. Alternate reduction and oxidation thus constitute the chemical cycle at each region of the surface as the activation wave passes.

Immediately after repassivation iron wires of all kinds are resistant to activation and transmit imperfectly and slowly. This non-reactive phase (comparable with the refractory phase of living tissues) passes off by degrees, within a time which varies, according to the kind of wire, from some minutes (steel wire)[1] to a second or less (pure iron wire).[2] Armco wire is remarkable in having a very brief period of recovery, of less than one second in HNO_3 of 70-80 v.% at 20°; after this interval it again transmits activation waves to an indefinite distance as before.

This combination of rapid repassivation and prompt return of transmissivity shown by Armco wire in strong acid makes it possible to obtain in rings of wire activation waves of limited length which travel at a moderate rate; by the time such a wave has completed the circuit of the ring the wire has recovered its transmissivity and the wave continues its circular motion; under favorable conditions this circuit transmission lasts indefinitely.

In order to demonstrate this phenomenon a circular loop of wire 22 cm. in diameter is suspended by thin glass hooks in a ring-shaped volume of acid 2 cm. wide and 3 cm. deep, contained in a circular trough made by cementing a section of glass cylinder *ca.* 5 cm. high and 20 cm. outside diameter to the bottom of a crystallization dish of 24 cm. diameter. A small piece of platinum wire is inserted where the 2 ends of the wire are hooked together to form the loop; this obviates irregular action at the junction. The temperature is regulated by a water bath. A suitable concentration of acid is 75 to 80 v.%.

Interference of activation waves is shown when the passive wire is touched with zinc at any point. The 2 diverging waves meet at the opposite side of the ring and there instantly and completely extinguish each other, the whole wire becoming again passive. The experiment can then immediately be repeated with the same result. Interference can also be readily demonstrated in a long straight wire immersed in a bath of acid and touched simultaneously at opposite ends, or in a vertically suspended wire over which a thin stream of acid is kept flowing from a siphon. The effect is a result of the intersection of the oppositely oriented local circuits of the 2 activation waves; the associated electric currents annul one another by compensation and the associated chemical action ceases. A sim-

[1] Lillie, R. S., *J. Gen. Physiol.*, 1920, iii, 107; 1925, vii, 473.

[2] Lillie, R. S., *Science*, 1928, lxvii, 593.

ilar interference of excitation waves in living tissues has long been known, and is shown clearly in rings cut from large hearts[3] or medusæ.[4]

Circus transmission in such rings of tissue is shown when a single excitation wave is started in one direction; in Cassiopea such "trapped" waves may last for days.[5] In the iron wire single activation waves are readily obtained by blocking the transmission of one wave with platinum-tipped forceps near the contact with zinc; the other wave continues its movement and when the platinum is withdrawn is left isolated in the wire. Its motion then continues uniformly round and round the wire until the materials are depleted or some other interfering condition arises. At any time its progress can be stopped by contact with platinum.

The following are typical speeds of transmission observed in a single wire in the same bath of acid (79 v.% HNO_3) at different temperatures:

Temperature	*Speed (cm. per sec.)*
8°	8
13-14°	13-14
18°	24-25
23°	33-35

The Q_{10} values (2.5 to 3) are higher than those usually observed with nerve or fully recovered passive iron. This is because at the time of the return of the wave on its circuit the wire is still incompletely recovered. The speed of transmission is slower during the relative refractory period than later (as is also the case in heart muscle[6] and nerve[7]); at any time the speed is limited by the degree of recovery attained. These observations indicate in reality the temperature coefficient of recovery, which is high in both living tissues and passive iron;[8] the coefficient of transmission in fully recovered wires is much lower ($Q_{10} = 1.4\text{-}1.5$) just as it is in nerve and muscle.

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[3] Mines, G. R., *J. Physiol.*, 1913, xlvi, 349.

[4] Mayer, A. G., *Publ.* 102. *Carnegie Institution*, 1908, 113.

[5] Mayer, A. G., *loc. cit.;* Harvey, E. N., *Carnegie Yearbook*, 1911, x, 130.

[6] Mines, G. R., *loc. cit.*

[7] Forbes, A., Ray, L. H., and Griffith, F. R., Jr., *Am. J. Physiol.*, 1923, lxvi, 553.

[8] Lillie, R. S., *loc. cit.*, 1925.