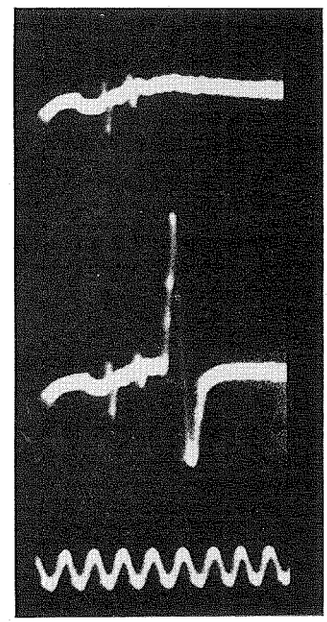
Animal Physiology
Combines Muscles, Nerves, and Electrons

By A. H. VAN HARREVELD

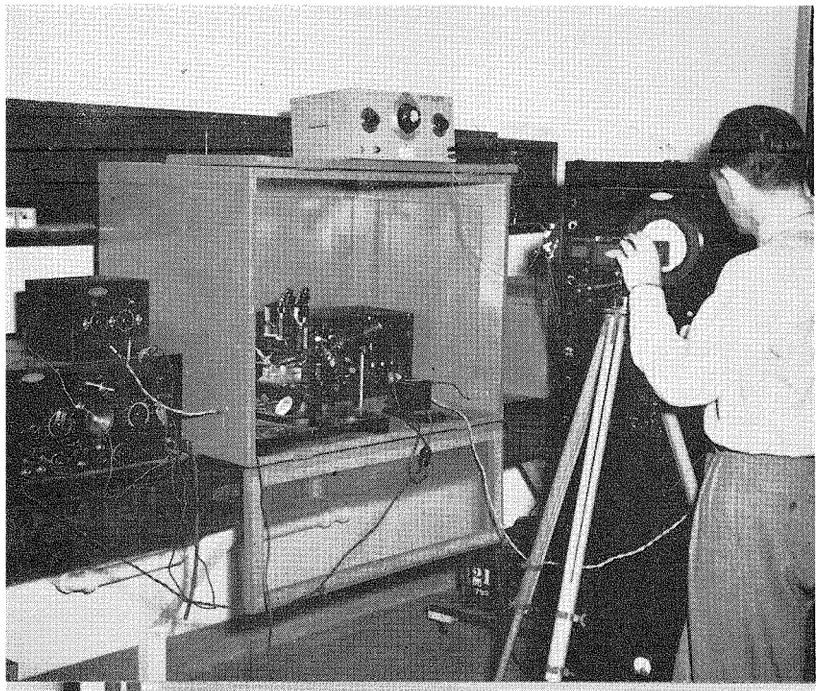
THE CRUSTACEAN NERVE-MUSCLE SYSTEM

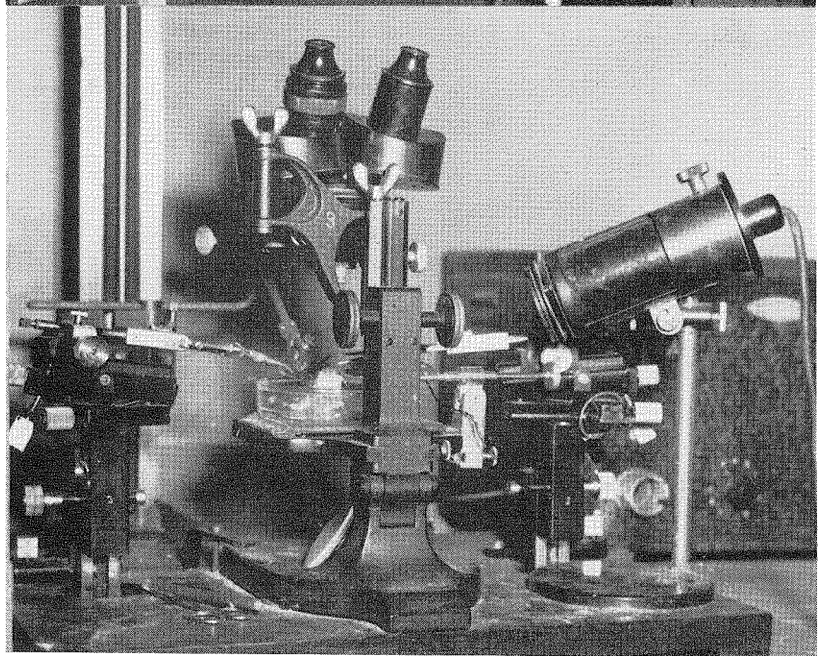
1. Fast and slow contractions

ANIMAL Physiology is represented at the Institute by comparative and vertebrate neurophysiology, a combination which has been found very advantageous for the development of several research problems. Special attention has been paid to the nerve-muscle system of the crustaceans (crayfish, crabs, lobsters, etc.). The functioning of the nerves and muscles of this group of animals has certain remarkable features, the study of which is important for the understanding of nerve-muscle systems in general. For instance, it was found that the muscle fibers of these animals can contract in two different ways. One contraction is fast and serves for the quick movements of the animal; the other contraction is slow and is used for sustained contractions. Both contractions take place in the same muscle fibers, but are brought about by different nerve fibers. The differences between these two types of contraction were further studied by the determination of the heat production and of the chemical changes in the muscle. Further investigations are planned to elucidate the mechanisms underlying these two types of muscle contraction and to investigate their presence in other invertebrates.



Tracings obtained from the central nervous system of the crayfish when two central fibers are stimulated with two shocks separated by short time intervals. In upper record the interval is 0.8 milliseconds, the two small tops indicate the activity of the two central fibers. In the middle record the interval is lengthened to 1.0 millisecond, and a large diphasic potential results, which is the response of the peripheral fibers, which are now brought into action. In the lower record each complete cycle represents 1.0 millisecond.

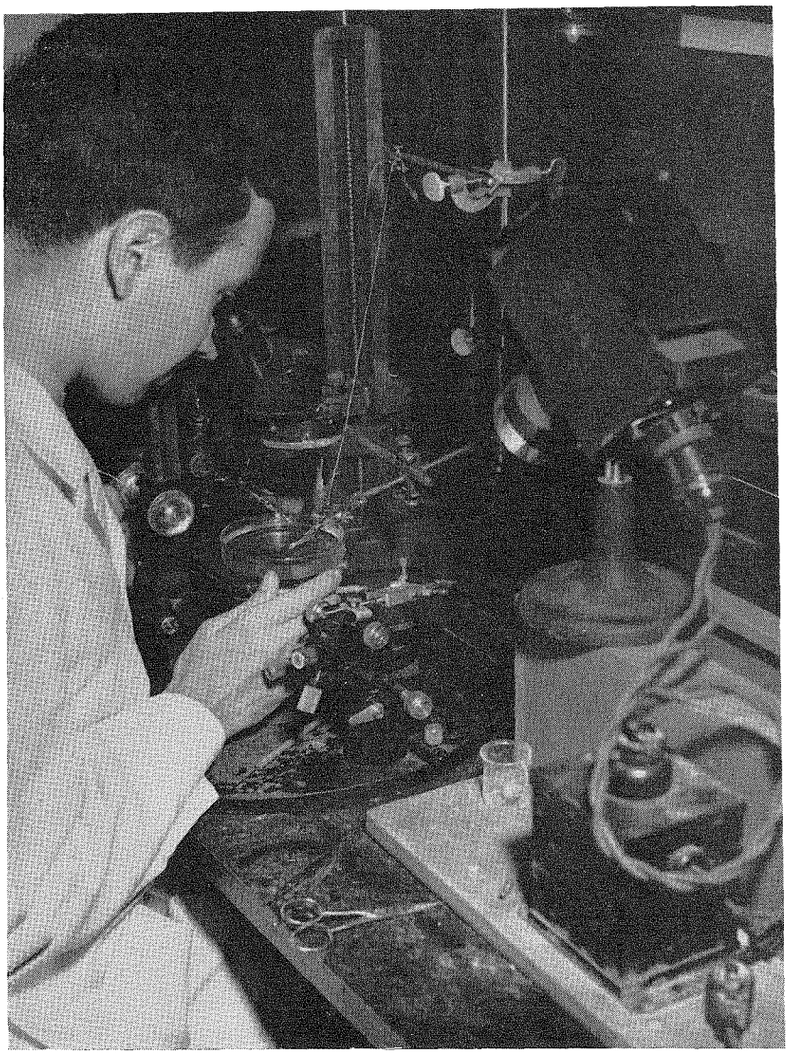




UPPER: A general view of the apparatus used in studying synaptic transmission in the crayfish. The instrument on lower left is a square wave generator able to produce shocks of variable duration, frequency and strength. With the apparatus on top of it, each square wave can be used to produce two short shocks of variable interval to study the effect of summation. In the cage is the set-up with the preparation and the pre-amplifier for recording action potentials, which become visible on the cathode-ray tube at right. Dr. Wiersma is at the camera. On top of the cage shielding the preparation, a timer. LOWER: Closeup of preparation with stimulating and leadingoff electrodes adjusted. The instruments on left and right side of the baseboard are micromanipulators with which the stimulating electrodes are brought in contact with single isolated fibers of the central nervous system in the head region. The leading-off electrodes are attached to the object table of the binocular and are applied to the freed part of the central nervous system in the tail. All parts not in contact with electrodes are submerged in perfusion fluid contained in the Petri dish.

2. Peripheral inhibition.

Another outstanding mechanism present in the

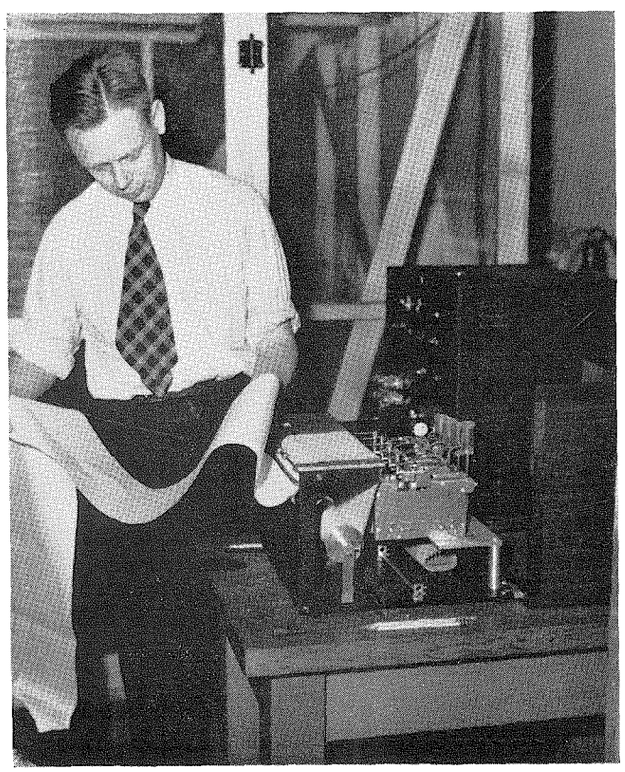


Dr. William Shallek preparing single nerve fibers in a crayfish claw. The nerve is exposed and just submerged in perfusion fluid. With a needle it is carefully divided into bundles which are then tested with the electrodes. The result of the stimulation of each bundle is noted and the ones not wanted are discarded, until only single nerve fibers (30 to 60 microns in diameter) remain. To obtain inhibitory fibers two micromanipulators must be used.

crustacean nerve-muscle system is that of peripheral inhibition. By the stimulation of a single inhibitory nerve fiber, the contraction caused by the stimulation of the motor fibers can be diminished or even completely suppressed. Certain muscles were found to receive a special inhibitory fiber, but, in general, inhibition seems to be a much less selective process. In crabs, for instance, one inhibitory fiber was found to serve no less than five different muscles. Whereas in the muscles with special inhibitory innervation this will have a function during normal movements, it is believed that general inhibition is of importance during moulting, which in these animals is almost as great an event as birth, but is repeatedly performed during growth.

3. Re-innervation of paralysed muscle

It was established that in the crustaceans a single motor nerve fiber innervates the thousands of muscle fibers forming muscles as large as, for instance, the big closer muscles of the claw of crabs and lobsters. In vertebrates, on the other hand, one nerve fiber innervates only a small part of a muscle, and the innervation of a large muscle is thus accomplished by a large number of motor nerve fibers. Each nerve fiber divides in the muscle into a number of branches each of which innervates one single muscle fiber. In this way 100 to 150 muscle fibers may be innervated by one motor nerve fiber. The observation was made that after the destruction of part of the nerve supply of a muscle, the muscle fibers which lost their innervation could be re-innervated spontaneously from the remaining motor nerve fibers. The mechanism involved in this re-innervation is an increase in the terminal branching of the motor nerve fibers which escaped destruction. In this way a muscle which was robbed of most of its muscle power by the destruction of a large part of its nerve supply can in a few months show a considerable return to its former strength. It is likely that this is one of the mechanisms responsible for the improvement of the paralysis observed after the acute phase of poliomyelitis in man. An attempt was made to re-activate the process, causing the increase of the terminal branching, in poliomyelitis patients who had stopped improving spontaneously. Definite though limited improvements were obtained.



Dr. van Harreveld and the electroencephalograph. This instrument, a recent gift of Mr. and Mrs. Fred S. Markham of Altadena, is used to record small potentials produced by the brain. Four channels of amplification are available which allow the leading off from four different spots on the skull.

The small potentials (between 30 and 100 microvolts) are amplified in the unit to the left. The unit to the right contains the power supply and a loudspeaker which makes it possible to make the electroencephalogram audible. In the middle is the recording device.

The amplification channels drive four crystographs which making inklines on a long paper strip, usually moved at the rate of an inch per second. The crystograph can follow frequencies up to the vicinity of 100 per second. This is ample since frequencies of the electroencehpalogram are usually between one and 30 per second.

For the investigation of certain aspects of the physiology of the central nervous system, crustaceans have been found to have definite advantages. As in the peripheral nerves of these animals, it has been possible to isolate and stimulate single nerve fibers in their central nervous system. This preparation has been provisorily surveyed only, and it is hoped that many further points may be developed. At present the main interest is centered on the function of the so-called giant fibers, very thick nerve fibers which are responsible for the coordination of swimming movements of the animal. They run the entire length of the central nervous system and transmit their excitation to the motor nerve fibers supplying the muscles involved in the swimming movements.

EFFECTS OF ASPHYXIATION OF CENTRAL NERVOUS TISSUE

In a series of experiments the effects of asphyxiation of central nervous tissue in vertebrates were investigated. When the asphyxiation is prolonged sufficiently to produce damage to the nerve cells, but not long enough to destroy them, there may result a highly increased reflex activity after the tissue has recovered from the acute effects of the oxygen lack. In many respects the state of hyperactivity of the reflexes is comparable with the effects of convulsive drugs like strychnine. It is hoped that it will be possible to ascertain by further study the nature of the changes produced by asphyxiation.

Many of the electrical phenomena observed in living tissues are believed to depend on the presence of membranes permeable to certain ions but impermeable to others. In the presence of suitable concentration gradients such membranes can give rise to ionic double layers which represent electrical potentials. Studies on such membrances in the nervous system have been carried out. Asphyxiation has been shown to destroy the double layer. In the most sensitive parts (nerve cells) the deterioration of the double layer starts within 10 seconds after the beginning of asphyxiation. The effect of drugs is now being investigated.

ELECTROSHOCK THERAPY AND ELECTRONARCOSIS

For a number of years the Physiology group has cooperated with the Department of Institutions of the State of California in introducing in the State Hospitals some of the shock treatments for mental ailments. During this time physiological aspects of electroshock therapy were studied. An improved shock apparatus was constructed which made it possible to apply a preset current independently of the resistance of the patient's tissues.

As an outgrowth of this cooperation, another form of electrical treatment for mental diseases was developed. Whereas in shock therapy the current application lasts but for part of a second, in electronarcosis, as this new form of current application is called, the current is passed throught the patient's head for several minutes, producing unconsciousness. The physiology of this procedure has been worked out in some detail. The effects of electronarcosis on the blood pressure, on the metabolism of the brain and on the anatomy of the central nervous system have been studied. The relation of various forms of current to electronarcosis was investigated. Finally the Physiology group has assisted in the application of this treatment to a group of patients afflicted with schizophrenia. The results were encouraging.