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Effects of Electricity on Living Tissue

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FOR centuries, man has been exposed to the hazards of electric shock. Undoubtedly, lightning discharges occurred at the surface of the earth long before it was inhabited. Human beings of the past have developed superstitions regarding this phenomena, and even at present people fear it, because of its possible fatal effects. This fear of electricity is not limited to the field of lightning. Many people are afraid to take hold of a door knob during dry winter days, because of electric spark that jumps between their fingers and the knob. If they knew more about the magnitude of the electrical potential (10,000 volts) associated with such discharges, their fear might be increased. If however, they understood still more about how electricity effects the living system, they would realize that such discharges are harmless. However, the fact remains that many people fear electricity and that they fear it because they do not understand its physiological effects.

Electric currents passing through a living animal may be fatal. They may produce sensory or motor responses or they may produce no physiological effects. Fatalities may be associated with responses but not always. Ordinarily a motor response (which can be detected by the twitching of a muscle when it is supplied with current) can be produced in humans by a current of 0.3 of a milliampere. However, if the current is administered in the proper manner this same living organ may conduct a hundred times this amount without any perceptible sensory or motor response.

The physiological effects of electric currents on living tissue are numerous and of the many variables that enter into the determination of these effects, there are included not only those that define the nature of the current but also those that define the electrical properties of the tissue itself.

Experiments described here were conducted to determine the types of electric currents that cause fatalities, the types that cause responses, and the types that are not perceptible. While these tests have not revealed all the phenomena associated with such currents, they have revealed the behavior of living tissue when subjected to electrical stimulus. This behavior can be predicted from calculations based on the properties of the current or voltage supplied and the electrical characteristics of the tissue. It is possible, on the basis of such calculation, to determine the magnitude of current required to produce perceptible responses or how this same current might be administered without producing any response.

The ultimate aim of such investigations has been to establish data which will permit the safe use of electricity in the field of medicine. The following is a description of some of the investigations that have been conducted for the purpose of establishing such data.

Fatal Electric Shock

Alternating current may cause death in animals or man by either cardiac or respiratory failure. The amount of current of definite duration necessary to cause these effects in an animal may differ somewhat from that required to produce similar effects in man. However, the effects of fatal shocks can be explained more completely from data taken on small animals than on larger animals. For this reason the following will be devoted to the fatal effects of alternating current on rats. Experiments were conducted to determine the fatal alternating current for duration ranging from 1-10 to 30 seconds, and at frequencies ranging from 25 to 750 cycles per second. These experiments were conducted in accordance with the following procedure.

For each experiment the rat was first anaesthetized with ether and then was tied down on a sheet of hard rubber with its legs projecting through holes suitably placed. Spring clips were attached to each leg to prevent withdrawal and to act as contacts. The two front legs were attached to one lead from the source of power.

The two rear legs were attached similarly to the other lead. The contacts were wrapped with cotton soaked in a saturated salt solution to reduce the resistance and minimize burning. Shocks were administered only after the effects of the anaesthetic had passed away.

The location of the leads influences the amount of current necessary to cause death, the effects depending on the vital organs situated in the path of the current. Thus when only the front legs (arms) form the two contacts, or when the contacts are made on front and rear legs (arm and leg) the fatal current is lower than when the rear legs alone form the contacts. The major resistance in all animals is at the skin surface and may amount to a thousand or more ohms per square centimeter depending upon the moisture of the skin, and in man, also upon the activity of the sweat glands; the resistivity of the moist tissues beneath the skin is low, equaling approximately that of a one per cent solution of sodium chloride.

For each time interval studied, and for each frequency, a series of experiments was carried out first to determine approximate values for the fatal amount of current. Shocks with successive increases in voltage were given at intervals of 5 to 10 minutes until death resulted. In most cases the current and voltage were read from meters properly connected to the circuit leading to the rat. For shocks of short duration it was necessary to determine these quantities by means of an oscillograph. Having limited the field of search by this method, individual rats were exposed to voltages near the fatal value in small steps between successive rats until the minimal fatal current was reached. By repeated experiments for each duration of time and each frequency, the variation of the fatal voltage with duration of the shock could be obtained although at the expense of many rats. A record was kept of the current, voltage, and cause of death for each animal that was killed. If the shock caused the rat's heart to stop beating while its breathing continued for a short period, the cause of death was attributed to cardiac failure. If the shock caused the rat to stop breathing and the heart continued to beat for a short time, the cause of death was recorded as a respiratory failure. Some shocks of long duration caused a pronounced rigor mortis which developed even while the current flowed and which was due to overheating. It was found that the fatal voltage for a given time and frequency varied considerably with different rats, but that the current required to cause death was nearly constant. This variation in fatal voltage was due to the differences in the electrical resistances of individual rats. Some variation was found in the time and current required to produce hyperpyrexia. The weight of the animal was of significance in this respect, and to obviate this difficulty rats of nearly the same weight were used.

The duration of the current was controlled by two automatic switches. One of these switches was used to operate synchronously with the voltage supply closing the circuit as the voltage was rising through zero. The second switch closing at the end of the shock formed a short circuit around the animal. This short circuit provides a means of stopping the current without the secondary shocking effect that might be produced by arcing when the main circuit was opened. The wave form of the current and voltage along with their magnitudes were checked with an oscillograph.

The conclusions reached as a result of these experiments are briefly as follows:

1. For shocks of equal durations the current required to kill by cardiac or respiratory failure is larger at high frequencies than at low frequencies.

2. For ordinary power frequencies the curve showing the relation between the time and current required to kill is a composite of two intersecting hyperbolas.

3. The explanation of the shape of the curves (Fig. 1-3) is to be found in the variation in susceptibility of different organs to electric shock; in general, shocks fatal in a short time give rise to cardiac failure; those requiring greater duration, to respiratory failure.

4. Currents smaller than those producing fatal cardiac or respiratory effects, if prolonged, may result in death by hyperpyrexia, but within the range of ordinary power frequencies, hyperpyrexia occurs only after cardiac or respiratory failure.

Purposes Of Experimental Investigations

Electricity is a most universal tool. Its manifold uses are not limited to the common fields of power production and communication. It has opened a newer field of science—electro physiology. Its uses for diagnosis of human ills is nothing new. The x-ray and electrocardiograph are indispensable in the modern hospital. Of the later electrical developments in the field of medicine perhaps one of the most important is the electric knife which cauterizes as it cuts. This device can be used successfully in brain surgery. The production of heat internally (diathermy) by the use of high frequency alternating currents is becoming increasingly common. The removal or addition of drugs to the body by the use of electric current is a more recent development. The advantages of this process are that the drugs can be applied to the portion of the body where they are desired. They can be supplied in accurately controlled amounts and distributed uniformly. All of these processes necessitate sending current through living tissue. This must be done without fatalities, injuries, or great discomfort. The direct determination of the behavior of living tissue to different types of electrical stimulation requires extensive, lengthy experimental tests. A more simplified approach to the problem can be made through the use of the equivalent circuits of the tissue. The behavior of tissue to electrical stimulation can be predicted and explained on the basis of these circuits. They serve as a useful agency by which it is possible to safely apply current to living bodies without undesirable results.