EFFECTS OF ELECTRIC SHOCK ON MAN

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In comparison to the total number of accidental deaths in the United States, which is now approaching 100,000 per year, the number of electrocutions is small indeed. In recent years the number of electrical fatalities has remained practically constant at about 1,100 per year, of which slightly over one-quarter are caused by natural lightning. Beyond a doubt, electricity is potentially the most dangerous commodity in general use by the public. The small number of electrical fatalities undoubtedly is due to the general recognition that electricity is inherently dangerous. The electrical industry need not be ashamed of the record, particularly when one considers the ever increasing use of electricity in the home and industry. However, the industry must remain alert to protect and to better the record. This is especially important since the consumption of electricity has been doubling every ten years for the last several decades. Knowledge of the possible effects of electric current on man is the starting point at which to incorporate safety into the design of electrical equipment. This knowledge is essential in explaining and justifying safety regulations, safe work procedures, rescue and resuscitation methods for electric shock victims. This information is vital in the general education of the public in the proper use of appliances and machines. Such knowledge is also valuable to the physician in diagnosis and treatment of accident victims.

Although high voltage often produces spectacular and awesome destruction of tissue at contact locations, it is generally believed that the effects of electric shock are due to the current actually flowing through the body. Even though Ohm's law ($I = E/R$) applies, frequently it is difficult to correlate voltage with damage to the body because of the large variations in contact resistance usually present in accidents. For this reason, criteria of the danger from electric shock are based solely upon current. The electric shock hazards of both high-voltage and low-voltage circuits are derived from known effects of electric currents as determined from low-voltage experiments. Experiments involving currents large enough to cause sudden death cannot be made on human beings, and resort is made to animal experimentation. Although translation of results obtained on animals to man is conjectural, in many instances analysis of human accidents has permitted satisfactory correlations to be made.

It is important to distinguish between the direct effects of electric current and general shock to the nervous system, which is commonly called "shock." Because of the wide variation in the physical condition of individuals, it is impossible to justify any electric shock as safe for <u>all</u> individuals. The press contains frequent accounts of fatalities ascribed to heart failure due to overexcitement, intense emotion, fear or shock. For such susceptible persons it is possible that contact with any electric circuit which permits currents in excess of the threshold of sensation might result in fatality. This possibility must be recognized, and an occasional death is to be expected from casual contact involving electric currents known to be safe for most normal individuals. Death in such cases must be considered due to shock to the nervous system and not to the primary effects of electric current. In contrast, the establishing of reasonably safe currents is a vital problem of practical importance for the vast majority of normal individuals.

The ratio of fatalities to injuries for electric shock accidents is very high in comparison to the corresponding figure for all other accidents. However, it is indeed fortunate that victims who survive the first effects of serious electrical accidents often recover without permanent disability.

The discussion begins with the first tingling sensations resulting from barely perceptible currents, proceeds with reactions produced by currents of increasing intensity, and includes various causes of electrocution. The paper is concluded with mention of effects caused by high-frequency currents, burns and blisters, and the necessity for prompt application of approved methods of resuscitation for victims of severe electric shock accidents.

Man is very sensitive to very small electric currents because of his highly developed nervous system. An almost limitless number of thresholds of sensation could be defined depending upon the locations selected for applying contacts to the body. The effects of electric stimulation depend, to a very considerable extent, upon the type of contacts, whether the contacts are firm and involve an appreciable area, or whether they are point contacts. Currents almost too small to measure produce severe piercing pain when they flow in an open cut or wound.

Determination of man's high sensitivity to electric current is illustrated in Fig. 1. This shows one of 115 subjects in the process of determining his threshold of perception when holding two small platinum wires firmly but lightly on the tip of the tongue. A threshold is defined as the average value of current obtained from a large number of subjects required to produce a prescribed effect. The tongue is the most sensitive part of the body so far investigated quantitatively, and the thresholds for men were 45 microamperes when using pure direct

Fig. 1 - Determination of perception current on the tongue.

current and 60 cycle alternating current. Here the first sensations are those of taste and are distinctly different from the nerve or muscle stimulation usually associated with electric stimulation applied to other parts of the body.

Perception on the hand is important, as it is essential that the user not get the sensation of shock when using home appliances, hand tools, or surgical instruments. Shocks due to currents only slightly in excess of the threshold of perception are usually considered annoying rather than dangerous. However, they are startling when they are not anticipated. Such shocks may cause an involuntary movement or loss of balance, and the ensuing fall or movement might result in painful injury. Obviously, the slightest shock to a surgeon during an operation might be disastrous to a patient. Figure 2 shows a subject in the process of determining the threshold of sensation with small copper wires held in the hands. Figure 3 shows another subject at the instant of perception when using a slightly different technique. For these tests the current was gradually

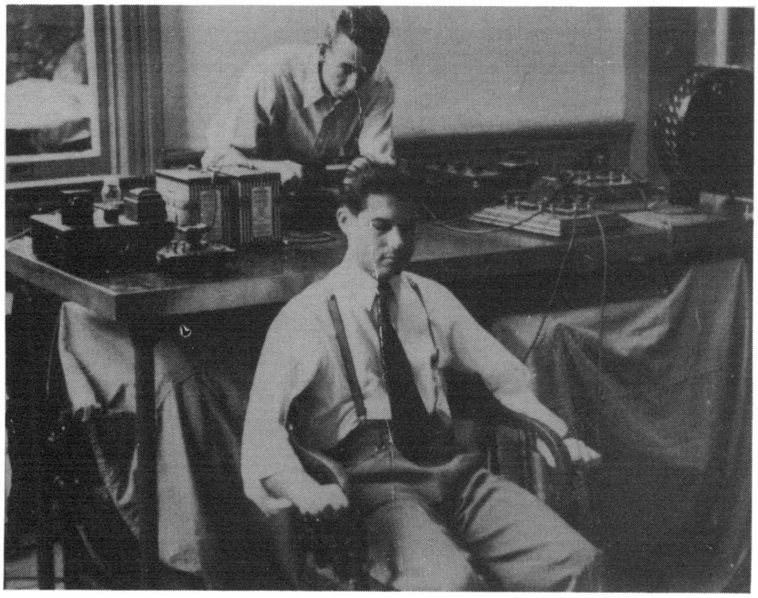


Fig. 2 - Determination of perception current on the hands.

Fig. 3 - Determination of perception current on the hands.

increased and several trials were made on each individual to determine the smallest current that could just be felt. Only subjects in good physical condition were used, and only those parts of the skin which were free from cuts and abrasions were subject to quantitative tests. The hands were moistened with a common salt water solution to minimize the range of contact resistances and to permit the use of low voltages for safety.

Experimental results using pure direct current are shown in Fig. 4. It should be noted that the data from the 115 subjects follow a normal distribution, as evidenced by the fact that the data closely follow a straight line when plotted on probability paper. Because of the considerable number of subjects used and because a normal distribution was obtained, it is believed that valid statistical predictions can be made, not only for the particular group used in this investigation, but also for a large cross-section of the adult population. The threshold, or average value, based on tests made on these 115 men, using direct current, was 5.2 milliamperes. The first sensations with direct current are those of warmth, in contrast to the tingling sensation which is characteristic when alternating current is used.

Results obtained from 167 men when using 60 cycle commercial alternating current are shown in Fig. 5. A comparison of two groups totaling 142 men is shown in Fig. 6, in which the solid dots represent data obtained from 114 men at the beginning of World War II. The open dots are values from an entirely different group of 28 men who were tested after the end of the war. The results of both tests are consistent and illustrate the accuracy which may be obtained from tests of this type. The threshold of perception for the hands holding a small copper wire was established at approximately 1.1 milliamperes. Here the values are plotted as per cent deviations from the mean of each group, respectively. This procedure was found to give increased accuracy in statistical predictions derived from relatively small numbers of subjects.

Similar perception tests were made on the group of 28 men using the small copper wire electrode, with the middle finger resting lightly on a polished copper plate, and with the middle finger tapping the copper plate at a rate of once or twice a second. Deviation curves at various frequencies for these three contact conditions were obtained, and the response for 1/2, 50 and 99 1/2 per cent of the group permitted construction of curves showing the effect of frequency on perception currents from 60 to 200,000 cycles (Figs. 7, 8 and 9).

Comparative tests were made on four women at the time the tests were conducted on the 28 men using the copper wire electrode with sinusoidal waves from 30 to 100,000 cps. The data for the women fell consistently within the range of the corresponding data for the men. Similar data were also obtained at the Electrical Testing Laboratories, New York, on 42 men and 28 women, using four different test electrodes and 60 cycle alternating current. The ratio of average perception current thresholds for women to men was approximately 2/3. Thus it seems reasonable to conclude that the threshold of perception for women can be taken as 66 2/3 per cent of the corresponding value for men.[1,2]

With increasing alternating current the sensations of tingling give way to contractions of the muscles. The muscular contractions and accompanying sensations of heat increase as the current is increased. Sensations of pain develop, and voluntary control of the muscles that lie in the current pathway becomes increasingly difficult. Finally a value of current is reached for which the subject cannot release his grasp of the conductor. At this point he is said to "freeze" to the circuit. The maximum current a person can tolerate when holding a conductor in one hand and still let go of the conductor by using the muscles directly stimulated by that current is called his "let-go" current. Let-go currents are important, as experience has shown that an individual can withstand, with no ill aftereffects, except possibly sore muscles, repeated exposure to his let-go current for at least the time required for him to release the conductor. Figures 10 and 11 are photographs of subjects in the process of determining their let-go currents. It is noted that the current flowing between the hands is sufficient to affect the muscles of the entire body.

Let-go currents determined for 134 men and 28 women are shown in Fig. 12. In these tests the subjects held and then released a test electrode consisting of

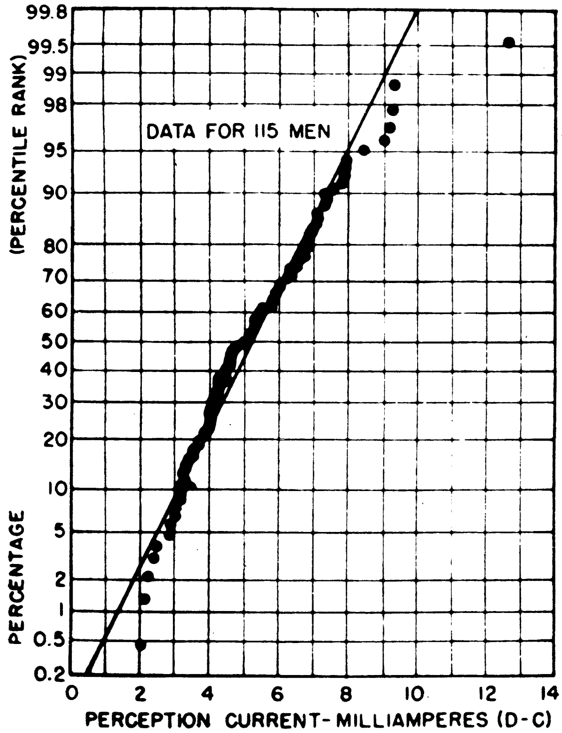


Fig. 4 - DC perception distribution curve.

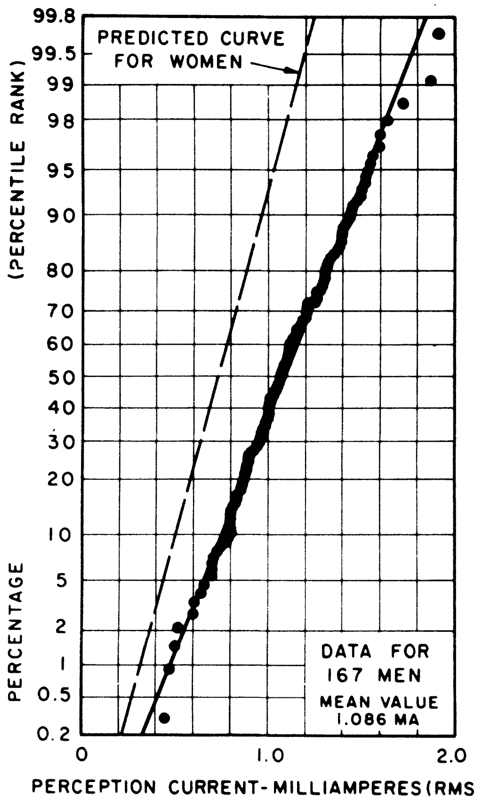


Fig. 5 - Sixty-cycle perception distribution curve.

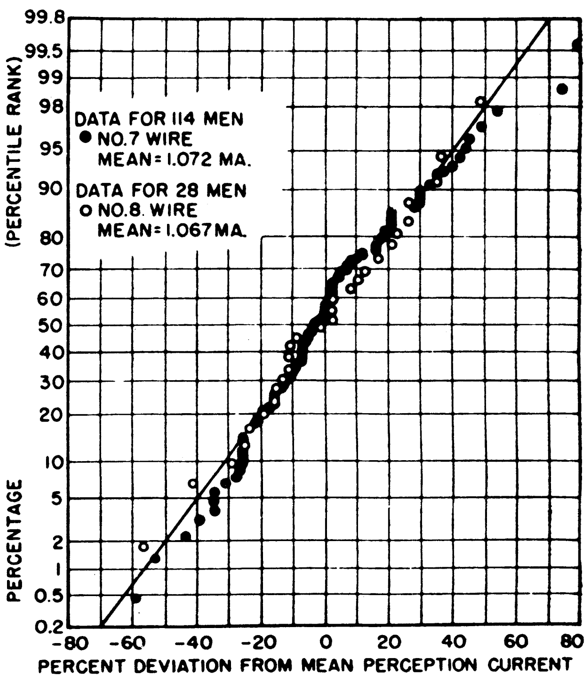


Fig. 6 - Sixty-cycle perception deviation curve.

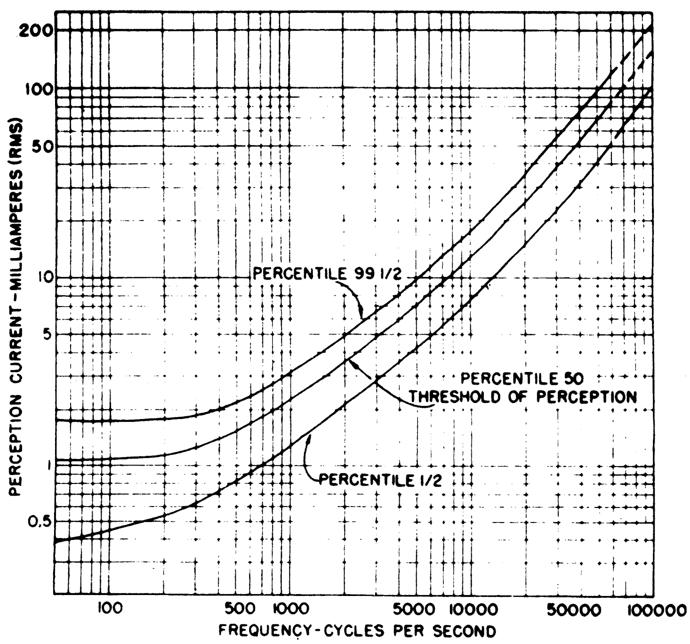


Fig. 7 - Effect of frequency on perception current for hand holding wire.

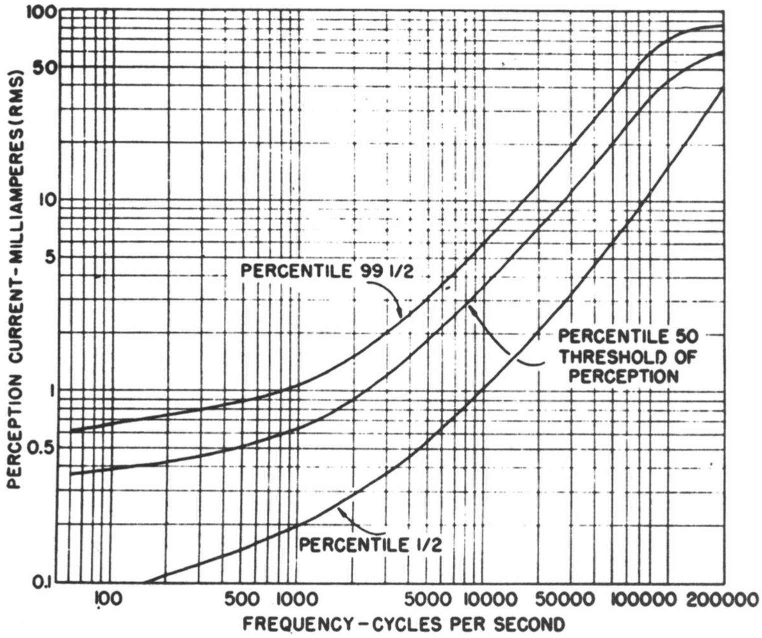


Fig. 8 - Effect of frequency on perception current for finger touching copper block.

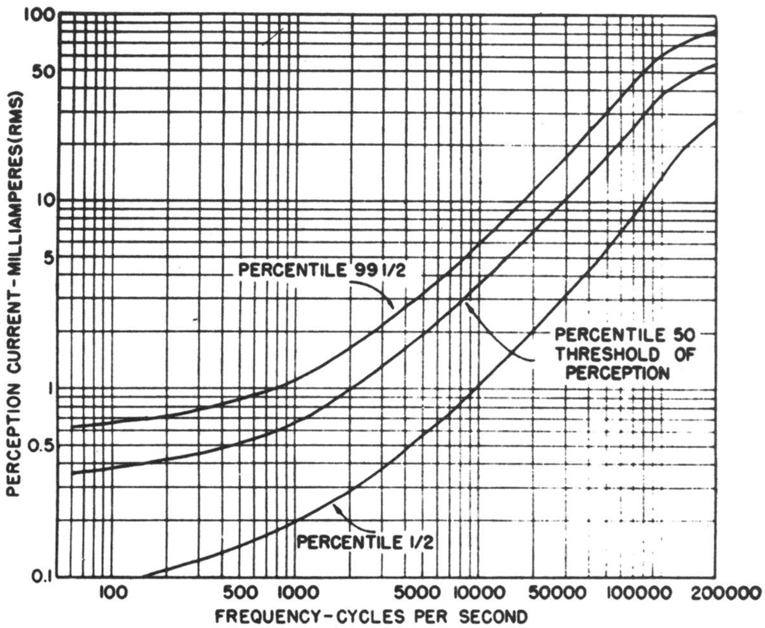


Fig. 9 - Effect of frequency on perception current for finger tapping copper block.

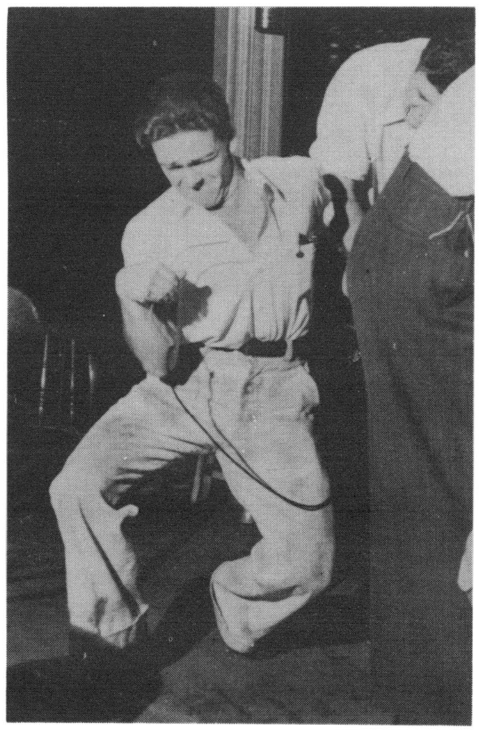
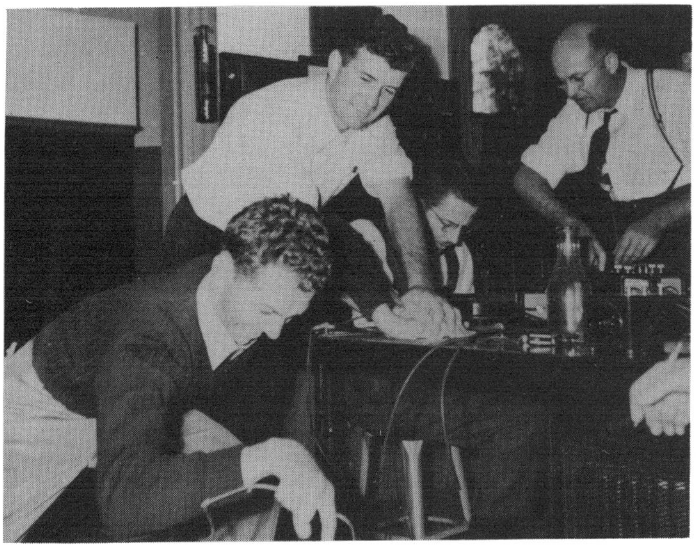


Fig. 10a - Determination of let-go current.



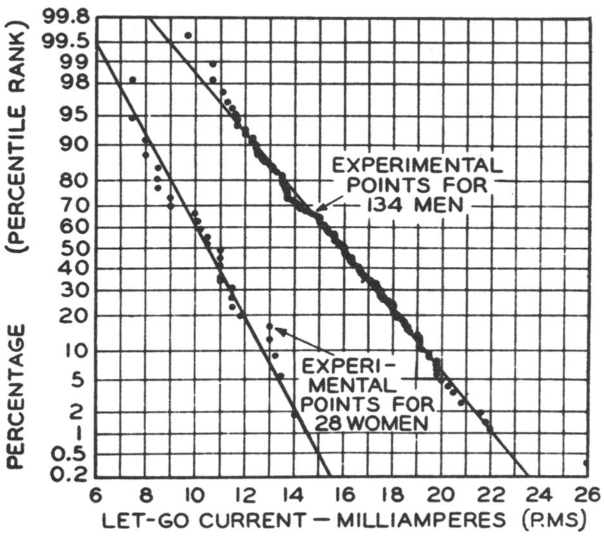


Fig. 10b (upper left) - Determination of let-go current.
Fig. 11 (above) - Subject at about two milliamperes in excess of his let-go current.
Fig. 12 (left) - Sixty-cycle let-go distribution curves for men and women.

a No. 6 copper wire. The circuit was completed by placing the other hand or foot on a flat brass plate, or by clamping a conductive band lined with saline-soaked gauze on the upper arm. After one or two preliminary trials to accustom the subject to the sensations and muscular contractions produced by the current, the current was increased to a certain value and the subject was commanded to let go of the wire. If he succeeded, the test was repeated at a current of a slightly higher value. If he failed, a lower current was used, and the values were again increased until the subject could no longer release the test electrode. The end point was checked by several trials, and the highest value was taken as the individual's let-go value in order to eliminate the effects of fatigue. The experimental points plotted in the figure were obtained with hands wet with salt water solution to secure uniform conditions, and to reduce the sensation of burning caused by high current densities at tender spots and at the instant of releasing the electrode. Other tests were made with dry hands, hands moist from perspiration and hands dripping wet from weak acid solutions. The effect of the size of the electrodes was also investigated. It was found that the location of the indifferent electrode, the moisture conditions at the point of contact and the size of the electrodes had no appreciable effect on the individual's let-go current. It is believed that the results obtained from tests in which hands wet with saline solution grasp and then release the small copper wire may be used to predict let-go currents of a specified degree of safety with an accuracy sufficient for most practical purposes.

Sixty-cycle let-go currents were measured on 28 women. The women ranged in age from the late teens to the early twenties. They were light in stature and obviously not accustomed to hard physical work, and their forearm muscles were not particularly well developed. Although the women volunteered freely for the tests, it proved impossible to develop enthusiasm or any degree of competitive spirit at the higher currents. The results are probably representative for the sedentary type. However, from observation of the reactions of the subjects having the greatest muscular development, it is possible that values were considerably lower than those which would have been obtained had a group of mature, healthy women accustomed to physical labor been used. Results based on these data, therefore, should be conservative and on the side of safety.

The average value, or let-go threshold, was established at 15.87 and 10.5 milliamperes for men and women, respectively. The ratio of the let-go thresholds, women to men, is approximately 2/3. This ratio is frequently used in estimating let-go currents for women for other frequencies and waveforms. It is believed that the lower value for women is due to their somewhat poorer muscular development rather than to any difference due to sex. No satisfactory theory has been advanced to explain why the women to men perception and let-go threshold ratios are seemingly identical.

There was considerable variation in an individual's let-go current in repeated tests made at weekly intervals, the trend usually being toward higher values (Fig. 13). Therefore, the largest current released on the first test was taken as the let-go current for a given frequency. This was done to include the element of surprise to as great an extent as possible and to give conservative results. Psychological factors, especially fear and competitive spirit, were the most important causes for the variations. Physiological factors also played an important part, but so far their mechanism remains unknown. It seemed that the let-go current in both sexes was related to the muscular development of the wrist and forearm. Husky subjects having low let-go values could almost invariably be persuaded to continue the test until their values were in line with those of similar physique.

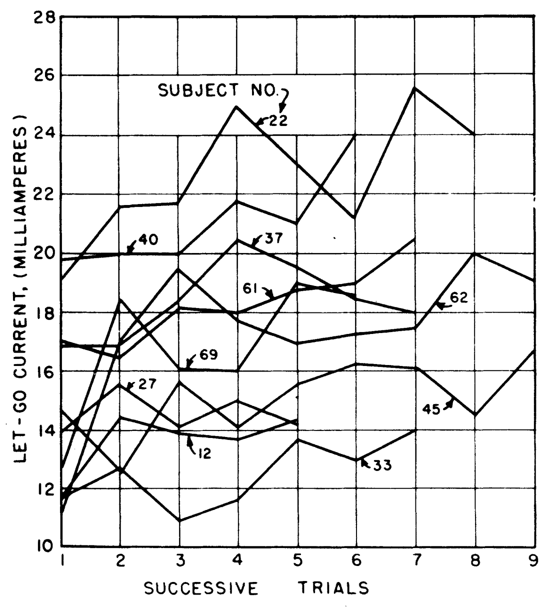


Fig. 13 - Effect of repeated trials on let-go currents.

Let-go current tests were conducted using sinusoidal waves having frequencies from 5 to 10,000 cps on smaller groups of men, ranging in number from 24 to 30. Deviation curves for various frequencies were obtained, and the results were plotted to show the effect of frequency on let-go currents (Fig. 14). It is apparent that the current values become dangerous progressively to an increasing number of persons as indicated by the various curves. Figure 15 shows curves of proposed reasonably safe let-go currents for men, women and children. Values for the men were taken from the lowest curve of the preceding figure. Values for women, for frequencies other than 60 cycles, were computed as 66 2/3 per cent of the corresponding values for men. Values for children were estimated at 50 per cent of the corresponding values for men. Although it is extremely difficult to evaluate pain, the upper curve shows what is believed to be representative of the relative discomfort for men. The relative discomfort curve is the reciprocal of the let-go current curve for men, arranged to indicate 100 per cent corresponding to 60 cycles.

Tests using gradually increasing direct current produced sensations of internal heating rather than severe muscular contractions. Sudden changes in the current magnitude produced powerful muscular contractions and interruption of the current produced a very severe shock. Muscular reactions when the test electrode was released at the higher values were objectionable and sooner or later all subjects declined to attempt higher currents. Tests were made on 28 men; in each case little difficulty was experienced in releasing the electrode. The maximum a subject would take and release was termed his "release" current, since this represents a psychological limit rather than the physiological limit of the let-go tests. Experimental values are given in Figs. 16 and 17. Because of the relatively small number of subjects used, the average dc release current for a large number of men was computed as equal to the average dc release current times the ratio of the average 60 cycle let-go current for 134 men to the average 60 cycle let-go current of the 28 man sample. Thus the probable average dc release current for a large group of men is estimated at 76.1 milliamperes. Assuming a similar distribution for women, the corresponding dc release current would be 50.7 milliamperes.

At the conclusion of the 60 cycle let-go current tests on the women, the experiments were terminated with one or two release tests using direct current. After one or two preliminary trials, the current was increased to a maximum of 35 milliamperes, which each subject released without complaint or difficulty. In one case a woman was tested at the same time as the dc release tests were being made on the men. She released 56 milliamperes direct current before refusing more.

Although the deleterious effects of electric shock are due to the current actually flowing through the human body, in accidents the voltage of the circuit is usually the only electrical quantity known with certainty. While current and voltage are related by Ohm's law, the great variances in skin and contact resistances are so unpredictable that let-go voltages are relatively meaningless. On very high voltage circuits, skin and contact resistances break down instantly, and thus they play only a minor role in limiting the current received by a victim. However, on the lower voltages the resistances at contact locations become of increasing importance, and these resistances are of paramount importance on very low voltage circuits. Obviously, wet contacts create a most dangerous condition for receiving an electric shock, and let-go voltages under these conditions may be of limited interest.

Figure 18 shows 60 cycle let-go voltages hand to arm band with wet contacts and with skin intact. From these and other similar tests it is concluded that

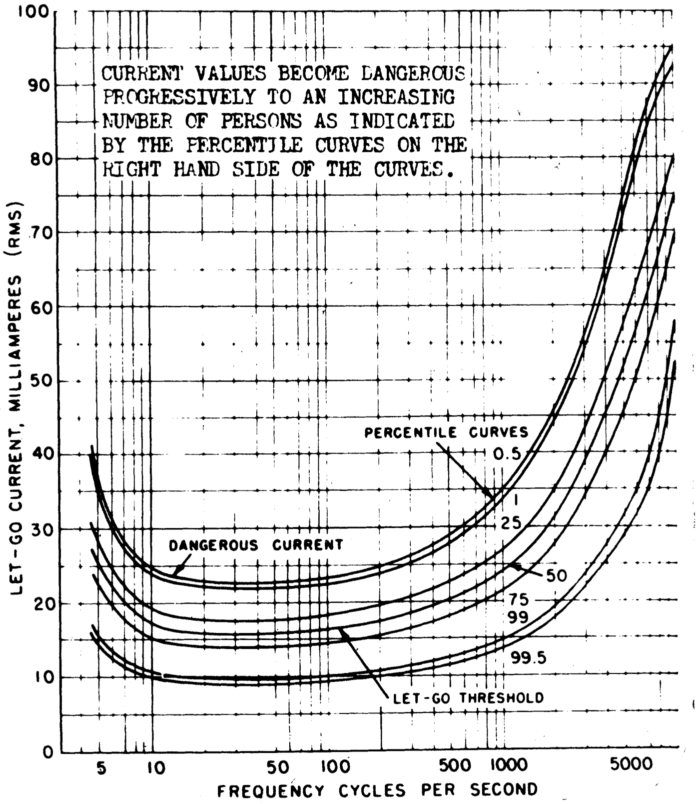


Fig. 14 - Effect of frequency on let-go currents for men. Values for women are approximately 66 per cent of the current values shown on the curves.

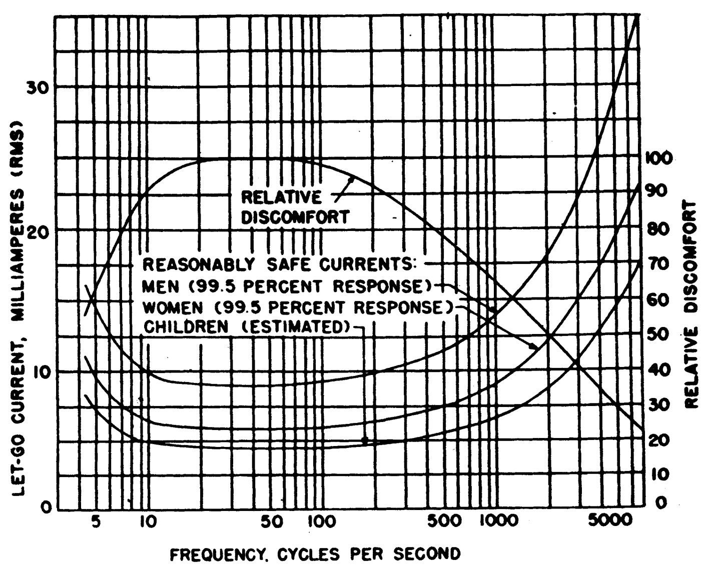


Fig. 15 - Reasonably safe let-go currents.

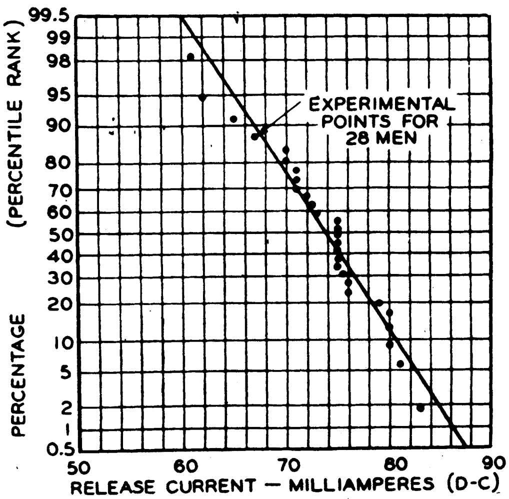


Fig. 16 - DC release current distribution curve.

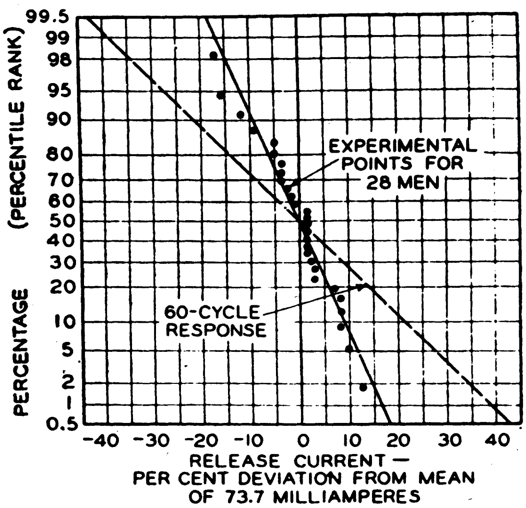


Fig. 17 - DC release current deviation curve.

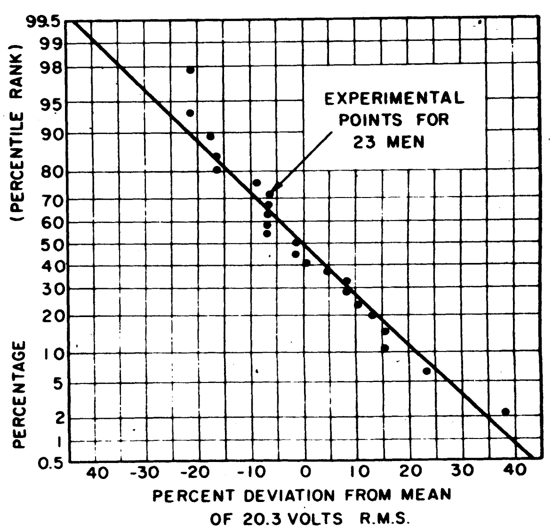
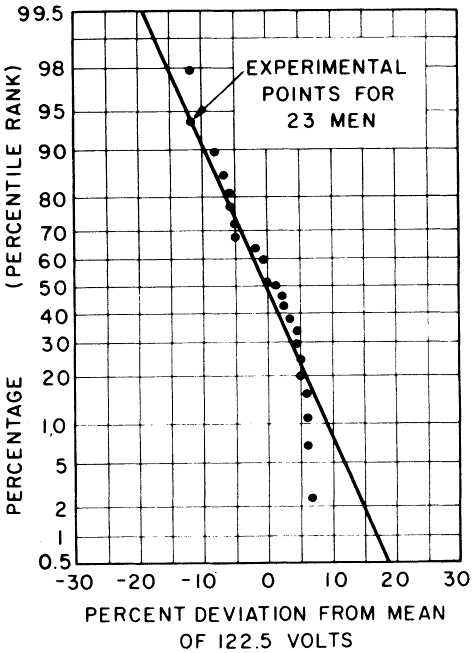


Fig. 18 - Sixty-cycle let-go voltage deviation curve (wet contacts -- hand to arm band).



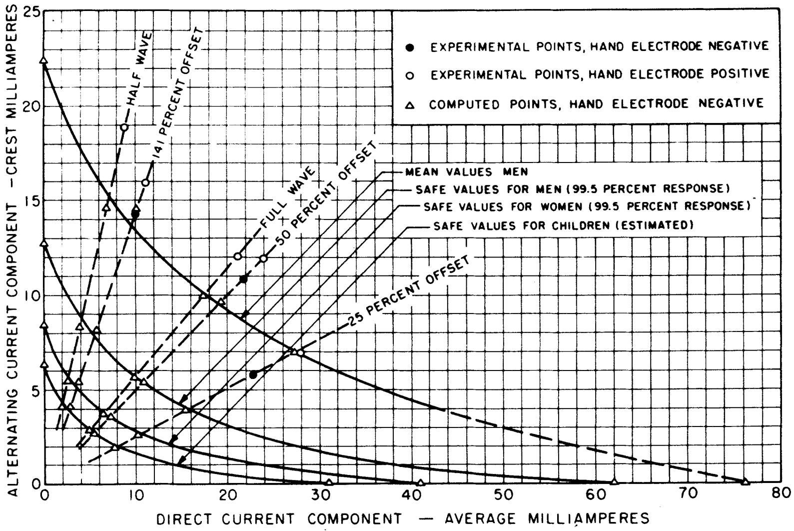


Fig. 19 (left) - DC release voltage deviation curve (wet contacts -- hand to hand). Fig. 20 (above) - Effect of waveform on let-go currents.

reasonably safe 60 cycle let-go voltages hand to hand are about 21 volts, and hand to both feet ankle deep in salt water, 10 volts. Figure 19 shows results obtained with direct current with the hand-to-hand-current pathway. Reasonably safe dc release voltages are 104 volts hand to hand, and 51 volts hand to both feet ankle deep in salt water.[6]

A discussion of the detailed studies made to determine the effect of waveform on let-go current will not be included in this report. Tests were made using synthetic waves consisting of a third harmonic superimposed on the 60 cycle fundamental, in which the harmonic component was controlled in both magnitude and phase relation. Comparative tests were made using 180 cycle sine and triangular waves. Tests were also made using composite waves consisting of sinusoidal 60 cycle currents superimposed on direct current, and using the output of full-wave and half-wave rectifiers. From these tests it was concluded that the crest and not the rms value is the critical factor in muscular stimulation with low-frequency alternating currents. Man's greater tolerance to electric current with increasing frequency suggests that the effect of higher harmonics, or repetitive pulses superimposed on low-frequency alternating current, would be less and less as the frequency of the superimposed current was increased. At very high frequency, it might be expected that the sensation of heat would be largely masked out by the pain and the muscular stimulation of the lower frequency components. Results of this investigation using composite waves are shown in Fig. 20. It is very important that the let-go current from a device having only a very small ripple, such as the output from a well-filtered power supply, would be materially less than that obtained from pure direct current, such as that supplied from a battery.[3-6]

The higher 60 cycle let-go currents were frequently sufficient to stop breathing during the period the current was flowing across the chest, and the reactions at the instant of current interruption during the dc release tests occasionally threw the subject a considerable distance. The muscular reactions during accidents frequently cause fractures, and the contractions resulting when a victim grasps bare overhead wires may be sufficient to freeze him suspended to the circuit in spite of his struggle to drop free. In many accidents a victim frees himself by breaking the conductor, or his body weight may assist him in interrupting the circuit; however, fortuitous circumstances must not be relied upon to provide safety to human life. Currents only slightly in excess of one's let-go current value are very painful, frightening and hard to endure for even a short time. Failure to interrupt the current promptly is accompanied by a rapid decrease in muscular strength due to the pain and fatigue associated with the accompanying severe involuntary muscular contractions, and it would be expected that the let-go ability would decrease rapidly with the duration of contact. Prolonged exposure to currents only slightly in excess of a person's let-go limit may produce exhaustion, asphyxia, collapse and unconsciousness followed by death.

Currents considerably in excess of those required to cause a stoppage of breathing due to excessive contraction of the chest muscles may produce temporary paralysis of respiration due to action on the nerves. It has been known for some time that respiration might be inhibited by currents passing through the respiratory nerve center located in the base of the brain. These victims are almost always unconscious and they appear dead. The paralysis may last for a considerable period of time after interruption of the current and resuscitation must be applied immediately to prevent asphyxial death. Often the paralysis disappears in a few minutes or in a few hours and continued application of artificial respiration saves the victim. Mere cessation of natural breathing is not likely to produce serious aftereffects or permanent damage if artificial respiration is applied immediately, as evidenced by the many persons who have been resuscitated successfully. Unfortunately little is known regarding the magnitude of the currents required to produce respiratory inhibition or unconsciousness.

With contacts on external parts of the body and with the current pathway involving the chest, currents considerably in excess of those just stopping breathing due to muscular contraction of the chest muscles may produce respiratory inhibition, heart block, ventricular fibrillation or irreversible damage to vital parts of the nervous system. Ventricular fibrillation is nearly always fatal and is commonly called instantaneous electrocution. Respiratory inhibition, heart block, or serious damage to the nervous system requires shocks of considerably greater intensity than those required to produce just ventricular fibrillation. For this reason, the fibrillating threshold is of extreme importance, as no man should knowingly be subjected to shocks of this magnitude. Experimental work on human hearts is obviously impossible and resort must be made to animal experimentation. Evaluation of the fibrillating threshold is difficult not only because of the uncertainty of relating the results obtained on animals to man and because the susceptibility of the heart to fibrillate varies at different parts of its cycle, but also because of the very limited amount of data available. Use will be made of data obtained in a joint investigation by Columbia University and the Bell Telephone Laboratories. The experiments were made on sheep, calves, pigs and dogs, whose chest dimensions, body weights, heart weights and heart rates are comparable to man, although several species of smaller animals, including guinea pigs, rabbits and cats, were included to establish the general trend of the effects with weight and other physiological factors.[7]

Considerable thought having been given to the subject, the statistical procedures developed for analyzing nonlethal currents to the results of this

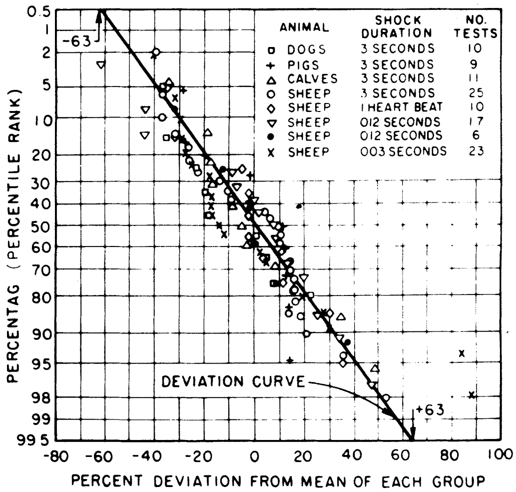
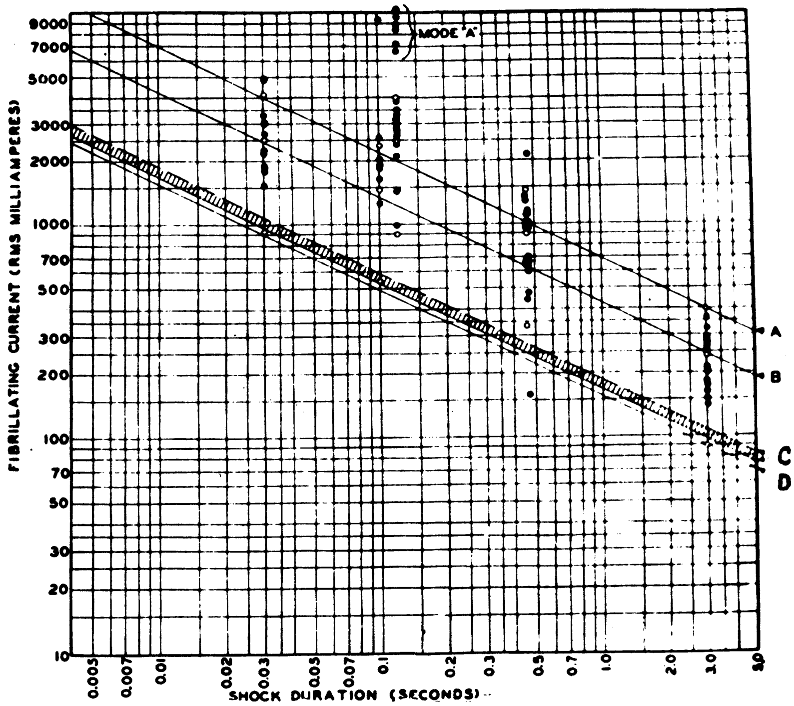


Fig. 21 - Sixty-cycle fibrillating current deviation curve for animals.

investigation were applied. Figure 21 shows experimental points for 60 cycle shocks varying in duration from 0.03 to 3.0 seconds applied to dogs, pigs, calves and sheep, in which the points are plotted as deviations from the mean of each test respectively. The greater scattering of the points about the deviation curve is attributed to the experimental difficulty of applying the short shocks at the instant the heart was most susceptible to fibrillate, and also to the relatively small amount of data for any individual test. This method of plotting data gives improved accuracy for tests made using small samples, as the deviation curve is governed by the majority of the points for the entire series. Justification for this procedure is based on the finding that deviation curves representing similar physiological phenomena induced by electric stimulation generally have identical slopes.[6,8]

Figure 22 shows the results obtained from sheep plotted on log-log graph paper in the attempt to establish a relation between fibrillating current and shock duration. The solid dots represent 99 points for the sheep. The open dots represent points derived from the deviation curve of Fig. 21 and the mean values of the various tests corrected for different body weights. The danger threshold is based on the probability that one individual in a group of 200, that is, 1/2 per cent of a large group, might suffer ventricular fibrillation if subjected to shocks in excess of this limit. The cross-hatched area between the two parallel line C-D represents the probable minimum fibrillating threshold for all 70 kg mammals including man. The lines have a slope of -1/2, which indicates that it is the energy in the impulse which is responsible for the hazard to life. Using the conventional resistance of 500 ohms for the resistance of the human body between major extremities gives a danger fibrillating threshold of 13.5 watt-seconds.

Further consideration of the problem, utilizing data obtained from research on dogs conducted both in Russia and the United States, together with an analysis of 15 human accidents investigated personally by the writer in Japan, Switzerland, France, England, Sweden and the United States, permits extending the work to cover the danger threshold for impulse shocks. Figure 23 shows the results of the study applied to simple surges which may be represented adequately by a single exponential discharge, such as a capacitor discharge or artificial lightning. The points represent all available serious human surge accidents, and although no surge fatalities were reported, it would appear that shocks in excess



● - Experimental points
o - Calculated points
A - 99½ per cent line for 57.4 kg sheep
B - 50 per cent line for 57.4 kg sheep
C - ½ per cent line for all 70 kg animals including man
D - ½ per cent line for 57.4 kg sheep

Fig. 22 - Effect of shock duration on fibrillating currents.

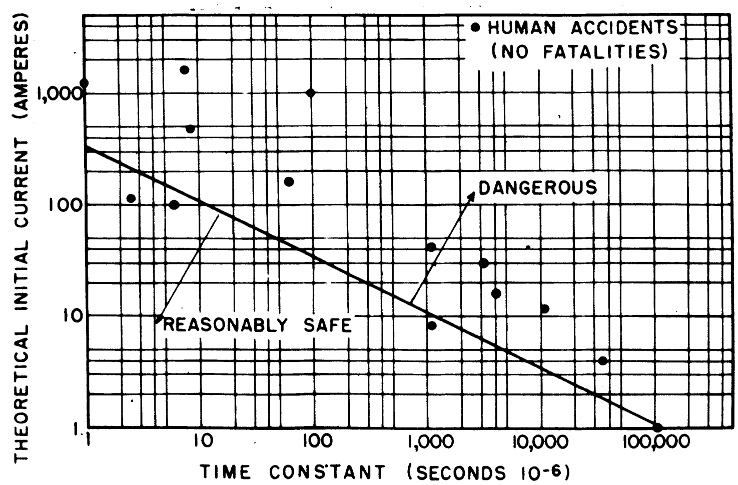


Fig. 23 - Criterion for reasonably safe surge currents.

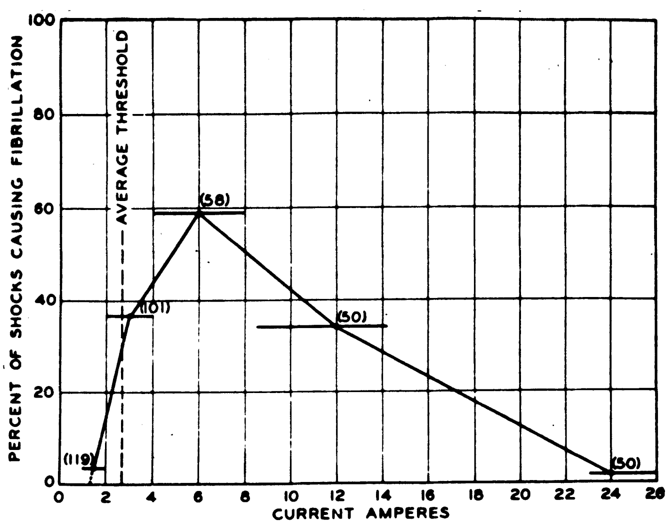


Fig. 24 - Effect of current on the susceptibility of inducing ventricular fibrillation in hearts of sheep.

of the theoretical danger limit must be considered hazardous. The theoretical energy values are 13.5 watt-seconds for short power-frequency shocks and low-frequency oscillatory discharges, and 27 watt-seconds for short dc shocks and surge discharges. It is anticipated that the study will be of value in reducing or establishing the hazard from industrial equipment capable of producing impulse shocks, and in evaluating the effectiveness of grounding schemes used for protection against natural lightning and similar problems.[9]

For short shocks the susceptibility of the heart to fibrillate increases with increasing current until a most dangerous current is reached -- then the susceptibility decreases. At relatively high currents the likelihood of producing ventricular fibrillation is almost negligible. Figure 24 was taken from the work at Columbia University to illustrate this effect. The explanation of the phenomenon is that very high currents paralyze the nerve centers in the heart, the heart is contracted and silenced, and fibrillation is prevented. Death is inevitable if the shock is of appreciable duration; however, if the shock is of short duration, and if the heart has not been damaged, interruption of the current may be followed by a spontaneous resumption of its normal rhythmic contractions. This is offered as explanation for frequent accident cases in which victims apparently withstood relatively high currents. This phenomenon is the basis for counter shock, or defibrillation shock treatment to arrest ventricular fibrillation, and extensive research is now under way at The Johns Hopkins University to develop practical procedures for reviving accidental victims of ventricular fibrillation.[10] It is also believed that the massage and accompanying stimulation of the heart produced by application of approved methods of manual respiration may be beneficial in assisting the heart to regain its normal rhythm.

Another important effect of electric shock is the electric burn or blister; in fact, burns and blisters are the most common result of electrical accidents. Burns are of two types, thermal and electric. Electric burns are produced by the current flowing through the flesh or the tissues, especially at point contacts where high current densities are present. Electric burns are often caused when high-voltage arcs or sparks bridge the gap between the energized conductor and the body (although electric burns may be produced at poor or varying contacts during low-voltage accidents). Blisters or burns destroy the protective resistance of the epidermis, thereby permitting greater currents to flow. Should the current flow for a long enough time, the heat developed by the current may raise the temperature of the body to a value sufficient to cause death.

Electric burns are slow to heal, but seldom become infected. Thermal burns are the result of high temperatures in close proximity to the body, such as produced by an electric arc, vaporized metals or hot gases released by the arc, or by overheated conductors caused by short circuits. These burns are similar to burns and blisters produced by any high temperature source. Currents of the let-go level are more than sufficient to produce deep burns, and both types of burns may be produced simultaneously. Any serious burn should receive prompt medical attention.

The reactions produced by high-frequency stimulation decrease in severity as the frequency is increased, and sensations of heat become predominant. At low values of current, apparently subjective sensations of heat are caused by stimulation of the heat-sensitive mechanisms, but at higher currents the sensations are undoubtedly due to the actual increase in body temperature. As the frequency increases, the tingling sensations produced by currents of the perception level change to sensations of heat. The transition occurred between 100 and 200 kc for the 25 subjects tested. Currents just perceptible above the transition manifest themselves by sensations of heat only. The reactions associated with let-go currents remain essentially the same up to 5 kc. At 10 kc sensations of heat are definite, the time required to release the conductor increases appreciably and the muscular reactions are quite sluggish. Many authorities are of the opinion that heat or burns are the only effects of high-frequency currents; however, the high-frequency domain is largely unexplored in this respect, and there is much to be learned regarding the electric effects produced by very high frequency and extremely short pulsed-currents.

No discussion of electric shock would be complete without mention of rescue and resuscitation for victims of serious electric shock accidents. Rescue the victim from the circuit promptly and safely. In many cases the victim may remain in contact with the circuit because of his inability to let go of the conductor, or due to unconsciousness. Apply artificial respiration if the victim is not breathing, or if he appears not to be breathing. Continue resuscitation without interruption until he revives, until rigor mortis sets in or until he is pronounced dead by a physician.

Approved methods of resuscitation have received universal acceptance because of successful field experience. The prone-pressure method advanced by Sir Edward Shafer in 1903 has been replaced recently by the back-pressure arm-lift method popularly known as the Hogler-Neilsen method. This method provides a larger exchange of air and is easy to apply. The method is applicable in cases where the victim can be placed in a horizontal position. Use the pole top method where artificial respiration must be applied in a vertical position, such as on poles or other structures. Many lives are being saved by prompt application of approved methods of resuscitation to victims of electric shock accidents.

CONCLUSION

A summary of the possible quantitative effects of electric currents on man is given in Table I. The data on which these results are based were collected over a period of many years and, as a result, the number of subjects used to establish a given threshold varied considerably. As previously mentioned the perception threshold for women was assumed equal to 66 2/3 per cent of that for men. The let-go threshold for women was determined for 60 cycle alternating current only; values for the other frequencies were taken at 66 2/3 per cent of the corresponding values for men.

Obviously no experimentation can be performed on man to determine the current likely to produce instantaneous death. The values at the bottom of the table were derived from tests made on animals and are what might be termed "best estimates." They are to be regarded as possible values only, and are subject to revision should more reliable data become available at some future date.

The known lethal effect of electric currents are summarized as follows:

A. If long continued, currents in excess of one's let-go current may produce collapse, unconsciousness and death. Although the causes of death are

TABLE I

Quantitative Effects of Electric Current on Man

Effect	Milliamperes (thousandths of an ampere)					
			Alternating Current RMS Values			
	Direct Current		60 Cycle		10,000 Cycles	
	Men	Women	Men	Women	Men	Women
No sensation on hand	1	0.6	0.4	0.3	7	5
Slight tingling. Perception threshold	5.2	3.5	1.1	0.7	12	8
Shock -- not painful and muscular control not lost	9	6	1.8	1.2	17	11
Painful shock -- painful but muscular control not lost	62	41	9	6	55	37
Painful shock -- let-go threshold	76	51	16.0	10.5	75	50
Painful and severe shock -- muscular contractions, breathing difficult	90	60	23	15	94	63
Possible ventricular fibrillation from short shocks:						
Shock duration 0.03 sec.	1300	1300	1000	1000	1100	1100
Shock duration 3.0 sec.	500	500	100	100	500	500
Ventricular fibrillation -- certain death	Multiply values immediately above by 2 3/4. To be lethal, short shocks must occur during susceptible phase of heart cycle					
Possible ventricular fibrillation from impulse shocks:						
DC short shocks and surge discharges	27.0 watt-seconds					
Power-frequency short shocks and low-frequency oscillatory discharges	13.5 watt-seconds					

not known with certainty, death is probably caused by asphyxiation or heart failure due to exhaustion and shock to the nervous system.

B. Currents flowing through the chest, head or nerve centers controlling respiration may produce respiratory inhibition. This is caused by a nerve block which stops the nerve impulses between the respiratory center and respiratory muscles. Respiratory inhibition is dangerous because paralysis of the respiratory organs may last for a considerable period even after interruption of the current. An approved method of artificial resuscitation must be applied promptly to prevent suffocation.

C. Ventricular fibrillation is caused by moderately small currents which produce overstimulation rather than damage to the heart. When fibrillation occurs, the ventricles go into asynchronous or fibrillary twitchings in contrast to their normal synchronous contractions, the rhythmic pumping action of the heart ceases and death usually follows in a few minutes. The hearts of certain small animals recover from ventricular fibrillation spontaneously. However, the hearts of larger animals do not. It is believed that once ventricular fibrillation occurs in man it is unlikely to stop naturally before death. Prompt application of resuscitation insures the most favorable conditions in the event fibrillation should cease before death.

D. Heart block or suspension of heart action may be caused by relatively large currents. In cases where the shock is of short duration and where damage to the heart has not occured the heart may regain its normal rhythm automatically. It is believed that resumption of normal action is aided by the massaging action produced by approved methods of manual resuscitation.

E. Destruction of tissues due to high temperatures may cause complications leading to death.

F. Delayed death. Patients who have been revived sometimes die suddenly without apparent cause. This may occur minutes, hours, or even days after the accident. This is thought to be due to (1) aggravation of pre-existing conditions, (2) the result of hemorrhages affecting vital centers, or (3) the effects of shock. Delayed death may also be due to burns or other complications.

G. Combinations of the above may occur simultaneously, or they may develop progressively, thereby making accurate diagnosis difficult.

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CORRECTION

On page 15 in the last issue of PGME (Feb., 1956), the first line under Eq. (1) should have read:

"where P_0 is the total radiated power and G is"

instead of:

"where P_0 is the power density at the antenna and G is"