contraction into ventriculo-systolic time, the following results would occur:

1. The presystolic murmur would go up to and into the first sound.

It would not necessarily stop with the advent of the first sound, for, as I showed in my article in the *BRITISH MEDICAL JOURNAL* of January 11th, 1913, the pressure on its contents which a contracting auricle can exert varies, roughly, inversely as the cube of its diameter.

The auricle having expelled most of its contents into the ventricle before the contraction of the latter commences, it could contract on the residue of its contents with far greater effect, and exert a far greater pressure; than the ventricle could on the full total of its contents. An auricle when small is more than a match for a ventricle when large; the auricle, in fact, is in somewhat the same position as the small piston of a Bramah press, which can overcome and force up the larger in virtue of its being the smaller. Blood would therefore flow from the contracted auricle into the large contracting ventricle, and the murmur, like the blood, would go into ventriculo-systolic time. The murmur would be crescendo in character, in harmony with the increasing pressure under which, as it contracts, the auricle can expel its residual contents into the ventricle. (In my communication "On the Genesis of the Venous Pulse"⁷ I pointed out why regurgitation from the auricle, in the absence of valves at the great veins, could not occur.)

2. A systolic murmur might be absent for years, though the auriculo-ventricular valve was incompetent.

Patients with mitral stenosis often live for long periods without any signs of regurgitation occurring, yet the auriculo-ventricular valve suggests from its appearance after death that it has been incompetent through, perhaps, most of the time. Why has this incompetent valve not leaked? or why has it leaked only towards the end of the illness? The rounded, hypertrophied auricle one often finds in these cases⁶ has for a long period prevented regurgitation by prolonging its contraction into ventriculo-systolic time. It has nearly emptied itself and become small—say, half its initial diameter—by the time the ventricle starts contracting, and it continues to try and drive its residual contents into the ventricle. It could now exert greater pressure on its contents, urging them forwards, than the ventricle could oppose to them, for the ventricle can never raise a pressure greater than that in the aorta without its contents escaping into it.

The auricle, therefore, would allow no regurgitation from the ventricle so long as the auricular contraction continued, and consequently the incompetent stenosed mitral valve would not leak. In fact, any leak would, so to speak, take place forwards from the auricle to the ventricle during the early part of ventricular contraction in cases of mitral stenosis accompanied with an auriculo-systolic murmur.

Incidentally it is interesting, as showing what auricles may do, to recall the case observed by Allan Burns where the ventricles were calcified, and the auricles had accomplished for a long time the whole work of the circulation.⁸

3. A systolic regurgitant murmur would replace the presystolic crescendo murmur when the auricle failed to contract to a sufficiently small chamber before the oncome of the ventricular systole.

If the auricle does not get small in time, because of the difficulty of expelling its contents quickly enough into the ventricle, the oncome of the ventricular systole would catch it before it had the physical advantage of being small enough to exert sufficient pressure on its residual contents to match or master the ventricle. Regurgitation into the auricle would then occur, a systolic murmur appear, the auricle would speedily dilate, and cardiac breakdown take place.

Rest or bleeding might temporarily give the auricle a chance of recovering its function, and becoming small in time to oppose the ventricular contraction. In that case the systolic murmur would again disappear, and be replaced by the presystolic. In time the breakdown would occur again in the same way, and probably be permanent, the auricle remaining dilated, and allowing regurgitation from the ventricle.

As soon as it is recognized that the auricle may be to the ventricle what David was to Goliath, simply because it starts first, the auricle will "come into its own" and be

respected as it deserves. Not recognizing this has misled and wronged many a good observer. Dr. Barclay wrote: "The more powerful contraction of the ventricle must overcome that of the auricle if there exists anything like antagonism between them." This false conclusion must have made it very difficult for him to accept the evidence of his own senses and affirm so correctly that "the essential character of this (presystolic) murmur is that it continues up to the first sound, during which it ceases."⁹

Dr. Dickinson, on the other hand, because the auriculo-systolic murmur was heard by him during the apex beat (as also it was by Professor Potain) concluded that it must be ventriculo-systolic in origin and regurgitant.¹⁰ He was forced to a false interpretation of a true observation through imagining relative muscle was everything and relative size was nothing in any struggle between the auricle and ventricle.

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The Goulstonian Lectures ON DEATH BY ELECTRIC CURRENTS AND BY LIGHTNING.

DELIVERED BEFORE THE ROYAL COLLEGE OF PHYSICIANS
OF LONDON.

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LECTURE II.—DEATH BY ELECTRIC CURRENTS (concluded).

SOME excellent experiments further illustrating the importance, so far as life is concerned, of the quantity of current traversing the thorax in electric accidents were published in 1911 by Weiss and by Zacon. These were made on dogs anaesthetized with chloral; the electrodes were placed either in the mouth and rectum or on the head and leg, and the amperage, voltage, and the duration of the current received by the animal in each case were noted. Tracings of the femoral blood pressure and the respiratory movements are given. These authors concluded that the resistance of the dog's tissues to alternating currents (12 to 75 periods per second) was the same as to continuous currents, and that chloral anaesthesia gave no protection against electric shocks. With alternating currents given for a few seconds, death would occur when about 70 to 100 milliamperes traversed the thorax with the heart *en route*; with continuous currents, death was not caused unless the current was as large as 300 milliamperes, roughly speaking. If, however, smaller electric currents were administered for long periods, it was found possible to produce death by tetanus and asphyxia; thus currents of 35 to 45 milliamperes were too small to produce cardiac fibrillation, but after about ten minutes' application caused death by continued inability to breathe, and slow asphyxiation. It was observed that large currents—400 milliamperes or more—could be passed through the head with comparative impunity, the heart continuing to beat though rather irregularly, and the respiration stopping only for so long (35 and 58 seconds in two instances) as the current passed. With still large currents, however, thus passed through the head and central nervous system, respiration might fail to begin again when the current was turned off, and death from asphyxia would then occur. The resistance of the animals generally diminished about 10 per cent. during the passage of the current.

Death by Alternating Currents of High Frequency.

It is necessary to go back a little at this point and consider more carefully the frequency of the alternating currents that have been used to produce death. Hitherto I have considered only the ordinary alternating currents that are so widely used domestically and industrially, in which the direction of the current is changed perhaps from 50 to 300 times in a second. Such currents are, as we have just seen, three or four times as dangerous to the life of animals, *cæteris paribus*, as continuous currents. The question arises: How far does the rate per second of these alternations affect the dangerousness of these currents? The answering is extremely surprising and interesting. In 1891 Tesla, in America, experimented with alternating currents in which the number of alternations per second was very great indeed, and found that very large quantities of electricity could be passed with impunity through the human body when at these very high rates of alternation. Thus, d'Arsonval (1892), using currents alternating from 400,000 to 1,000,000 times a second, found he could pass as much as 1 ampere through his body with impunity, and later (1893) took currents up to 3 amperes. These currents were twenty or thirty times as large as those required, under similar conditions, to cause death in the case of the ordinary alternating currents at much lower frequencies and pressures. Yet he felt no painful sensation while they traversed his body; there was no burning of the tissues at the points where these large currents entered and left him, and his muscles were not thrown into tetanus. Various explanations of these observations were offered. Jones (1893) assumed that, as a matter of fact, the currents passing through the body were to be measured in milliamperes rather than in amperes, its effective resistance being immensely increased by the high rate of frequency of the alternations; similar explanations were offered by Hedley and by Swinton. Others assumed that such high-frequency currents travelled by the surface of the body only, and did not penetrate to the deeper tissues owing to the very brief duration of each alternation. Sutherland quoted the view that one alternation might not have passed fully through the body before it was wholly or partly neutralized by the succeeding current of opposite sign, a view that is quite unimaginable to an electrician. The most reasonable and, no doubt, the correct explanation was furnished by d'Arsonval, who assumed that human muscle and nerve are so constituted as to be insensitive to alternating currents of very high frequency. The same explanation was given by Thomson (1894), who found that, using currents of over 10,000 alternations a second and very high voltage (100,000 to 200,000 volts), he could take a current, equal in heating effect to over 1 ampere of ordinary current, from one hand to the other, without pain and with only a moderate sensation of warmth at the points where the current entered and left the skin. Using electrodes with a surface of 6 sq. in., he found the virtual resistance of the human body from hand to hand to be about 700 ohms; using his two hands and wrists immersed in saline solution as electrodes, he could take a current of 1.5 amperes, the body absorbing power at the rate of 800 watts, without appearing to be in any way injured by it. In other words, alternating currents at these high frequencies were at least twenty or thirty times less dangerous to human life than alternating currents of the ordinary frequencies—25 to 150 cycles a second—used industrially. That animals can be killed by these alternating currents of very high frequency was shown by Bordier and Lecomte, among others; a couple of rabbits after receiving currents of 300 and 400 milliamperes for a minute became paraplegic, and died in twelve and fourteen days, and a third rabbit died in general tetanus from failure of the respiration two minutes after having a current of 500 milliamperes passed through it for thirteen minutes. Similar results were obtained with guinea-pigs and rats. Kennelly and Alexanderson have recently made further experiments with high-frequency currents of various frequencies. The experimenter's hands were placed in vessels full of saline solution, and the current was sent across from one hand to the other. At the slow rate of 60 alternations a second, only 8 milliamperes (at 5 or 6 volts) could be borne; at 11,000 alternations (12 to 20 volts) 30 milliamperes could be taken, and at 100,000 alternations (200 to 360 volts) no less than 800 milli-

amperes. If high-frequency currents are passed through animals for long periods they may succumb to the heating effects of the currents, as d'Arsonval has shown (Bordier and Lecomte).

Some admirable investigations into the influence of the alternations on the morbidity, so to speak, of alternating currents were made in 1900 by Prevost and Battelli. Using dogs as the subject for experiment, they found that the optimum or most fatal frequency was about 150 alternations per second. Thus, using a continuous current, and with the electrodes in the mouth and rectum, different dogs required pressures of from 50 to 80 volts to produce death by cardiac fibrillation. When the continuous current was replaced by an alternating one, it was found that with alternations up to 150 a second currents at only from 15 to 25 volts were needed to produce death; at 200 alternations a second 40 volts were necessary; at 300 alternations, 50 volts. An alternating current of 350 alternations a second was about as fatal as the continuous current; at 500 alternations 150 volts were needed to produce death, and at 1,720 alternations a second no less than 400 volts. In other words, the cardiac muscle of the dog, and in all probability that of man too, is least tolerant of alternating currents at a frequency of 150 alternations a second; it is about three times as tolerant of continuous currents, and about twenty times as tolerant of alternating currents of the relatively high frequency of 1,720 alternations a second. There is no doubt that this must rest on some physiological property of the heart muscle; one may compare the fact, noted by d'Arsonval and by Thomson, that high-frequency currents taken by the hands are painless, even at a strength of 2 or 3 amperes, whereas even so little as 20 or 30 milliamperes of an ordinary low-frequency alternating current taken in the same way give rise to tetanus and very severe pain indeed; Trotter found the pain of a 35 milliampere continuous current taken for three seconds through an area of four or five square inches of his hand almost insupportable. Deaths by electricity would be very much fewer than they are now if high-frequency currents could be used in place of the ordinary alternating and continuous currents universally employed. Hence it is a thousand pities that the economical production of high-frequency currents on the commercial scale is not possible for mechanical reasons, and that the electrical properties of such currents unfit them for industrial usage.

Summary of the Experimental Results.

The chief experimental results obtained in the electrocution of animals by both alternating and continuous currents have now been placed before you, and they may conveniently be summarized here under a number of different heads.

I. Living animals of different species are killed by electricity with very different degrees of facility. For example, many experimenters have endeavoured to electrocute frogs, but all, I believe, without success, whatever the current used and however it may have been applied. The frog survives electric shocks and the prolonged passage of electric currents at all sorts of voltages—10, 100, 1,000 volts and more—and shocks from induction coils and charged Leyden jars. The only inconveniences it suffers appear to be transient pareses or paralyses, and, in the case of strong currents passed for many seconds or minutes, the formation of burns. The frog is thus immune because its heart always begins to beat again regularly and normally after the passage of the electric current, and because its respiration does the same; and also, as Priestley pointed out in 1767, because "its constitution enables it to subsist a long time without breathing." At the other extreme of the scale comes the dog, which can be killed with certainty by an alternating current of perhaps 15 volts or 60 milliamperes applied so as to pass largely through the heart muscle for a couple of seconds only. The dog is very easily killed by electricity because its heart muscle is thrown into a state of fibrillary contraction by comparatively weak currents, and very rarely (except in the puppy) can recover from the fibrillation and beat normally again. In addition, there is the fact that currents that are too strong to throw the dog's heart into a state of fibrillation are yet able to kill the animal by respiratory paralysis and asphyxia, so that a current that may not be fatal to the dog by its action on the heart

may yet kill it by action on its central nervous system. Birds and other living creatures—such as apes, horses, cats, rabbits, guinea-pigs, rats, mice, and so forth—appear to come between the frog and the dog in the scale of liability to death by electricity at relatively low voltages, the rat's heart always recovering spontaneously from the state of fibrillation into which it is thrown during the passage of the current, the rabbit's heart often recovering spontaneously, the guinea-pig's rarely, the adult dog's never. It is generally found that young animals are less easily killed by electricity, other things being equal, than adults of the same species; thus Battelli found that cardiac fibrillation would cease spontaneously in electrocuted newly-born puppies, though not in adult dogs, and Kronecker¹⁷ has produced transient cardiac fibrillation by electrization of the heart of a newly-born child with ectopia cordis, though there is no reason to suppose that this fibrillation is ever recovered from by adult human beings in whom it has been induced—a point, however, about which we have no certain knowledge. In the case of discharges from Leyden jars and condensers, the young animal is killed by relatively smaller quantities of electrical energy than the adult. It should be added that different animals of the same species often show different degrees of susceptibility to electric currents that can only be explained by idiosyncrasy.

II. The sudden or rapid death of animals killed by the application of electric currents may be brought about experimentally in several different ways, of which the following are the most important:

(a) By asphyxia due to prolonged muscular tetanus and inability to perform the movements necessary for respiration, when the current is passed and the tetanus maintained for as many minutes as are necessary to complete asphyxia. The heart in these circumstances goes on beating to the end. A dog may take ten minutes to succumb in this way (Weiss); presumably living and breathing creatures of any kind could be killed by this method.

(b) By primary heart failure. In a typical case, the heart muscle is thrown into a state of fibrillary contraction, and the heart ceases to beat as soon as the current is turned on, while respiration continues. When this happens the blood pressure in the femoral artery falls steadily, reaching zero in ten or fifteen seconds in the case of the dog; should the heart for any reason begin to beat again, the animal will probably recover—the rat always recovers thus, the dog hardly ever.

(c) By primary failure of the respiration, due to the action of the electric current on the central nervous system, or Brown-Séquard's inhibition. Animals apparently killed in this way will often recover if artificial respiration is perseveringly carried out. This mode of death occurs when large currents at high voltages are sent through the body.

(d) By simultaneous failure of both heart and respiration; seen, for example, in dogs receiving an alternating current at from 240 to 600 volts for two seconds, from mouth to rectum.

(e) Death may occur after the lapse of hours or days, as the result of the injuries to the tissues caused by the passage of strong currents.

III. After being exposed to currents of high voltage, say 600 volts and over, animals tend to show a number of signs that indicate grave involvement of the central nervous system. This is more marked in small animals than in large, other things being equal, as the current density will be greater in the smaller animal. Such signs are arrest of respiration and its resumption in an irregular manner; the occurrence of clonic spasms (such as are not seen in man); loss of sensation and the reflexes; great prostration and slow recovery. All these phenomena are absent when one is dealing with electric currents of low electromotive force. They may be taken as evidence of nervous shock or Brown-Séquard's inhibition.

Special mention may be made at this point of the "electric sleep" produced by Robinovitch in animals by the use of interrupted continuous currents (the so-called "Leduc currents") at from 5 to 10 volts and about 1 milli-ampere. The cathode is applied to the head, the anode to the trunk, of the animal. This electric sleep may be kept up for eight hours or more; it is associated with a rise in the arterial blood pressure, and is said by Robinovitch to be due to central inhibition.

IV. The particular electrical details and considerations that determine whether a certain electric current will be fatal or not to an animal in any given instance are very complicated. Hence it is not possible to say off-hand that a current of such-and-such a voltage or character or strength will cause death; there are at least six factors that must be considered separately here, although when one comes to work out their influence in any particular instance they must be considered together.

(a) *The Voltage of the Current.*—Given the optimum conditions, continuous currents are not fatal to dogs at voltages below about 60 volts. An ordinary alternating current at 15 volts will kill a dog, and a similar current at any voltage up to about 600 volts will be equally effective, by causing the dog's heart to fibrillate. But the alternating currents passing at pressures of from 1,200 to 4,800 volts, administered under the same optimum conditions, are not necessarily fatal, because they are too large to cause the dog's heart muscle to fibrillate; although if continued long enough they may cause death by permanent paralysis of the respiratory centre.

(b) *The Amperage of the Current.*—Given the optimum conditions for causing death—that is to say, such an arrangement of the electrodes as will cause the current to traverse that part of the thorax in which the heart lies—the dog will be killed by an alternating current of as little as 70 milliamperes or a continuous current three or four times as great. But the very much larger currents forced through the thorax by much higher voltages—1,000 to 5,000 volts—are not fatal, because they do not throw the heart into a state of fibrillation; thus Weiss passed an alternating current of 7 amperes (at 4,600 volts) through a dog weighing 22 lb. for three seconds without killing it. These large currents may prove rapidly fatal by respiratory paralysis, or, after the lapse of days, by the burns and other injuries they may have inflicted on the tissues at the electrodes.

(c) *The Duration of the Current.*—The time during which the animal is exposed to the current is of great importance. As has been mentioned already, quite small currents at low voltages, that have no apparent influence on the action of the heart or on the central nervous system, but are strong enough to tetanize the muscles, may cause death by asphyxia if kept on for long enough—over ten minutes in the case of the dog. With the stronger currents at higher voltages, that kill by cardiac fibrillation, Battelli found that contacts up to one second in duration were often not fatal to the dog, though contacts of from one to three seconds invariably were fatal. Weiss showed that alternating currents as small as 70 milliamperes passing through the thorax required not less than four or five seconds to produce a fatal result. Again, with very high voltages (several thousand volts) and alternating currents of several amperes, with which death when it occurs is due to injury of the central nervous system, the passage of the current for several seconds may be survived by a large animal, though one second may be fatal to a small animal of the same species. Crile and Macleod found alternating currents at 2,300 volts fatal to anaesthetized dogs in twenty seconds, but not necessarily fatal in one, five, or ten seconds. The same thing is seen with continuous currents. Some of the differences seen here between different animals of the same species must be set down to idiosyncrasy.

(d) *The Character of the Current, Continuous or Alternating.*—Continuous currents, whether from a dynamo or a battery, are much less dangerous at comparatively low voltages than the ordinary alternating currents used industrially. Thus a continuous current applied for a few seconds will not be fatal to a dog below pressures of 60 or 70 volts, while an alternating current with from 25 to 150 periods a second will be fatal at a pressure of 10, 15, or 20 volts. But at higher pressures, where death, when it occurs, is due to failure of the respiration by nervous inhibition, the continuous current may be the more dangerous of the two, because its passage is the more injurious to the central nervous system. Thus an alternating current at 600 volts passed from the head to the feet of a rabbit for three seconds may do it little injury, while a continuous current of 550 volts electromotive force may be fatal to it in one second in similar circumstances. Again, with alternating currents, the number of alternations per second

is of the greatest importance in determining the dangerousness of the current. Ordinary alternating currents and the very similar polyphase currents so widely employed commercially alternate from, say, 25 to 300 times a second, and, other things being equal, are three or four times as dangerous to life as direct or continuous currents. But increase in the frequency of the alternations per second brings about a great diminution in the dangerousness of such currents, because it lessens their tendency to produce fibrillation of the muscle of the heart. Thus, at 350 alternations per second, alternating currents are no more dangerous than continuous currents, and at 1,720 alternations are about six times less dangerous, in the case of dogs. When the alternations are increased to tens or hundreds of thousands per second, as is the case in the so-called Tesla or high-frequency currents, the danger to life is still further reduced.

(c) *The position of the electrodes with regard to the heart and the central nervous system.* The importance of this factor is enormous, and was perhaps never widely appreciated until it was emphasized by the work of Prevost and Battelli. Even now it seems to be neglected by d'Arsonval and by many other writers upon the subject of death by electricity. It may be illustrated by a single experiment. If the two electrodes are applied to the two hind legs of a dog, alternating currents of about 4 amperes at 1,200 volts are not fatal to the animal, because with this arrangement the amount of current passing through the heart is not enough to cause it to fibrillate. If the two electrodes are now shifted to the two fore-legs, alternating currents up to 270 milliamperes and below about 80 volts are not fatal, for the same reason. But if the electrodes are placed on either side of the thorax, so as to concentrate the current on the heart, death is produced by alternating currents at only 15 volts pressure and a strength of about 50 milliamperes. Yet the resistance between the two electrodes is much the same—about 300 ohms—in each of the three cases. To me it does not seem possible to imagine a better demonstration than this of the importance of the current-density through the heart, or, to put the matter more definitely, the number of milliamperes per square centimetre of cross-section through the heart at right angles to the direction in which the current flows, in determining the danger to life incurred by exposure to electric currents. One cannot believe that the shock to the dog's nervous system, to which alone d'Arsonval attributes such a death by electricity, was greater at 15 volts than at 80, or at 80 than 1,200 volts, in the three variations of the experiment described above.

(f) *The Resistance at the Electrodes.*—This extremely important factor is very variable in amount unless great care is taken. It is obvious that it should be reduced to the lowest practicable value in any experiments designed to bring out the dangers of industrial electric currents to life, and to ascertain the lowest voltages that may be fatal. To quote an example, Grange in 1884 failed to kill dogs by alternating currents at 825 volts pressure, simply because his electrodes were so ill applied that the dogs' resistances were about 80,000 ohms, so that only 10 milliamperes of current can have flowed through the animals, a quantity much below the lethal dose. Later experimenters have found that the more careful and rational application of the electrodes makes the dog's resistance, in circumstances otherwise similar, only 300 ohms or thereabouts. Cunningham cut this resistance down still further to about 77 ohms in one instance—an error in the opposite direction. His electrodes must have been so large as not to concentrate the current satisfactorily on the sensitive spot, the heart. The result was that continuous currents of 700 milliamperes or more, sent through the thorax from one side to the other, were not necessarily fatal to the dogs he employed, while Zacon and Prevost and Battelli found 200 or 300 milliamperes of continuous current to be fatal to the dog if suitable electrodes were applied. Crile and Macleod observed resistances of about 1,000 ohms in their experiments on dogs.

Death by Electric Currents in Man.

We are now in a position to summarize what is known and what may be inferred as regards the killing of human

beings by electric currents. This may conveniently be done on lines similar to those adopted above in the case of animals. I must ask to be allowed some repetition here, in the hope of making an obscure business clearer; for the literature of the subject makes it plain that the various factors controlling the results of electric accidents in man are by no means generally appreciated at their proper value or understood.

I. It is often assumed that different persons are differently vulnerable by electricity, and that in identical circumstances shocks that would be fatal to some would not be fatal to others. This is certainly true of the lower animals—for example, Battelli found an alternating current of ten volts fatal to one dog, but not to two others which were killed at 15 volts. It is probably true of man, but experiments to prove the point are naturally lacking, and it is not possible to prove or disprove it by the evidence of fatal or non-fatal electric accidents, because there are so many variable factors that determine the result in these besides that of idiosyncrasy. In other words, one is not justified in concluding that it is idiosyncrasy that has protected a person "A" from death by electric shock that has proved fatal in apparently similar conditions to another person "B," unless one is able to prove that all the other conditions really were identical; and that, practically speaking, can never be done. There are three other factors that have been emphasized as important in determining the result in electric accidents, and those are *fright*, *general anaesthesia*, and *sleep*. Much stress is laid on *fright* by d'Arsonval, who says that sudden physical surprise often has disastrous results for the vital functions, so that a shock that is unexpected may be fatal, but not fatal if it is expected. He even attributes the comparative failure of the methods employed in the electrocution of criminals in America to the fact that surprise at the moment of shock is lacking in this operation. Jellinek has recorded a case in which a man died of fright alone, having come into contact with a conductor which he believed to be carrying a current at high potential, but actually was not electrified at all. Great importance is attached by d'Arsonval to the *status somaticus et psychicus*, the state of body and mind, of anybody exposed to and receiving an electric shock; Aspinall supposes that persons of weak intellect can stand stronger currents than normal persons. This, again, is a matter that can only be determined by experiments made in definitely known conditions, and none such have been made; there is no evidence that fright increases the liability of the lower animals to death by electric currents. It is said that persons under the influence of *general anaesthetics* are able to survive exposure to currents that would be fatal were they conscious; several experimenters have found that general anaesthetics do not afford protection in this way to the lower animals, though Jellinek says that they do—much probably depends upon the depth of the anaesthesia obtained. As regards *sleep*, this also is generally believed to protect life against electric currents that would be fatal during waking hours; in modern literature one often sees quoted the case of a man who was severely burnt but not killed by contact during sleep with a conductor carrying a current at 5,000 volts, recorded by Aspinall. Here again there is need of further evidence. The analogous idea that sleep protects against death by lightning stroke is at least as widely spread, and dates from the time of Seneca.

In the vast majority of cases death by electric currents is due to accident; but in Italy both suicide and murder by electricity have been attempted, the former with success (Jellinek).

II. The death of human beings may be brought about by electric currents in several different ways.

- (a) There is no doubt that it might be due to prolonged tetanus of the muscles, which could prevent the performance of respiratory movements, and so lead to death by asphyxia after some minutes. But I am not able to find that it ever has come about in this way as a matter of fact, the victim always being able either to break the contact and interrupt the passage of the current for himself, or to call for help and get the contact broken by somebody else before asphyxia has occurred in this way.

- (b) In man primary heart failure is undoubtedly the commonest mode of death by electric currents. The experiments on animals already detailed show that such deaths are due to fibrillation of the ventricles of the heart. This fibrillation has been seen occurring in the hearts of two criminals electrocuted in America and examined immediately after death (Schumacher); a few minutes later the left ventricle was firmly contracted and empty, while the right ventricle and the auricles were relaxed in diastole and full of blood. It is probable that in the adult man, as in the dog, horse, and ape, fibrillation of the heart, once it is established, is irremediable, practically speaking.
- (c) and (d). Death by failure of the respiration while the heart continues to beat, brought about by nervous inhibition, or by failure of both heart and respiration together, is probably not so common in man. There is a great want of evidence on this point; naturally enough, as the people who are present at deaths by electric shock are generally workmen who do not busy themselves with observations of the pulse and the respiration of the victim. A good many cases have been recorded in which death did not occur until ten, twenty, or forty minutes after the shock had been received, and was then apparently due to failure of the respiration to re-establish itself. The experiments upon animals would lead one to believe that such deaths are really due to failure of the respiratory centre in the central nervous system. The *post-mortem* evidence in such cases should suggest death by asphyxia, and such evidence has sometimes been found after death by electric shock.
- (e) Brief reference may be made to the fact that a good many cases have been recorded in which the victim of an electric accident has died after a few days or weeks from complications (shock, gangrene, suppuration, exhaustion following extensive amputations) arising out of the injuries caused by the electric current. Mills and Weisenburg have recorded fatal cases of bulbar and bulbo-spinal paralysis, apparently due to electric shock.

III. Severe nervous shock, with or without some more definite lesion such as the paralysis of a limb or a paraplegia, is not rare in industrial electric accidents, and makes permanent invalids of a number of persons who survive the shock. Brief loss of consciousness is common in non-fatal cases of electric shock, and may be followed by an appearance of intoxication or even by mania—a fact that finds no parallel in the experiments done on the lower animals; just as in the lower animals attacks of convulsions are often determined by non-fatal shocks, but do not seem to occur in man (Battelli, Robinovitch).

Opinions as to the importance of nervous shock in fatal electric accidents are divided into two groups. On the one hand, Battelli and a number of writers believe that it is a transient affair, functional in nature, not important. On the other hand, d'Arsonval holds that it is by nervous shock alone that electric currents produce sudden or rapid death, by a sudden affection of all the vital functions. Jellinek goes further, and is more definite, setting down sudden death by electricity to a local trauma of the cells in the central nervous system, caused by what he calls a dynamogenic working of the electric current that may be compared to the local trauma of the nerve cells met with in the commotio cerebri of direct or indirect violence. He brings forward the elaborate details of his histological researches to prove that these minute lesions of the nerve cells and other tissues are to be met with in men and animals killed or injured by electric currents; but, as Schumacher points out, the cell changes and small haemorrhages found by Jellinek are in no way specially characteristic of death by electricity. It must be remembered that, as a rule, large amounts of electric energy and long periods of exposure to the passage of the current have been employed in cases in which marked changes have been found in the central nervous system after death; whereas in the majority of fatal accidents by electric shock as they actually occur, only a small current has passed through the victim and only for a short time, while

none of it has had occasion to travel by way of the central nervous system.

IV. All the electrical and physical details of the circumstances in which electric currents pass through the body are of the greatest importance in determining whether the result will be fatal to a human being or not. For the sake of clearness they are best discussed under six heads.

(a) *Voltage of the Current.*—With alternating currents, death has occurred from shocks at voltages as low as 65 volts, and a good many instances of death at such pressures as 100 to 120 volts have been recorded. It is only in very exceptional circumstances that these low voltages can cause death; unless the patient's skin is wet and he makes a good contact not only with the electric conductor, but also through wet boots or clothes (according as he is standing or sitting) with the ground or some other conductor, there is not the smallest chance of death by currents at such low voltages. As the voltage rises so does the case with which a fatal amount of current may be forced through the victim increase, and so it is that the large majority of deaths by electric currents are brought about by the alternating currents at much higher pressures—say 500 to 5,000 volts—that are in common industrial use. But here comes in a paradox. It would appear that if good contact is made currents at very high voltages become less dangerous to man, just as we have seen that they do to animals, and probably for the same reason—that large currents passing through the body do not happen to throw the heart into irremediable fibrillary contractions. Thus a number of instances have been recorded in which men have received industrial currents at 10,000 volts without being killed at once, although making good and prolonged contacts in such a way that large currents, too large to be fatal, one may say, must have streamed through the chest and heart. A very good example of this was recorded by Mr. Clement Lucas; others have been reported in France and Monte Carlo.⁶⁶ But if the victim makes a bad contact, or a contact of high resistance, either with the conductor at high voltage or with the ground, then the amount of current diverted through him may be small enough to kill him by cardiac fibrillation.

One often hears the question asked: What voltage is dangerous to life? No simple answer can be given to this question; the degree of danger depends on so many factors besides that of the voltage of the current from which danger is apprehended. As regards continuous currents of electricity, I have not found records of many fatal accidents at voltages below 220 volts, but in one case a direct current at only 95 volts caused death, in another a current at 110 volts.⁶⁶

(b) *The Amperage of the Current.*—All the industrial electric currents met with in daily life, the currents used for lighting, heating, cooking, driving machinery of all sorts, have ample intensity (measured in amperes) to cause death if applied to the human body under favourable conditions. The only sources of electricity that might be expected to kill, but fail to do so for want of sufficient amperage, or rather milliamperage, are the induction coils used by *x-ray* specialists and others.

As regards the minimum number of milliamperes required to kill a human being under conditions favourable for killing there is no certain knowledge. Weiss calculates that from 70 to 90 milliamperes of an ordinary alternating current would be enough if the current went through the chest and heart; d'Arsonval states that much less than 100 milliamperes suffice to kill. One can make a rough calculation in some of the fatal accidents that have occurred; a number of persons have been killed by alternating currents at about 110 volts, passing from one hand to the other or from the hands to the feet, and experiments show that the resistance of the human body from hand to hand or from the hands to the feet may be from about 1,000 to 1,500 ohms, when the skin of both hands and feet is wet, so that one may guess the fatal current to have been from about 70 to 110 milliamperes in these instances. The experiments of Dixon Mann showed that alternating currents of from 15 to 30 milliamperes sent through the chest do not upset the heart's action; and Trotter found that continuous currents up to 35 milliamperes, though almost insupportably painful, were not fatal when passing from the hands to the feet.

When very large industrial currents are forced through the body by high voltages, we meet again with the paradox that, while small currents may kill instantaneously, large currents are much less fatal. For example, the American electrocutions have shown that currents of 5 or 8 amperes may pass for many seconds through the body without causing permanent arrest of the heart or respiration. In the non-fatal cases of shock by currents at 10,000 volts, of which I spoke a few minutes ago, it is true that no measurements of the amperes passing through the victims were made, but it is reasonable to suppose that they may have amounted to several amperes. It is plain, then, that currents of a fraction of an ampere may cause sudden death by throwing the ventricles of the heart into fibrillary contraction, though much larger currents of several amperes do not act thus and so are not fatal. But I do not know of any examples or experiments to show at what point or amperage the transition from small dangerous to large non-dangerous currents takes place.

(c) *Duration of the Current.*—The animals experiments showed that this is a factor of great importance in determining death or survival. And so, probably, it is in human beings; but its importance could only be determined by a series of comparative experiments under known conditions, and these are for obvious reasons not likely to be made. The fact that electric currents produce muscular tetanus, and often cause the victim to grip firmly any conductor from which he may be receiving a current of electricity, tends to make contacts of long duration; for example, Mr. Clement Lucas's patient clutched his 10,000 volt cable for thirty seconds before he was rescued.

(d) *Industrial alternating currents* are, other things being equal, more dangerous than *continuous currents*. So far as one can guess, in the absence of any experimental proof, it seems that a continuous current must be two or three times as strong as an alternating current, to kill a human being. In cases that are not immediately fatal it seems that the after-effects are more serious with continuous currents, no doubt because these electrolyse the tissues through which they pass, and thus leave behind them chemical and physical traces of their passage; whereas alternating currents naturally effect little permanent electrolysis or polarization in the tissues through which they travel.

(e) *The position of the electrodes*, or the points at which the current enters and leaves the body, are of great importance, as has been emphasized by Aspinall among others. For all practical purposes the heart is the danger point in persons making accidental contacts with conductors carrying electric currents. For it rarely happens that contact is made by the head, so that current has the opportunity to pass through the central nervous system (cases recorded by Zwaluwenberg, Zacon), and even then it is more than probable that death, if it does occur, is due to cardiac paralysis, and not to inhibition or action on the consciousness or psychical functions. Hence it is safe to say that, so far as sudden death is concerned, electric currents are dangerous to man in proportion to the degree to which they tend to pass through the heart. Thus a current travelling from one hand or arm to the other, or from a hand to the feet, or from the neck or the top of the trunk to the feet (as in a case recently described to me by Dr. R. S. Trevor) is highly dangerous; similarly, currents going through the left side of the body are commonly supposed by electricians to be more dangerous to life than those on the right side. But currents entering by one foot or leg and leaving by the other are, practically speaking, free from the danger of sudden death, because the strength (in milliamperes) of the current that flows through the heart under these conditions is necessarily far below the lethal minimum, however strong the current passing through the lower part of the body may be. For this reason, if one has to rescue the victim of an electric accident while he is still exposed to the current, it is advisable to try and draw or push him away with one's feet rather than with one's hands, unless one can be sure that one's hands are well insulated from the victim by dry clothes, etc. The desire to protect the cardiac region against the passage of electric currents has led to several brilliant but not practical suggestions that persons exposed to accidental electric shocks should wear garments woven of copper wire. Such a copper undergarment,

closely applied to the skin of the upper and lower parts of the trunk, but insulated by a belt of indiarubber from the middle zone in which lies the heart, would divert the bulk of any current from that region, it is said,⁴¹ and so save life.

(f) *The resistance at the electrodes*, at the points where the current enters and leaves the body, is a factor of the very greatest importance. This is best illustrated by a few actual examples:

A man in a factory stood barefooted in a mixture of sugar and potash, and with his hand touched a bare conductor carrying a continuous current at 95 volts, and was killed on the spot (Jellinek); the resistance between his hand and his feet, between the ground and the conductor, that is to say, cannot have been more than perhaps a few hundred ohms in these conditions. Had his hand or his feet been dry he could have handled the conductor with impunity, even without discomfort.

Zwaluwenberg details the case of a carpenter at work in an attic 4 ft. high at a temperature of about 100° F.; he was in a state of extreme perspiration, and kneeling on a well-earthed gaspipe, when his head came into contact with a cable carrying a 50-cycle alternating current at 100 to 110 volts, at a point where the insulation was worn away. The man made an outcry, was rescued in a few minutes, was seen to gasp several times, but died at once in spite of artificial respiration and traction of the tongue. In this case also the skin at the points of contact, the head and knees, was soaking wet, and so the resistance at the electrodes was reduced to so low a point as to permit the passage of a current strong enough to throw the heart into a state of fibrillary contraction and cause death. Had the man's skin been dry, or had he not been kneeling on a good conductor, he would not have lost his life.

Many other instances might be quoted to show the great danger of wetness to the skin or of the feet and boots, conditions that are inevitable among operatives and labourers of all sorts when there is risk of contact with conductors carrying electric currents at even these low voltages. There have been fatal accidents in domestic and in public bath-rooms even, when persons in baths or standing barefoot on wet floors have laid wet hands on electric lamps or bare wires that chanced to be directly connected with electric light mains carrying currents at a couple of hundred volts or so.

But with these electrodes, the hands and feet, in their more normal condition of dryness, the case is quite different; the danger to life is *nil*. The resistance of the human skin to the passage of electric currents is relatively great, and the skin is by far the most resistant of the tissues of the human body. Thus, Trotter quotes many experiences with himself and other people, showing that when the hands and feet are dry, conductors carrying continuous currents at 500 volts may be handled freely with impunity, for the normal resistance of the dry skin at the electrodes (the hands and feet) and of the boots is so great as to permit only a few milliamperes to pass through the body to the ground. When he was wearing old boots worn into holes and thoroughly wetted by walking in muddy streets and grasped the 500-volt conductor for three seconds, only 35 milliamperes of current passed through him; his resistance from boot to boot was reduced to 13,000 ohms, in place of the normal 45,000 to 200,000 ohms with ordinary boots that were not wet. One often reads accounts of people who have touched live conductors with high voltages without suffering material injury; in the great majority of such cases their immunity has been due to the high resistance presented to the current at the points where it had to enter and leave the body. The effect of the resistance at the electrodes and in the body in determining the result of electric accidents is shown schematically in the following table, in which it

Total Resistance of Body assumed to be:	Result of Brief Exposure to Passage of Alternating Current at a Pressure of:		
	100 volts.	1,000 volts.	10,000 volts.
Very low, with good contacts, 1,000 ohms	Certain death, slight burns	Probably death, marked burns	Survival, burns and other sequelae very severe.
Higher, about 10,000 ohms	Painful shock, but no injury	Certain death, burns probably slight	Probably death, severe burns.
High, with bad contacts, 100,000 ohms	Scarcely felt	Painful shock, but no severe injury	Certain death, burns slight if resistance remains high.

is assumed that the current traverses the thorax on its way through the body.

Prognosis.

The prognosis in cases of severe electric shock has been very variously estimated. Cunningham (1899), for example, speaks of artificial respiration as "the only and almost invariably futile, method in vogue in electrical accidents at the present day," for the resuscitation of persons apparently killed by electric shock. The opposite view is held by Lauffer (1912), who says "there are few cases of electrical accident where the victim cannot be restored from the electrical shock, if appropriate immediate efforts at resuscitation are instituted" by performing artificial respiration with only a few seconds' delay. Jellinek (1905) is almost equally encouraging, stating that death by electric shock is in most cases only apparent death, and advocating immediate artificial respiration. This holds for cases of sudden death by electric currents; in the instances where death occurs many hours or days after the shock, it is caused by the burns or thromboses or other lesions due to the intensity of the current. There may be excellent general health after very extensive and severe electrical injuries; Weiss quotes the case of a man who was so badly burned by electricity that both legs and both forearms had to be amputated, yet he subsequently enjoyed good general health.

Treatment.

In spite of all the experimental work that has been done on the electrocution of the lower animals, the treatment of persons apparently killed by electric currents remains much where Priestley left it in 1767. He tried artificial respiration, and artificial respiration is still the most successful treatment available. It is best carried out by the prone pressure method of Schäfer, because it is the simplest and the least dangerous in the hands of the inexpert; by some authorities Sylvester's method, in which the victim is placed on his back and not on his stomach, is preferred (Brauchbar). The French generally recommend that rhythmical traction of the tongue should be performed at the same time, as was first recommended by Laborde (1894). This, however, could not be done easily with the patient in the prone position. Gibbons recommends the use of a special form of bellows. Atropine, recommended by Eggleston, has not proved of much service. The importance of getting to work with the artificial respiration without a moment's delay has often been emphasized by those who have had much experience of electrical accidents. No less important is the necessity for continuing artificial respiration until it is certain that death has occurred; nothing less than cooling of the body or the onset of rigor mortis should be considered to be evidence of death here.

Recovery after two hours of apparent death is mentioned by d'Arsonval (1910), who gives a first-rate account of the steps that should be taken in rescuing and resuscitating the victims of electric shocks. It must be remembered that the great majority of electrical accidents take place in workshops and other places where immediate skilled assistance is very rarely available, so that any but the simplest of treatments could not, practically speaking, be employed.

It is worth while to mention two other possible methods of treatment. It has been seen that in most cases death by electric shock is due to cardiac failure, the heart being thrown into fibrillary contraction. Prevost and Battelli, and others after them, have shown that the fibrillating hearts of the lower animals can be made to beat regularly and rhythmically once more by passing strong electric currents through them within a given time—a few minutes; so that the apparently dead animal is brought to life again. It is more than probable that the same treatment—a hair of the dog that bit them—could be applied with success to human beings apparently killed by electric currents, but there are two practical difficulties here. In the first place there is no experimental evidence, in the case of man, to show what voltage and what strength of current should best be employed in this method of resuscitation. In the second place, there would usually be great difficulty in providing the current at the required voltage for use on the spot and within a few minutes. Still, this method is well worth further investigation and

trial. The second mode of treatment I wish to mention is that tried, though without success, by Stanton and Krida. These authors started out from the work of Crilo and Dolly on the resuscitation of animals killed by chloroform and by asphyxia, which showed that recovery after apparent death was possible if the pressure in the coronary arteries could be raised sufficiently, by the arterial injection of salt-solution and adrenalin, to restore some sort of circulation through the substance of the heart. If this was done mechanical stimulation of the heart through the chest wall would then cause it to beat vigorously again, and the animal seemingly killed by chloroform or asphyxia, as the case might be, would be brought back to life. Stanton and Krida tried this method of resuscitation on dogs subjected to the ventricular fibrillation caused by electric currents of low voltage, but it did not prove successful.

NOTE.—A list of references to the literature will be given at the end of the third lecture.

Memoranda:

MEDICAL, SURGICAL, OBSTETRICAL.

SODIUM CARBONATE IN RINGWORM.

THE following method was shown me by a conscientious but rather ignorant woman who has had charge for many years of a home for waifs and strays. She said that she had never known more than two applications necessary. Take a piece of sodium carbonate (the household washing soda) about the size of a walnut, and hold it against red hot iron (I use the poker heated in the consulting-room fire); then rub the melted end freely into the ringworm, and particularly thoroughly if it is in the scalp, which must have had the hair round cut short. One application is sufficient on the body, but on the scalp it may be necessary to repeat it six or seven days later. Usually no dressing is necessary, though if sore boric acid ointment may be used. This apparently heroic treatment is practically painless, leaves no permanent mark, and, so far, has not failed me.

Penkridge, Staffs.

W. W. NOCK, M.R.C.S., L.R.C.P.

Reports

ON

MEDICAL AND SURGICAL PRACTICE IN HOSPITALS AND ASYLUMS.

COUNTESS OF DUFFERIN HOSPITAL, BARODA.

CONGENITAL ABSENCE OF RECTUM AND LARGE INTESTINE.

(By CLIFFORD MAYER, M.D., B.S.Lond., Chief Medical Officer, Baroda State.)

B. D., a Hindu female infant aged 3 days, was admitted on November 23rd, 1912, for intestinal obstruction. The history was that the child, soon after birth, had passed some meconium, and since then only a little mucus and blood. Castor oil had been given and glycerine enemata tried by a local practitioner with no effect. There had been vomiting since the day before.

On admission, the temperature was subnormal and the pulse hardly perceptible. The anal canal admitted the tip of the little finger. The abdomen was very distended, and on palpation a doughy, sausage-like mass on the right side was imperfectly made out. Intussusception was diagnosed. The child was infused. The pulse improved, and two hours after admission the abdomen was opened by an incision in the right rectus close to the middle line. On incising the peritoneum a blind end of much distended gut projected for about six inches. The bowel was relieved of its contents, a Paul's tube tied in, and the gut securely fixed to the abdominal opening.

The operation was well borne, and for the first four days progress was very satisfactory, the child taking its feeds very well. On the fourth day the Paul's tube came out, and on the fifth day a pemphigoid rash broke out on the