**Death by electric currents and by lightning : the Goulstonian lectures for 1913 delivered before the Royal College of Physicians of London / by A.J. Jex-Blake.**

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# DEATH BY ELECTRIC CURRENTS AND BY LIGHTNING.

## The Goulstonian Lectures

FOR 1913

DELIVERED BEFORE THE ROYAL COLLEGE OF PHYSICIANS OF LONDON.

BY

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# The Goulstonian Lectures

FOR 1913,

ON

# DEATH BY ELECTRIC CURRENTS AND BY LIGHTNING.

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# DEATH BY ELECTRIC CURRENTS AND BY LIGHTNING.

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## Lecture I.

## DEATH BY ELECTRIC CURRENTS.

In these lectures I propose to consider, first, the subject of death by electric currents, and next, death by lightning. I do this because a good deal is known for certain as to the way in which industrial and domestic electric currents bring about death in man, and much valuable experimental work has been done illustrating the effects of such currents upon the lower animals. In the case of lightning, however, although plenty of observations upon its victims have been made, the nature of lightning itself has always prevented the making of experimental observations of its effects upon living creatures. It is true that in the middle of the eighteenth century a few desultory experiments were made with the electric discharges brought down from heaven during thunderstorms by kites and lightning conductors of various kinds. But all experimentation of this kind came to an abrupt end when, in 1763, Professor Richmann of St. Petersburg was killed outright in his own laboratory by a miniature lightning stroke a foot long, while investigating the nature of the discharges collected by a lightning-rod set up on his roof above and brought down into his room (Arago).

### *Death by Electric Currents.*

I believe that no loss of human life from industrial currents of electricity occurred before 1879, though currents strong enough to have caused death were employed in lighting the operatic stage in Paris (at the first performance of Meyerbeer's *Le Prophète*) as long ago as 1849, and in lighthouses on and off the coast of England in 1857. In 1879 a stage carpenter was killed at Lyon by the alternating current of a Siemens dynamo that was giving a voltage of about 250 volts at the time. The man became insensible at once and died in twenty minutes; artificial respiration was not applied. The first death in this country took place at a theatre in Aston, outside Birmingham, in 1880, where a bandsman short-circuited a powerful electric battery, became insensible, and died in forty minutes. Since that date the annual number of deaths from electric shock has steadily increased, particularly during this century, in which the industrial employment of electricity has extended so widely, and is now quite large. In the ten years 1901–10 the Registrar-General's returns show a total of 183 such deaths in England and Wales, the population having risen from 32½ to 36 million during that period. In the three years 1901 to 1903 there were 25 such deaths; in 1908, 25; in 1909, 29; in 1910, 26. Only 2 of these 183 victims were females, because women are so much less exposed to contact with dangerous electric currents than are men. Many deaths by electricity occur annually on the Continent, though I can only bring forward a few scattered figures to prove it. In Germany, 33 were killed in 1908, 52 in 1909, 46 in 1911. In Austria, 11 were killed by electricity in 1907, 10 in 1910, 10 in 1911. In Switzerland, 21 were killed in 1905, 19 in 1906. I think it probable that about 200 persons are killed by electricity annually over the whole of Europe. As regards the United States of America, where electricity is so very extensively employed, I have not been able to find any statistical records. As long ago as 1888 Brown estimated that during the past five years some 200 people had been killed by handling live electric wires. One must remember that in America life is held very cheap, and that safeguards and protective legislation tend to be regarded as undue restrictions upon industry and commerce. I imagine that not less than 200 persons are accidentally killed by electric currents every year in America.

As a rule, only a single person is killed by electricity in any single accident; but in an accident occurring in 1909 at Olginate, a village in Lombardy, 10 people were killed outright by a three-phase current at 3,000 volts. One was saved by artificial respiration, and about a dozen more were severely injured (Hoest).

It is necessary before going further to explain the meaning of certain technical terms that cannot be avoided when electric currents are under discussion. Any given electric current is maintained by an electromotive force or pressure that for practical purposes is measured in volts; to give a hydraulic analogy, the pressure or voltage, or, as it is still sometimes confusingly called, tension, that drives the current through an electric lamp corresponds to the head of water, or pressure measured in pounds per square inch, that causes water to run out of a turned-on tap. The rate at which a current of electricity flows, or the quantity (measured in coulombs) flowing in unit time, is measured in amperes; to give the hydraulic analogy, an electric current of so many amperes may be compared to a stream of water or so many gallons per second. The resistance met with by a current as it flows through a circuit or any part of it is measured in ohms; electric resistance is analogous to the frictional resistance met with by water flowing through pipes or in partially choked channels. An electric current that flows steadily in one direction is called "direct" or "continuous." For technical reasons it is often found more convenient to use currents that frequently and regularly reverse, flowing first in one direction round the circuit and then round in the opposite direction, say from 50 to 150 times a second; these are called "alternate" or "alternating" currents of electricity. An alternating current that reverses the direction of its flow 100 times a second is described as an alternating current of fifty periods or cycles a second, or as having a frequency or periodicity of fifty cycles; the frequency of an alternating current is of great importance in considering its dangerousness to life. Electric energy, or the power of doing work, is measured in joules; one joule represents the energy expended in one second by one ampere in one ohm.

### *Post-mortem Evidence as to the Cause of Death.*

The interest of men of science, of physicians and pathologists, in deaths due to industrial electric currents was first shown in France. In 1882 the celebrated French medico-legal expert and pathologist, Brouardel, made a careful *post-mortem* examination of a man killed in Paris at the Tuileries by a 250-volt alternating current, and he decided that death was fulminating, due to the electric discharge, and directly caused by arrest of the heart. Bourrot at the same time examined a second and similar case *post mortem*, and came to the conclusion that death was due to violent excitation of the vagus nerve and consequent arrest of the heart, with the result that the heart could not resume its functions, and death by asphyxia followed. In 1885 a man killed instantaneously by electric shock at the Health Exhibition in London was examined forty hours after death by Sheild and Delépine. Rigor mortis was marked; extreme fluidity of the blood was observed, even the right heart being free from clots. The authors came to the conclusion that "No doubt the vital spots at the base of the brain are in such cases markedly implicated." As the result of a *post-mortem* examination made by Pla in 1891, he concluded that death by electric shock was due to an instantaneous suppression of all the organic functions. The brain and its membranes were hyperaemic in this case; the blood was fluid, but showed no microscopical change. The victim had died twenty minutes after receiving the fatal shock. In 1892 Buchanan described the case of a man who came in contact with a 2,400-volt alternating current, and fell back insensible with one cry for help. Ten minutes later he was found to be livid, with dilated pupils and blood-stained mucus coming from the nares. Artificial respiration was performed; the man inspired slightly three times and then died, becoming quite rigid in about four minutes. The *post-mortem* examination was made thirty-one hours later; rigor mortis was still marked, the blood was liquid and tarry, the brain was congested, the spinal cord was congested but healthy. Buchanan remarked that the cause of death was evidently asphyxia. In the same year Crossland recorded the case of a youth of 17, who was killed by a current at a pressure of 115 volts. *Post mortem* the blood was found to be "fluid-inky," but no other lesion could be discovered.

It is well to say something at this point as to the infliction in America of the death penalty on criminals by means of electricity, which had been widely discussed in the lay press and the medical papers of America and this country since 1889, and was first put into practice in the State of New York in August, 1890. Various suggestions had been made as to the strength and nature of the current to be used, and the methods and sites of its application to the body of the criminal. The upshot was that alternating currents of high electromotive force—1,200 to 1,700 volts, while Carleton recommended 3,000 volts—were used, with large electrodes fixed to the head, neck, arms, legs, and elsewhere; the current was turned on several times in each case, and for periods lasting up to 70 seconds or more. Each execution, or "electrocution" as it was first called in 1892, lasted from 3½ to 8 minutes. Enormous quantities of electricity were employed in these executions. To quote one example, an alternating current of 7 amperes was maintained for 70 seconds through the body of one criminal, at a pressure of 1,500 volts; assuming that the man weighed 10 st., here was enough energy expended to raise the temperature of his whole body through more than 5° F., quite apart from any heat generated by the prolonged contraction of the electrically-stimulated muscles. Spitzka states that within twenty minutes of an electrocution the temperature of the body rises to 120° or 129.5° F. in many cases, and that coagulation of the myosin of the muscles takes place. The whole muscular system was thrown into complete tonic rigidity, we are told, when the current was turned on, and this was maintained until it was turned off. The *post-mortem* examinations of persons thus electrocuted showed, among other things, extensive capillary haemorrhages in the brain and in the floor of the fourth ventricle, and it was assumed that death was due to injury to the brain. No doubt these haemorrhages were caused by the rupture of small vessels following on the great rise in the blood pressure produced by the prolonged tonic spasm of the muscles; they are not a common feature after death by electric shock. But I think it is obvious that the *post-mortem* changes observed in such electrocutions as these are not of much use in explaining the mode of death by electric shock in industrial accidents, in which the voltage of the current is often much less, the quantity of current passing through the body of the victim is very much less (probably rarely approaching 7 amperes), and the duration of the contact is not often more than a few seconds. The conditions in which electrocutions have been performed and the electrical quantities involved in them are so very different from those ordinarily obtaining in death by accidental electric shocks, that as a matter of fact electrocutions have thrown no light at all on the mode in which deaths by misadventure with electric currents as they commonly occur are brought about. The objects of the responsible authorities were to produce instant insensibility, in the first place, and in the second place death, and both of these objects were attained by the method of electrocution adopted. It was generally supposed that death in electrocution was due to asphyxia or injury to the brain; although, and to my mind quite unjustifiably, it was also argued that it was the subsequent *post-mortem* examination, and not the electrocution, that was the real cause of death, a view that was upheld again and again from time to time in the public press of America until at any rate as late as the year 1905.

During the last twenty years a great many *post-mortem* examinations have been made in cases of sudden death by electric shock, but I do not think that any useful purpose would be served by going through them in detail, as they do not in general throw light on the exact way in which death has been brought about. Stress may, however, be laid on a few points commonly observed. In the first place, burns of greater or less superficial extent are generally seen at the points where the electric current has entered and left the body. They have been carefully studied by Sheild and Delépine, and by Mally, and are due to the relatively great resistance offered by the skin to the passage of the electric current, which is transformed into heat in proportion to the amount of resistance it meets and to the square of the current. If the current is at a low voltage and the contact is brief, the resulting burns may be so slight as easily to escape notice. But if contact with the electric conductor is prolonged, the burning may be very extensive and deep—in extreme cases it has even been found necessary to send for the fire brigade to extinguish the burning victim, who is kept alight by the transformation into heat of the electric energy being poured into him. In the second place, abnormal fluidity of the blood has often been found *post mortem;* in this, those cases of sudden death by electric shock resemble cases of sudden death by asphyxia. In the third place, no pathological changes are regularly found in the heart muscle, although there are good reasons for believing that in most instances death is directly due to paralysis of the heart. In the fourth place, the central nervous system often shows neither macroscopical nor microscopical changes of importance, except in the cases where relatively large quantities of electricity have passed through the body for long periods of time; when this happened, capillary haemorrhages have often been found in the brain and cord, with chromatolysis or destruction of the Nissl bodies in the nerve cells. In a word, the *post-mortem* evidence as to the cause of death by electric currents in industrial accidents is generally negative, but may suggest asphyxia in some cases, in others organic vascular and nervous lesions in the brain and cord.

### *Evidence from Anatomical and Electrical Considerations.*

When one comes to look into a number of both fatal and non-fatal instances of accidental shock by industrial electric currents, it becomes apparent that the part of the body through which the current flows is extremely important in determining the result of the shock. Practically speaking, there is but the smallest danger of sudden death if the current enters one foot or leg and leaves it by the other or by the lower part of the trunk, however high the voltage and however great the current thus forced through the lower part of the body and the legs. But there is a danger, even with electric currents of as low a voltage as 65 volts, when the current travels through the thorax, and so has the chance to pass through the substance of the heart. The degree of danger here depends upon two factors—first, the resistance presented to the flow of electricity by the skin at the points at which the current enters and leaves the body, and, secondly, upon the voltage of the current. The resistance of the skin varies very widely in any given case, being high when the skin is greasy or dry, or when the area of contact with the electric conductor is small, and relatively low when the skin is wet or the area over which it comes into contact with the conductor is great. To give a single example illustrating my meaning, one may handle a bare wire carrying, say, an electric lighting current at a pressure of several hundred volts with complete impunity, so long as the hands by which the current enters or the feet or boots by which it leaves the body are dry, because in these circumstances the amount of current flowing through the body is too small to be dangerous. But if the hands and feet are damp or wet, the electrical resistance of the skin at the points of entry and exit of the current may be so much lowered that a relatively strong current will flow from the hands through the body to the feet; and if the proportion of this current that passes through the heart is strong enough to paralyse it, then sudden death will occur.

Hence the cardiac region in the thorax is the chief danger area of the body in cases of dangerous or fatal electric shock. Experimental evidence obtained from animals makes it certain that the central nervous system constitutes another area of danger; but for practical purposes the number of industrial accidents recorded in which the current entered by the head and left the body without traversing the region of the heart would seem to be small—at any rate, I have not been able to find any.

The direction in which an electric current flows through the body, whether from right to left or left to right, or whether from the head to the feet or the feet to the head, has no influence on the effects it produces. As a matter of convenience one always speaks of a current as "entering" at the point where the body comes into contact with the uninsulated electric conductor carrying the current, and "leaving" at the place where it is in contact with some indifferent but conducting substance—with the earth in the case of a person who is standing—by means of which the current after passage through the body is conveyed back to the source whence it came. But it must be understood that these words "entering" and "leaving" are used without prejudice to the actual direction in which the current flows through the body in any given case.

### *Experimental Evidence.*

It is upon the evidence obtained by the experimental electrocution of animals that most of our knowledge as to the modes of death by electric shock rests. No electrical apparatus capable of producing currents strong enough to kill animals was invented before about the middle of the eighteenth century. At that time electricity suddenly developed into a popular and spectacular science in France and Germany, just as in the middle of the nineteenth century table turning, spiritualism, and clairvoyance were popularly taken up all over England and America with the greatest energy. In neither case was much real scientific progress made by this arousal of popular interest; birds, beetles, and other living creatures were electrocuted by frictional electricity by Gordon (1745), Gralath (1746), Nollet (1749), and many others (Benjamin). It was noted that the birds exhibited ecchymoses where the electric sparks struck them, much like the ecchymoses seen on persons killed by lightning (Nollet). Priestley in 1767 killed kittens and dogs with the discharges of condensers, and tried without success to resuscitate a kitten by artificial respiration, distending the lungs by blowing with a quill into the trachea. Abildgaard (1775), using condensers and Leyden jars, tried without success to electrocute a 3-months-old foal; he succeeded in killing cocks and hens by electric discharges sent through the head, and made the important observation that fowls treated in this way and to all appearances dead could be brought back to life by electric shocks sent through the body from breast to back, but remained dead if not treated in this manner. Thus, a cock received the discharge of a Leyden jar through its head, and fell down apparently dead at once, blood coming from its nose and throat, no doubt in consequence of the rupture of some superficial vessels by the mechanical violence of the spark; but when a second Leyden jar was discharged into its breast the cock leaped up and flew away with alacrity, upsetting and breaking the Leyden jar. Abildgaard concluded that when death took place in the fowls it was due to syncope brought on by nervous shock.

Brodie (1828), in some experiments made to explain the mode in which death is produced by lightning, was led to suppose that electric shocks caused death by destroying the functions of the brain. He speaks of restoring to life the guinea-pigs apparently killed by electric discharges by means of perseveringly inflating their lungs by bellows. Brown-Séquard (1850) expressed the opinion that animals killed by electric discharges died by asphyxia, tetanus being set up and preventing respiration till death ensued. It must be remarked, however, that this explanation does not account for the many instances in which death occurs without the establishment of tetanus, but with simple failure of the heart or respiration.

Some important experiments on the electrocution of animals by sparks from the large induction coil belonging to the Polytechnic were made in 1869 by Richardson. They led him to believe that death could take place in two ways—either by failure of the respiration or by failure of the heart; in each case as a consequence of injury to the nervous centres. The heart was the last organ to be brought to rest. In the case of a pigeon anaesthetized with methylene bichloride and killed by a six-inch spark from the induction coil, and apparently killed outright, all four chambers of the heart went on beating for an hour and a quarter after death. Discussing the *post-mortem* observations he made, Richardson was finally led to a number of conclusions that are certainly erroneous. "Death," he said, is due "in all cases where it is instantaneous to the sudden expansion of the gaseous part or atmosphere of the blood, combined in extreme degrees of shock with a sudden conversion of animal fluid from the fluid into the gaseous condition." He had found that the vessels of the brain were distended, the arteries contracted, and that sometimes there were slight serous or haemorrhagic effusions beneath the arachnoid; "often, on lifting up the brain and medulla, there is a free escape of bubbles of gas," but he does not say whence this gas came. I cannot find that any other observer (except Corrado in a couple of instances) has observed gas in the blood vessels as the result of electrocution, either in animals or man. The large Apps induction coil Richardson used gave sparks up to 29 inches in length, and even with 29-inch sparks could produce no fatal effects unless reinforced by the use of Leyden jars; the currents he obtained would have been very small, presumably a few milliamperes at most, though the voltage would have been very great—tens or hundreds of thousands of volts; and these facts explain to some extent the inconclusive character of Richardson's results.

The fact is that electricity is a science in which beyond all others science is measurement. For all practical purposes accurate measurements of the strengths of currents, of electromotive forces and of resistances, were luxuries at the command of a few physical laboratories only until the end of the Seventies of last century. Until after the year 1880 the men of science who investigated the subject of electrocution never even thought of giving any precise figures whereby one could calculate the electrical dimensions of the currents they employed. Their statements are qualitative and not quantitative, and so are of historical rather than practical interest in any discussion about the cause of death by electricity.

One of the first experimenters to give accurate measurements of the voltages and currents he used was Grange (1884). He failed to kill guinea-pigs by continuous currents at 31 and 48 volts, and rats with currents of 62 volts; with an alternating current at 825 volts he failed to kill a dog weighing 17 lb., but some of his other attempts at electrocution were more successful. His failures were due to the want of skill with which he affixed the electrodes to the dogs, for he found the resistance of his dogs to be as much as from 50,000 to 80,000 ohms, while later experimenters have observed resistances of only a few hundred ohms when the electrodes were rationally applied to the animals. Grange found capillary haemorrhages in the central nervous systems of the animals he killed, and concluded that these haemorrhages were the cause of death. The fact that later experiments have shown that alternating currents at voltages as low as 10 or 15 volts suffice to kill dogs if electrodes are used so as to reduce the resistance of the animals to a minimum, proves what care is necessary in drawing definite deductions as to the possibilities of death by electric shocks; for here we have Grange failing to electrocute dogs with alternating currents of no less than 825 volts electromotive force.

In 1885 Mann made some interesting experiments on the effects of electricity on the action of the human heart. He applied the electrodes to the praecordia and back, and found that a slowly alternating current of from 15 to 30 milliamperes did not prejudice the heart's action. His method of experimentation was admirable, and failed to give more positive results only because the voltage he employed between the two electrodes was not large enough to drive stronger currents through the thorax, fortunately for the person on whom the experiments were made. It would be of the greatest interest to know how high a voltage can be used, and how large a fraction of an ampere can be passed with impunity through the human heart, from front to back through the thorax, with electrodes applied to the best advantage; because it is the strength of the current passing through the heart that is the main factor in determining death in the large majority of industrial accidents as they actually occur, and it is a quantity that has never yet been measured. Experiments to determine these points, however, in human beings would be far too dangerous to be justifiable —unless, indeed, some American criminal condemned to death were to offer to take on the task and were allowed to do so.

In 1885, and further in 1887, d'Arsonval made some interesting remarks on deaths caused by industrial electric currents, advancing the views as to their mode of production that he has continued to hold faithfully ever since. These deaths, he said, were brought about in one of two ways:

(1) By direct action, the mechanical effect or disruptive action of the electric current on the tissues; or

(2) By indirect or reflex action on the nervous centres.

In the first case death is final; in the second it is often apparent only, so that the victim may recover if treated by artificial respiration immediately after receiving the shock. Most of the victims of industrial electric accidents had died of asphyxia, he believed.

In 1889 Donlin published some details of ten autopsies made on electrocuted criminals in America, and advanced the view that death was due to action of the electric current (conducted by the blood) upon the ganglia of the heart, causing a spasm of the heart muscle; in other cases it was produced by disorganization of the blood and interference with the circulation. I cannot find that these two theories ever had much vogue, or that the spasm of the heart muscle and disorganization of the blood have ever been observed experimentally, either before or after Donlin's elaboration of these views. An editorial in the *Lancet* (1890) brought forward the explanation that electrocuted persons died "by concussion of the brain and explosion within the closed cavity of the skull"; here, again, we have a theory of the cause of death that lacks any experimental evidence in its favour or even rational support. As a contrast may be quoted the excellent experiments made in 1890 by Tatum, upon dogs for the most part. He found no *post-mortem* lesions unless he used current densities many times in excess of those needed to produce death; weak currents might produce death by arresting respiration, strong currents by a permanent arrest of the heart without influencing respiration, while currents of intermediate strength might kill by arresting both the heart and the respiration simultaneously. Tatum appears to me to have been the first to give due prominence to the fact that death by electricity is generally due to paralysis of the heart, and depends on injury of the heart muscle rather than of the nerves of the heart. He also showed that section of the vagi and the use of atropine or curare gave no protection against the fatal result in these electrocutions—observations that are hard to explain on the theory that death by electric currents is due to nervous inhibition. Tatum also showed that a given current would be most fatal when the two electrodes were placed in the neighbourhood of the heart.

One may say that from the year 1890 onwards three main theories of the cause of death by electricity have held sway. The first was d'Arsonval's theory, that it was due to nervous inhibition of the heart and respiration. The second, as advanced by Tatum, attributed death to direct paralysis of the cardiac muscle by the passage of the electric current through it. The third, based mainly on the *post-mortem* examinations of electrocuted criminals in America, put death down to the gross lesions—haemorrhages—found in the brain and bulb of the victims, and produced by the vast quantities of electrical energy employed to procure an easy death.

In France the first theory was, naturally enough, generally adopted, and it was supported by many others besides the French (Biraud, Jenks, Hankel, Cunningham, Witz, Hedley, Durand, Verhoogen, Gardé, Jones, Dürck). The second theory was supported by a number of authors, some of whom held that both were true in given instances (Witz, Gardé, Hedley (1895), Dürck, Kratter, Oliver and Bolam, Cunningham, Bordier and Lecomte, Lebrun). The third met with comparatively little support outside America (MacDonald, Goelet, O'Neill, Corrado), but was reiterated with some elaboration in a modified form by Jellinek (1903). But the subject has always had great attraction for the abstract philosopher, and so it is not surprising to find that the industrious production of what may not unfairly be called "freak theories" of death by electricity has continued. Thus, Shettle (1895) attributed such deaths to the fact that the electric current deprives the arterial blood of its active magnetic properties, and prevents the corpuscles from constantly inducing magneto-electric currents in the nerves. Bennett (1897) put them down to a violent, rapid, and excessive disturbance of the normal atomic electrical equilibrium of the body, to such an extent as to cause complete and instantaneous disease and death. Coulter (1899) quotes the view that the whole volume of the blood seems to be suddenly forced to the head in the electrocution of criminals; "this alone in each and every case would explain the cause of death." I quote these views to show that the old principle of explaining *obscurum per obscurius* dies very hard.

Towards the end of the nineteenth century it became apparent that more extended experiments on animals were required to settle the mechanism of death by electric shock. In 1898 Oliver and Bolam published some investigations made upon etherized dogs and rabbits with an alternating current at 100 volts. They came to the conclusion that the deaths produced by currents of such voltages were by a primary cessation of the heart's beat as a rule, while currents at higher voltages might paralyse both heart and respiration together. Under no circumstances did these authors produce a primary failure of the respiration, and they note that it had been frequently recorded by bystanders that the persons killed by accidental shocks from industrial electric currents had breathed a few times after receiving the shock, although to all appearances dead.

### *Fibrillation of the Heart Muscle.*

It had long been known (Ludwig and Hoffa, 1850) that one effect of electric currents on the mammalian heart might be to paralyse the ventricles by throwing them into a state of fibrillation, also known as *Herzdelirium*, fibrillary contraction or tremulation, consisting in a fine and rapid but inco-ordinate twitching of the separate muscular bundles. Kronecker and Schmey (1884) had produced fibrillation in the dog's heart by the mechanical stimulation—a pin-prick—of a certain point on the anterior aspect of the ventricle, also by ligature of the coronary arteries and by electrical stimulation. They attributed it to the destruction or paralysis of a nervous co-ordinating centre located in this particular part of the heart's muscle. McWilliam (1887) made further investigations into cardiac fibrillation, and denied that it was in any way a nervous phenomenon. He believed that it depended on physical or chemical changes in the substance of the heart muscle itself. The subject was very carefully examined again by Prevost in 1898, and it demands further consideration here because there is little doubt that cardiac fibrillation is the immediate cause of death in the majority of cases of death by electric shock in man. Prevost found, as McWilliam had found before him, that cardiac fibrillation was produced with much greater ease in certain varieties of animals and birds than in others; that in some—the dog or pigeon, for example—it was generally fatal and irremediable, while in others it tended to cease spontaneously after a longer or shorter period, the heart beginning to beat normally again; and that in the young of any given species cardiac fibrillation was more readily recovered from than in the adult. Thus, guinea-pigs weighing 1 lb. would often recover from cardiac fibrillation spontaneously; while with heavier animals weighing 2 lbs. the heart would fail to begin again to beat normally, the guinea-pig dying of asphyxia with great dilatation of the heart, though long massage of the heart might enable it to recover. As to the exact mechanism whereby cardiac fibrillation was produced, Prevost expressed himself as uncertain; he did not think it due either to stimulation of an intracardiac nervous centre or to anaemia of the muscle substance, as Kronecker at one time believed. It is explained by Boruttau as due to the different excitability of the different muscular bundles composing the heart wall and the various length of their refractory periods; all the bundles are strongly stimulated by the electric current, and so contract with their maximum frequency, but as these maxima are unequal the contractions are not synchronous. Why these small and rapid local contractions are not propagated in such a way as to make the heart beat as a whole remains unknown. They may be excited by the local ionic dissociations caused by the passage of the electric current, Professor Gotch tells me, as is also the case in the analogous Porret's phenomenon observed in the frog's sartorius muscle, and may fail to be transmitted to the adjoining bundles because, although excitability remains, the power of propagating the stimulus to contract may be lowered. Fibrillation is also to be seen in the auricles of the heart, but does not seem to be of any great importance here.

### *Later Experimental Evidence.*

An illuminating and most extensive series of experiments on the electrocution of animals was published by

Prevost and Battelli in 1899. The great merit of these authors was that they varied the electrical conditions of their experiments far more widely than any of their predecessors, and gave measurements not only of the voltages they employed but also of the amperages of the currents they passed through the various animals; they also registered the arterial blood pressure and the respiratory movements. Perusal of the published works of the vast majority of the other writers on this subject is apt to leave one with the impression that their authors were not particularly skilled physiologists or physicians in some instances, in others that they were not electrical experts or men of science. The work of Prevost and Battelli is both sound and brilliant, and shows a degree of competence in both physiological and electrical matters that inspires great confidence in their conclusions. They employed both alternating and continuous currents, and took great pains to ensure adequate electrical contacts between the terminals of their electric apparatus and the animal under experiment. In many cases one electrode was placed in the mouth, the other in the rectum; the resistance in different dogs with this arrangement varied between 250 and 400 ohms. Electrical contact was made for a few seconds or for a fraction of a second in different cases. An alternating current at five volts was painful to dogs when passed thus between mouth and rectum, but did not affect the respiration or the action of the heart. The current at a pressure of 10 volts in two seconds caused almost certain death, the ventricles of the heart being irremediably thrown into a state of fibrillation while the auricles continued to beat normally. Respiration stopped, owing to general muscular tetanus, during the passage of the current, beginning once more when it was cut off, but soon dying away again for want of irrigation of the respiratory centre in the bulb with blood, for after the current was turned on the blood pressure fell steadily away to nothing in about 15 seconds. Using metal electrodes covered with wetted cotton, suitably shaped and applied to the shaved chest-wall, they found the resistance of three dogs from one side of the chest to the other was about 300 ohms in each case, and these dogs were killed by alternating currents at 10 to 15 volts pressure. Fibrillary contractions of the heart muscle was found to be almost invariably fatal in dogs; life could be preserved for a time by massage of the heart and artificial respiration, but death ensued when these manipulations ceased, as the heart could not be induced to begin to beat spontaneously again. In the guinea-pig of medium size, however, massage of the fibrillating heart through the chest wall would sometimes restore the animal to life, the heart beginning its normal action again; the resistance of the guinea-pigs as arranged for electrocution was from 700 to 900 ohms, and pressures of from 20 to 120 volts were found to be fatal by heart failure, as a rule. It was noted that in the case of the rabbit cardiac fibrillation tended to spontaneous recovery in most cases, and in the rat always.

Hence alternating currents up to a pressure of 120 volts were not often fatal to rabbits, under the conditions of experimentation employed by Prevost and Battelli, and were never fatal to rats, as the fibrillation of the heart would cease spontaneously, and the respiration would begin again soon after the current was turned off in both these animals, But death could be procured by the use of these relatively low voltages if the contact was prolonged and the current kept on until asphyxia from prolonged arrest of the respiration occurred.

Using alternate currents at higher voltages—120 to 4,800 volts—Prevost and Battelli found that the effects produced were quite different, so far as life was concerned, and that death, when it occurred, might be caused in a different way. Thus, with the dog, alternating currents sent from the head to the legs at pressures of from 240 to 600 volts caused arrest of the heart (with ventricular fibrillation) and arrest of the respiration also, the animal inevitably dying. At higher voltages, however, 1,200 to 4,800 volts, the ventricles of the heart continued to beat vigorously, though the auricles were paralysed in diastole, and respiration ceased; hence at these high voltages death was due to asphyxia from failure of the respiration, and not, as at low voltages, from heart failure, or, as at intermediate voltages, by failure of both heart and respiration together. The very important observation was made that a dog killed by the ventricular fibrillation caused by a current at 40 volts could be brought to life again if a current at a much higher pressure—4,800 volts in the present example, or 240 volts in other instances quoted later—was sent through its body so as to pass by way of the heart. Very similar results were obtained with rabbits; alternating currents at 240 volts killed by throwing the heart into a state of ventricular fibrillation, but at pressures from 600 to 4,800 volts the heart was not paralysed, but went on beating with rising arterial blood pressure, though respiration was brought to a standstill. Death in these conditions was due to asphyxia from failure of the respiration, and prolonged artificial respiration was needed to bring the rabbit back to life, and was not always successful. Analogous results were obtained in the experiments on guinea-pigs and rats. It was noted that, using these high voltages, phenomena were produced in all these animals indicating that the nervous system received injuries; general convulsions might be produced, or the respiratory movements might be upset for half an hour or more with loss of sensation and the reflexes, and the severity of the nervous symptoms was more or less in proportion to the voltage and the length of time for which the current was applied. No such phenomena depending on injury to the central nervous system were seen in the experiments at voltages up to 120 volts.

Prevost and Battelli also experimented in much the same way with the continuous electric currents of dynamos and of primary batteries. They found that continuous currents at pressures below 50 volts were not fatal to dogs even in five seconds, whereas with alternating currents pressures of 10 to 15 volts were fatal in two seconds. Between 50 and 550 volts the continuous current was uniformly fatal to dogs, causing irremediable ventricular fibrillation; artificial respiration was useless. No continuous current at voltages higher than 550 volts was available ; but if it had been the authors thought that at some higher voltage it would have had the effect of stopping the cardiac fibrillation and restoring the normal action of the heart, just as was the case with the alternating current. In the case of guinea-pigs, the direct current was fatal by ventricular fibrillation at pressures of from 100 to 350 volts; but higher pressures, 400 to 550 volts, were not thus fatal, because although the heart fibrillated during the passage of the current, the extra shock of turning it off suddenly (the "extra-current at break," which d'Arsonval thought so important and fatal) restored its normal action to the heart. With rabbits, as with dogs, direct currents at pressures from 50 to 550 volts threw the heart into ventricular fibrillation, from which the rabbit might or might not recover spontaneously. With rats, the heart was thrown into ventricular fibrillation by currents at from 200 to 550 volts, but only for so long as the current was passing ; when it was turned off the ventricles resumed their normal mode of beating, but the auricles were paralysed in diastole for perhaps two or three minutes before they set to work again.

It is clear, then, from these experiments that direct electric currents are much less dangerous, *caeteris paribus*, than alternating currents, for dogs, rabbits, guinea-pigs, and rats. The experiments also show clearly the importance of reducing as far as possible the resistance offered to the passage of the current through the animal, and of placing the electrodes on it in the most favourable position for producing a fatal result—in other words, of placing them so that the current passes as much as possible through the substance of the heart, when the minimum fatal voltage is to be determined.

A further series of experiments was made in 1899 by Prevost and Battelli to determine the mode of death in animals by electric shocks from induction coils and condensers. These shocks were mostly at voltages varying from 1,500 to 33,000 volts, and the electric energy available was up to 1,000 joules per shock. The duration of each shock was no doubt exceedingly brief—at a guess, perhaps a thousandth of a second. One may summarize their results by saying that the fatal effect of these electrical discharges were in proportion neither to their voltage nor to the quantity of electricity (in microcoulombs) they contained, but to their electric energy measured in joules, taking the presence of thoracic respiration as evidence of life or death. It is worth noting that no such connexion between the amount of electric energy employed and the occurrence or not of a fatal result can be worked out in the case of animals exposed to shocks from the ordinary electric currents used industrially, or in the numerous experiments on animals already described. Young animals were generally more easily killed than old, weight for weight; the direction in which the shock passed made no difference to the result. Death was generally due to asphyxia, from central inhibition of the respiration without inhibition of the heart's action. A curious *post-mortem* lesion was sometimes found, especially in young guinea-pigs—namely, a loss of the elasticity and retractility of the lungs, which rendered recovery by the performance of artificial respiration impossible. It occasionally happened in the guinea-pig that the heart was thrown into a transient state of ventricular fibrillation; the amount of electrical energy available was not large enough to kill dogs.

In 1899 Cunningham independently made some experiments on the electrocution of etherized dogs, somewhat similar to those described a few minutes ago, and, so far as they went, with similar results. Using a continuous current at 115 volts, he found great differences in the strength of current that could be passed with impunity through different dogs; thus a large Newfoundland was killed by 300 milliamperes, while a small shaggy terrier survived 700 milliamperes, and currents smaller than 200 milliamperes were never fatal. Other experimenters have found direct currents of 200 to 300 milliamperes to be fatal to dogs; very possibly the discrepancy here may have been due to the occasional use by Cunningham of larger electrodes that did not serve to concentrate the current and make a sufficiently large proportion of it pass through the heart—a supposition confirmed by the fact that the recorded resistance (77 ohms) of one of his dogs from side to side of the chest was only a quarter of the resistance commonly found in their own experiments by Prevost and Battelli and by Weiss. Such deaths he attributed to the immediate and permanent cessation of the co-ordinated contraction of the heart caused by the electric current. He then went on to investigate the effect of electric currents applied directly to the central nervous system of the etherized dogs. He found that strong currents (1.6 amperes) through the brain caused a deep inspiration, and cessation of respiration while the current flowed; the heart kept on beating and the blood pressure rose steadily to two or three times its original value, returning again to the normal when the current was cut off and respiration began once more. But if the current was kept on for as long as four or five minutes, the heart gradually stopped. He therefore argued that death by the action of electric currents on the brain and medulla was due to asphyxia, and not to heart failure. The strength of the ordinary electric currents that may be sent through the dog's head without causing rapid death is surprising; Houston found that even 6 amperes were not necessarily fatal.

A few more recent investigations remain to be mentioned. Battelli, in 1902, electrocuted dogs, rabbits, guinea-pigs, and rats with discharges from large Ruhmkorff induction coils giving sparks up to 15 and 45 cm. in length. He was able to kill the smaller animals either by arrest of the respiration, or, using a condenser as well, by throwing the heart into fibrillary contraction. With the larger animals, however, death could only be produced by asphyxia after prolonged electrification, the available current—measured in milliamperes—being too small to cause the heart muscle to fibrillate. Battelli stated that no human being had ever yet been killed by the discharge of an induction coil, and estimated that the larger of his two coils would have required a minimum time of two minutes to kill a man, when death, had the experiment been successful, would have been by asphyxia and not by heart failure.

The fact that d'Arsonval believes death by electricity to be due to inhibition, or paralysis of the central nervous system, has been mentioned already. In 1910 he recorded a further experiment that appeared to him to prove that death by electricity, if not due to material lesions of the nervous centres and the heart, was due to Brown-Séquard's inhibition or the action of electric shock on consciousness and the psychical functions. A dog is anaesthetized with chloroform and the cerebral cortex is exposed; stimulation of the cortex with the current from a single Daniell cell (1.1 volts) is found to produce movements of the limbs. If the dog is now killed by a current at 110 volts the heart is thrown into fibrillary contractions, the respiration stops, and the cortex ceases to be excitable by the Daniell cell. At the end of a few minutes respiration begins again, and then the cortex again becomes excitable, and, lastly, in some cases the heart begins to beat spontaneously once more. This experiment d'Arsonval takes to prove that all the vital functions are affected at the same time by an electric shock, so that in his view it is superfluous to inquire whether death is due to a paralysis of the heart or not. He admits that the recovery or death of an animal from a shock that may or may not be fatal depends entirely on the question whether the cardiac fibrillation is transient or is followed by permanent loss of the ability of the heart to beat spontaneously; and as it has been found that section of the vagi has no influence on the occurrence of this cardiac fibrillation, it is, in my opinion, impossible to agree with d'Arsonval when he attributes great importance to nervous inhibition in the large majority of the fatal accidents brought about by industrial electric currents.

## LECTURE II.

## DEATH BY ELECTRIC CURRENTS.

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 millamperes 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 larger 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, *caeteris 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 milliamperes. 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 frequence 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 Kronecker[17] 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 milliampere. 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.

(*e*) *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. H 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 ease 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.[56]

(*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, is 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, almost* free from the danger of sudden death, because the strength

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* A fatal case, however, is recorded by Mr. G. S. Ram; see *Proc. Roy. Soc. Medicine*, London, 1912, vi, Electrother. Sect., 17-36.

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

| 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. |

### *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 Crile 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.

## LECTURE III.

## DEATH BY LIGHTNING.

HAVING discussed the subject of death by industrial electric currents very thoroughly in the last two lectures, I am in a position to approach the obscure subject of death by lightning-stroke with the more confidence. This form of death is much commoner in most countries than it is in ours. In England and Wales the Registrar-General reported 124 fatal instances of lightning-stroke, 108 in men and 16 in women, during the ten years 1901–1910, a yearly average of only 12.4 deaths, or 0.36 per million living. In the twenty-nine years 1852–1880 there were 546 such deaths, the yearly average for that period being 18.8, or 0.88 per annum per million living. The number of these deaths varied widely in different years; three people were killed by lightning in 1863, 46 in 1872. The annual death-rate from lightning also varies widely in different parts of England. In the North Midlands from 1852 to 1880 it was 1.8 annually per million living; in the metropolitan district only 0.13 (Lawson)—a figure that should be of comfort for anybody who is in London during a thunderstorm. On the Continent much higher yearly death-rates are found. In Hungary the annual death-rate from lightning is said to be sixteen per million living (Milham); in Styria and Carinthia about ten per million, in Prussia 4.4, in France and in Sweden three, in Belgium two, so far as the imperfect statistics available go (McAdie and Henry). In the United States of America the annual death-rate per million is high, about ten, in consequence of the frequency of thunderstorms on the one hand and of the large percentage of the inhabitants engaged in outdoor labour on the other; about 700 or 800 deaths from lightning were estimated to occur in the United States every year by Henry in 1900, in a population of 76 millions.

Many more people are struck by lightning than are killed. For example, Jack records an instance in which a church was struck; 300 people were in it, 100 were injured and mostly made unconscious, 30 had to take to their beds, but only 6 were killed. Weber gives an account of 92 people struck in Schleswig-Holstein; 10 were killed, 20 paralysed, 55 stupefied, and 7 only slightly affected. In 1905 a tent with 250 people in it was struck, and 60 were left on the ground in various states of insensibility; one was killed outright, another breathed for some minutes before dying, the rest recovered.[44] As many as eleven [81] and eighteen [87] persons have been killed by a single stroke of lightning. Vincent mentions a stroke that threw down 1,200 and killed 556 out of a flock of 1,800 sheep. Dechambre believes that children are perhaps less liable to be struck than adults; but statements such as these are really not capable of proof or disproof.

### *The Nature of Lightning.*

Nothing was known or even, apparently, guessed as to the true nature of lightning and its connexion with electricity till 1708, when Wall drew attention to the similarity between it and electric sparks obtained by rubbing a piece of amber. The identity in kind of electric sparks and lightning was proved in 1752, when the experiment suggested by Franklin in 1750 was carried out in France by D'Alibard, and ordinary electric sparks were obtained, during the passage of a thunderstorm, from an insulated iron rod forty feet high set up in a garden at Marly-la-Ville. A few months later Franklin proved the same thing by his celebrated experiment of flying a kite up into a thunder-cloud during a rain-storm, and drawing sparks from the wet cord that held the kite. In this way it was proved that a flash of lightning is no more than a particularly large and powerful electric spark.

When electric sparks and their methods of production are examined, it is found possible to determine a large number of physical data about them—the voltage that is required to produce a spark of a given length, for example, the duration of a spark, the direction of its flow, the quantity of electricity (measured in coulombs) it contains, the rate of flow in amperes of the current that produces it, the amount of energy (measured in joules) expended in its production, and the rate and number of the oscillations composing it—for in a great many cases an apparently simple and single electric spark is really a complex built up of a rapid succession of sparks of diminishing intensity, first in one direction, and then back again in the opposite. All these measurements can be made with some accuracy, and many of them are of importance in determining the lethal or non-lethal effects of electric sparks upon animals.

But with lightning flashes the dangers of such investigations as these are obvious, and not one of the measurements just described above has ever been made as yet with any approach to accuracy in the case of lightning. One only has a number of vague suppositions and a few somewhat sketchy experimental facts to go upon. Still, such as they are, these are worthy of consideration.

1. *Voltage.*—This has never been measured, but has always been assumed to be very high. Lodge calculated that the production of a flash a mile long might require a difference of potential of five thousand million volts, and reckons the difference of potential concerned in an ordinary flash at millions or hundreds of millions of volts. Most authors content themselves with saying that the voltage of a flash must be millions or many millions of volts. Trowbridge found that his battery of twenty thousand small secondary batteries joined up in series gave him initial sparks 3.5 to 4 cm. in length, at a voltage of about 40,000 volts; but, when the two sparking

terminals were quickly drawn apart, he could get a flaming discharge 60 cm. in length. He also found that the apparent resistance of the air was much diminished, and the sparking distance at any given voltage was increased, when large quantities of electricity were employed and transmitted in the spark.

2. *The quantity of electricity in a flash*, in coulombs, never has been measured. Faraday believed that it was quite small, not enough to decompose a drop of water into oxygen and hydrogen, and later writers have agreed with this estimate. Lodge, for example, mentions seventy coulombs as the quantity in a certain flash, enough to decompose only one-tenth of a grain of water.

3. *The amperage*, or rate of flow of the electricity, has always been assumed to be large. Here, at last, we meet with a quantity that has been measured, though not by a method capable of very accurate results. Pockels has described some experiments made with the lightning flashes that struck lightning rods on an observatory in the Apennines; and from the amount of permanent (remanent) magnetism induced in some small basalt prisms by the current flowing down the lightning conductor when it was struck, he has calculated that in these particular lightning flashes the current was from 11,000 to 20,000 amperes. Trowbridge's view that with sparks of large amperage the resistance of the air seems to be reduced has been mentioned already.

4. *The duration* of lightning flashes has not yet been investigated as carefully as it ought to be; it is a matter for the meteorologists to settle by actual observations. Schmidt's experiments showed that the duration of many flashes was under $\frac{1}{5000}$ second, while others were multiple or oscillatory in character, and lasted for $\frac{1}{1000}-\frac{1}{2000}$ second, and yet others lasted for longer than $\frac{1}{200}$ second. Flashes passing from one cloud to another high in the air may last for as long as one second, according to Hann. Lodge, on the other hand, assumes that a single flash lasts for "some extremely small fraction of a second, say $\frac{1}{100000}$ or thereabouts," and so does Sylvanus Thompson.

5. *Direction and Course.*—A clearly-seen flash of lightning gives one the impression that the flash starts at one end and runs rapidly to the other end of its course. There is no reason to suppose, however, that what one sees here has any relation to the reality. A lightning flash is generally over in so small a fraction of a second that the retina has no time to form any accurate judgement as to which end of the flash began first; such impressions really depend upon the unequal sensitiveness of different parts of the retina to light. Meteorologists calculate that two-thirds of the flashes first run, as a matter of fact, from the earth to the clouds (Mache and von Schweidler). One's eye is equally deceived as to the course taken by the flash in a great number of cases, as is shown by the many published photographs of lightning. These photographs prove that most flashes are multiple, meandering, and branched, and quite unlike what the eye sees. The tendency of

lightning to send off branches or side-flashes at points where it changes its course has been illustrated and reproduced in the laboratory experiments of Trowbridge; who also draws attention to the explosive force that seems to be exerted at the points where either lightning flashes or electric sparks of large amperage change their direction.

6. *Oscillatory Character.*—Lodge has brought forward theoretical reasons for supposing that a lightning flash is an oscillatory discharge like that of a Leyden jar, and not a single rush of electricity; in other words, an alternating and not a continuous current of very brief duration. His view seems to be generally accepted, though not universally (Mache and von Schweidler). These oscillations would have an enormous frequency, possibly millions a second, according to Lodge; Emde has made elaborate calculations to prove that the frequency may be much less than this, and that the number of alternations may be only from 2,000 to 8,000 per second. Many of the photographs of lightning taken with a moving camera prove that what appears to the eye a single flash is built up, in reality, of a succession of flashes, travelling along the same path or closely similar paths (Milham).

7. *The Energy in a Flash.*—This has never been measured; but judging by the very violent disruptive or explosive effects of some flashes on such things as rocks and trees, it must be very great. Lodge calculates that the discharge from as little as an area of ten yards square of a cloud fully charged with electricity at a height of a mile would give a flash of over 2,000 foot-tons energy, or 101,000 joules—enough to convert about 40 grams of water at 18° C. into steam at atmospheric pressure. The energy in a great many lightning flashes must be very much larger than this.

Particular attention must be drawn to one feature of lightning flashes that distinguishes them from the ordinary industrial currents of electricity. Given a choice of several alternative paths to travel along, ordinary industrial currents travel along them all in quantities directly proportional to their conductances, or, as it is more usually put, inversely as their resistances. But the very brief alternating current got by discharging a charged Leyden jar behaves quite differently; for it will leave a good conductor such as a coiled up thick copper rod in order to spark across an extremely badly conducting air-space, preferring a path of low self-inductance (or low impedance) to one of low resistance. The same is true of lightning, as was first emphasized by Lodge; it explains the tendency of lightning to send side-flashes out of good conductors like lightning-rods into any objects near by, and the frequent failure of such rods to protect the buildings on which they are fixed from damage by lightning.

## *Classification of Lightning Flashes.*

Seneca (died 65 A.D.) distinguished three varieties of lightning—the penetrating, the shattering, and the burning. His classification persisted more or less until Arago offered a new system, and wrote of the forked, sheet, and ball lightning, with which we are all familiar. But for scientific and practical purposes[76] lightning flashes are now divided into two varieties—the A flashes and the B flashes of Lodge. The A flashes are the less sudden and less violent variety, and protection against them can be afforded by lightning-rods; they correspond to the "cold lightning" of the Germans. The B flashes are more sudden and violent, very destructive in their effects, and they contain a far greater amount of energy to be dissipated than the other variety; they correspond to the German "burning lightning," and often cause disastrous fires. No system of lightning-conductors will protect against them. Both varieties may be fatal to man. In all probability ball lightning is the result of a B flash striking the ground; it is a rare and very striking form of lightning. For some reason that I have not been able to fathom, medical writers who deal with lightning devote a great deal of attention to the "return strokes" of Mahon (1780) and Tyndall.[169] These have been rehabilitated by Lodge, who explains them as oscillations and overflows of electricity induced by the original flash; he describes them as electrical echoes, so to speak, due not to a statical disturbance of equilibrium as was at first supposed, but to induction and electro-magnetic inertia. Such induced flashes might be fatal to man, but there is no evidence to show that as a matter of fact they often are thus fatal; they are described by Vincent as "lateral flashes."

### *Theories of Death by Lightning.*

This has long attracted the attention of the human kind. Lightning is represented by weapons of destruction in the oldest records of it that we have—the seals, cylinders, and bas-reliefs (dating from perhaps three or four thousand years B.C.) found in the ruined cities about the Tigris and Euphrates,[90] a country where thunderstorms are common. The Greeks in the classical times took an optimistic view of death by lightning, arguing that Justice or Piety profited, though the victim, who might be buried with divine honours, perished; a non-fatal stroke was regarded as a sign of the favour of the gods. The Romans, contrariwise, took a gloomier view—considered death by lightning a punishment, and buried the victim without his just funeral obsequies; thunderstorms counted for a good deal in their science of augury, which seems to have been of great political service to the Romans. In literature and art the symbols representing lightning were borrowed from Zeus by Alexander the Great, as tokens of his own royal and divine power, and have been extensively so used since by other sovereigns; and one of them—the trident[53]—has now figured as such, on the reverse of our own bronze coinage, in Britannia's right hand, since the year 1797.

The ancients believed lightning to be generated in the clouds, either from the cosmic fire or from heat coming from the sun and the planets. Theories as to the way in which it caused death had no interest for them, and do not seem to have been formulated until much later. To quote a few early examples out of many, Janichius, writing in 1606, says that lightning kills man by very rapidly penetrating the pores and viscera of the whole body and changing all its parts very quickly, imbuing its fount of life—the heart—with a poisonous quality, and suffocating it with a sulphurous malice; or it may rupture the chambers of the heart by suddenly distending them with spirit and heat through fear. Kisling, in 1673, sets death by lightning down to the fire it contains; the fire rarefies the blood by its dilatatory force, dispels the nervous spirits, and stops the heart. Both these authors, it may be observed, arrive at the truth that death by lightning is often due to paralysis of the heart; but they get there through such a maze of erroneous reasoning and misstatement of fact that it is hard to give them much credit for the discovery on which they thus happened.

Very similar essays on death by lightning continued to be produced for, at any rate, the first two-thirds of the eighteenth century, and new modes in which such deaths might take place were elaborated by the impossible method of deduction. Thus Hoffmann, in 1703, asserted that persons killed by lightning died from want of air suitable for breathing, being asphyxiated by the quantity of sulphurous exhalations emitted by the flash. Röser (1704) attributed some of the deaths to a supernatural cause, the just judgement of God; others to such natural causes as the explosion of sulphurous and nitrous particles within the body caused by the flash, or to suffocation, or to injuries of the animal faculty or sense. Münnich (1732) concluded that lightning killed either by expanding the air in and around the body and so preventing respiration, or else by causing a vacuum which made the blood give up its gases and tear the weaker blood vessels, particularly those of the brain or medulla, leading to the extravasation of blood and death. He supposed, in fact, that the proximate cause of death by lightning was deprivation of external air. Stock (1734) enumerated three possible causes of death by lightning—first, terror; secondly, suffocation by inhalation of the nitro-sulphureous particles left in the track of the lightning; thirdly, the sudden expansion of the aërial particles in the spirits and humours of the body, whereby the spirits were dissipated and the humours rarefied to such a degree that vital movement and respiration could no longer be carried on. Rasbach (1737) stated that death by lightning was brought about by the narcotic effects of the sulphurous effluvia of the lightning, which penetrated the lungs and intercepted life by abolishing their vital functions. Vollmar (1765) attributed it to suffocation and the consequent symptomatic apoplexy, or to fear, or to the vacuum produced by lightning, or the expansion of the air inside the body, or, finally, to the reduction of the body to ashes. Hoffmann (1766), in a very elaborate and carefully written thesis, concluded that the main cause of sudden death by lightning-stroke was some lesion of the nerves and brain, inaccessible to the senses and too delicate to be demonstrable. He went on to enumerate six ways in which the brain and nerves might be fatally affected by lightning, all of them speculative and fanciful, none of them actually observed. Marherr (1766) ascribed death by lightning-stroke to tearing open of the blood vessels in the lungs, comparing it to the deaths caused by the wind of cannon balls on fields of battle, when the victim is not actually touched by the cannon ball but is killed suddenly by the vacuum caused by its passage near him.

It was perfectly natural that all these new theories as to the cause of death by lightning should arise in the seventeenth and in the first half of the eighteenth century. Great advances were then being made in physical science on all sides, and it was only to be expected that van Helmont's discovery of the existence of different gases in 1610, that the wholesale introduction of chemical ideas into the art of medicine by de la Boë (Sylvius) in 1650, and that von Guericke's discovery of the air pump and methods of producing vacuums in 1652, should lead to well meant, if crude, attempts to explain death by lightning-stroke in the terms of the advancing sciences of chemistry, physics, or physiology.

But there was little hope of any real progress in the matter until some explanation of the nature of lightning itself should be furnished, and this was done by Franklin. A fairly efficient frictional machine had been invented by von Guericke in 1662, and had been much improved since; the Leyden jar for storing electrical energy was discovered in 1745 by von Kleist, and now that the identity in kind of frictional electricity and lightning had been proved, it became possible, and natural, after a time, to utilize experiments with frictional electric machines and Leyden jars to throw light on the mode of death by lightning-stroke.[2]

Andrew Gordon, a Scottish Benedictine monk teaching at Erfurt, seems to have been the first to try the effect of electricity on the lower animals with fatal results. His cylinder electric machine gave currents strong enough to kill chaffinches. In the next year, 1746, Gralath similarly killed beetles, worms, and birds; Nollet noted that on dissection these birds showed ecchymoses similar to those seen on persons killed by lightning. Similar experiments were made by a number of people in the various countries of Europe, particularly in France, Germany, England, and Holland, where much general interest was excited by the recent progress of electricity; for at this time and for many years to come the science of electricity, such as it was, formed an ideal field for the activity of the practical joker. The results of these experiments narrowed the field of causes of death by lightning, and it came to be recognized that several of the current views were untenable. Thus Bidermann, in 1768, discussed them all under five different heads, rejecting many of them—for example, suffocation by concussion or compression or rarefaction of the air, combustion, apoplexy, congelation of the animal spirits. He concluded that lightning kills by a sudden injury to the nerves of the brain, caused by the rapid movement of the electric material, which abolishes their function; he believed that the nervous fluid was identical with or very nearly related to the electrical fluid. Abildgaard three years later proved that this was correct, and that shock to the nervous system was at any rate one way in which electricity, and therefore presumably lightning, might bring about death. He also made the very important observation that fowls killed by electric sparks remained dead if left alone; but that they could be recalled to life by the passage of another electric discharge through them from breast to back.

Brodie, in 1828, expressed the view that in most instances lightning killed by destroying the functions of the brain, and advised that the persons struck should be kept moderately warm, and have their lungs inflated by bellows so as to imitate natural respiration; similarly Auzouy (1858) and Dillner (1865) both laid great stress on respiratory paralysis in certain cases of death by lightning-stroke. In contrast to these interesting experiments of Brodie's may be quoted the gloomy and also erroneous views of two anonymous writers in the *Lancet* of 1830 and 1831. One says that speculating upon the mode in which lightning operates in producing death would be a vain and useless discussion; the intensity of the electric action instantly annihilates all connexion between soul and body, hence all means of resuscitation are vain. The other states that when the body is struck by lightning, complete death ensues; in asphyxia of this kind no vitality exists on which to act, for organic and animal life are both extinct. Oesterlen, in 1881, ascribed such deaths largely to an uninvestigated change in the blood, perhaps in the juices of the body in general also. Boellmann, in 1888, put death by lightning down to mechanical violence in the form of what he called cephalo-rachidian shock applied to the central nervous system through the cerebro-spinal fluid; he supposed the fluids in the lymphatic sheaths round the vessels to undergo a sudden increase in tension, thereby producing anaemia of the nervous centres and abolition of the function of the nerves. The part played by the heart and the continuance or stoppage of its action after a lightning-stroke does not seem to have attracted much further attention till many years later, though they are undoubtedly very important. Dillner (1865) laid great stress on it, assuming that the heart went on beating after apparent death in all persons who had been struck by lightning and yet were capable of being brought to life again. Should the heart cease beating for more than a short time, recovery would be, he considered, impossible. B. W. Richardson, in 1869, as a result of his experiments with a large Apps induction coil and Leyden jars, similarly attached great importance to the heart's action here, and stated that recovery was impossible if the heart was paralysed; and that in all cases where it was instantaneous, death by electric shocks was due to the sudden expansion of the gaseous part or atmosphere of the blood, combined in extreme degrees of shock with a sudden conversion of animal fluid from the fluid into the gaseous condition. He gives no detailed record, however, of the discovery of any such liberation of gas in the vessels of animals killed by electric sparks, though his papers are full of detail on other points. Here again we have a theory evolved from the imagination of its author, and lacking experimental proof of any kind. Dürck, in 1895, writing at a time when a good deal more had been found out as to the modes of death by electricity, came to the conclusion that death by lightning was due to permanent paralysis of the cardiac or the respiratory nervous centres, caused by the passage of the discharge; and Pélissié's conclusion was very similar.

### *Post-mortem Lesions after Death by Lightning.*

The lesions produced by lightning in fatal cases of lightning-stroke are of the most varied extent and description imaginable. One may begin a brief account of them by saying, *hibernicé*, that in a large number of cases no lesion whatever, either external or internal, may be found *post mortem*. Such cases are not at all rare, and have been recorded both in man and in domestic animals. Sestier, for example, found no external injuries in 19 out of 119 cases of death by lightning. The great majority of victims show superficial burns and scorchings of various depth and extent. Most commonly the burns are of the first or second degree, in the form of streaks that are taken to show the paths followed by the lightning, or in the form of isolated spots or areas. Singeing of the hair growing on these burns is highly characteristic of lightning-strokes, and may take place either with or without any singeing of the clothes in contact with the burnt skin, and also without any burning of the skin itself. Usually the burns are in the shape of bands or ribbons of hardened, discoloured, parchment-like skin, running down the trunk or legs. A very exceptional case is recorded by Cipriano, in which there were burns of the second degree on the neck, chest, and leg, while practically the whole of the rest of the body showed a burn of the first degree; the patient made a slow and difficult recovery. Vincent quotes the case of a woman who was struck and received burns of the first to the third degree from head to foot, and died from exhaustion after six months' suppuration. Less often the burns go deeper, and may even char the underlying bones or the tongue (Clark and Brigham) or the abdominal viscera. In many cases the deeper burns heal readily, if the victim survives; but in others slow healing with much pain and suppuration have been recorded. Patches of hair and of skin may be quite torn off. Persons struck or killed by lightning are said to exhale a peculiar or characteristic odour, oftenest described as resembling the smell of burning sulphur or of ozone; other writers compare the odour to such various smells as those of nitrous fumes, gunpowder accidents, acid, dilute sulphuric acid, sulphuretted hydrogen, nitrous acid, ammonia, electric sparks, and lighting matches, and it has also been described as *sui generis*.

Very characteristic, or even diagnostic, of lightning-stroke are the so-called "lightning-figures" often seen on the skin in both fatal and non-fatal cases. These consist of reddish, brown, or purple discolorations of the skin, described in different instances as resembling such things as coral, fronds of ferns, branches of fir-trees, trees, palms, pieces of outdoor scenery, or even "in outline a perfect map of North America, all of the important features being outlined with remarkable clearness."[174] In the eighteenth and the earlier part of the nineteenth century there was a great tendency to regard these lightning-figures as due to the direct transfer of particles from the neighbouring objects represented (trees, etc.) to the skin of the person struck, by some mysterious action of the lightning, which was even supposed to take the place of a photographic lens in some way. They are now thought with more reason to be analogous to the electric dust-figures, described by Lichtenberg, that indicate the distribution of electricity at a very high voltage on bad conductors. But it must be added that microscopic examinations of sections of skin showing these lightning-figures have not yet succeeded in demonstrating either their exact situation in the epidermis or cutis vera, or their mode of production. They may be the result of vasomotor paralysis. They do not seem to be generally due to haemorrhage (Haberda, Heusner, Schmitz), or to have any relation to the pressure of the clothes. They do not follow the course of the underlying bones, vessels, or nerves, as has been variously alleged on the strength of different isolated instances (Becher, Sonrier, Fischer). Mangin has suggested that they may be ideoplastic impressions, akin to hysterical stigmata in their method of production.

Considerably less common are lacerations of the soft tissues or the blood vessels, but when they do occur they are often very bizarre and striking. Lacerations of the scalp exposing the pericranium or bone are not rare, and in an unusual case recorded by Knaggs there was a lacerated wound of the right ear, which was almost torn off upwards. The formation of a haematoma in the neck, that might easily have been mistaken for an extensive bruise produced by mechanical violence, has been recorded (Macintosh, Niederheitmann); haemorrhages on either side of the dura mater are not rare, and bleeding from the external auditory meatus, with or without fracture of the bones of the skull, is fairly common. Lane described laceration of the membrana tympani. Very curious lacerations of the abdominal walls and thighs have been described by Dutt and others. In Dutt's case there was a lacerated wound five inches long two inches below the umbilicus; a penetrating wound of the abdominal wall two and a half inches long above and parallel to the left Poupart's ligament, had four feet of dark red, singed, and contracted small intestine protruding from it; and there was a four-inch lacerated wound in the left thigh below and parallel to Poupart's ligament. One might hazard the supposition that the victim in this case was struck while sitting or squatting on his hunkers. Wheeler described an instance in which lightning appeared to blow a cavity measuring three inches by one inch, and three-quarters of an inch deep, in the thigh; Vincent records an example in which six pounds' weight of flesh were lost from the thigh of a person struck by lightning.

To find a laceration in the heel or the sole, with or without comminution of the os calcis, is not very rare in persons struck when standing up or sitting out of doors, and may be taken as evidence that the electric discharge has changed its direction or met with increased resistance to its passage at this point. Penfold describes an instance in which the dense integuments of each heel "were cut as if with a sharp knife, and were torn open sufficiently to admit one's index finger easily, while the calcanea were comminuted into many pieces." The cut on the left heel was stellate, that on the right heel straight and in an antero-posterior direction. Similar cases have been recorded by Wilks, Daxenberger, Phayre, Davies, and others.

Lacerations of structures inside the body are not common, and when they do occur are not easily explained. Schneider has described rupture of the diaphragm, possibly by some sudden and violent change in the intrathoracic air pressure, in a soldier struck and killed while standing under a chestnut tree. Banham has met with a similar lesion in a horse, and quotes an example in which laceration and rupture of the heart was observed in three out of four horses struck and killed. I have been able to find only one instance of rupture of the heart by lightning in man—that recorded by Liman, who observed a hole two centimetres in diameter at the apex of the heart, with irregular walls and opening into both ventricles, which contained clots. Liman does not make any statement about the presence of blood in the pericardium in this case. A very curious instance has been reported in detail by Ouvrard, in which, although there was no external lesion of the thorax, the lower lobe of the right lung exhibited four wounds like those caused by small shot, and there was a haemothorax; the diaphragm below this was perforated, there was a slight tear in the liver, ecchymoses were seen on the gastro-hepatic omentum, there was a small round hole with bruised edges in the splenic region of the stomach, the left suprarenal and kidney showed ecchymoses, and the spleen itself was stripped of its capsule, which could not be found. The victim in this extraordinary case was seen to be struck, and cried out as she fell and died; the *post-mortem* examination was made within twenty-four hours. A small pulmonary apoplexy was found in Phayre's case. Another very unusual case was described by Claes. A sailor was struck on his ship, and showed characteristic ribbon-like burns and excoriations, due to the passage of the lightning down his trunk and limbs. He died in about twenty-four hours, after alternate periods of stupor and agitation, and towards the end with distended tender abdomen and stercoraceous vomiting. *Post mortem*, Claes found three pints of blood-stained serum in the abdominal cavity, with faecal matter, and exudative peritonitis on the intestines; there were six large black (and presumably necrotic) patches on the jejunum and ileum, in situations corresponding to the marks left by the lightning on the abdomen. It would appear, therefore, that the lightning in this case burnt the small intestine and allowed microbes to pass through its wall and set up a fatal peritonitis. Cases in which a fetus was killed *in utero* by lightning, while the mother was only rendered senseless for a few minutes and recovered, have been recorded by Franque and by Carpi; Harting describes the converse. In at least two instances women carrying children in their arms have been killed, the children being uninjured.

Injury to the tissues of the brain has often been assumed to be the cause of death by lightning, but the number of recorded instances in which it has actually been seen is small. Phayre described a case in which there was reason to believe that the lightning had entered the left side of the head; he found the left hemisphere to be wholly disorganized, an almost homogeneous liquid of deeply greyish colour, only a small part of the corpus striatum looking normal. Somewhat similar changes were noted by Johnston and by Dürck; Bauer found the brain very soft and anaemic in his case, and the cord had apparently deliquesced to a grey fluid substance. A doubtful case has also been recorded by Barnes; Dunscombe-Honeyball found the brain in parts almost diffluent in one of his fatal instances of lightning-stroke.

Fracture of bones by lightning appears to be common in animals, and is not rare in man. Extensive fractures of the skull were noted in Knaggs's case, extending from the left parietal eminence across the right parietal bone, in which fine fissures radiated from the main crack and down to the base across the middle fossa, the orbital plate of the frontal bone (as in Heffernan's case), and the cribriform plate of the ethmoid. Dunscombe-Honeyball describes two cases in which extensive fractures of the skull were found. An excellent diagram of the elaborate fissures of the skull in a case he describes is given by Schottin; in this instance two ribs were also fractured, but without injury to the underlying tissues. Gem has recorded fracture of the humerus and the spinal column. Fractures of the tibia, or of both the tibia and fibula, by lightning-stroke have been recorded by Roy, Wilks, and Penfold; in the last case the victim was sitting down at the moment when he was struck, and there was no contusion at the seats of fracture, so that one seems able to exclude the possibility that the fracture was due to falling or to the application of external violence in any way. To illustrate the extensive fractures of bones sometimes exhibited by animals I may quote Free, who describes the case of a man who was struck by lightning and rendered unconscious, and then developed acute Bright's disease. A horse that was with the man was struck at the same time as the man and was killed. Free says that "the dead horse was as soft as a jelly, partly owing to the fact that every large bone in its body was comminuted." The exact mechanism by means of which lightning fractures bones is obscure. In cases where the heel is lacerated and the os calcis comminuted, one may perhaps imagine that an extra development of heat and steam has taken place here, with the result that the electric discharge has, so to speak, blown its way out of the body. The example described by Clark and Brigham proves that enough heat may be developed in so deeply situated a bone as the orbital plate of the frontal bone to char it, so that it is not unreasonable to suppose that small steam explosions may result if the lightning develops a less degree of heat in a moist tissue. But it is not quite easy to imagine how the tibia and fibula could be broken, without showing any external injury, as in Penfold's case, if the fractures were caused by small steam explosions taking place inside these bones. Yet there is no alternative explanation to offer. For I do not think it is imaginable that any known forces of electric attraction or repulsion [37] could exert enough violence to break bones. At any rate, the physicists appear to know nothing of electric forces of the magnitude that would be required here.

In a few well recorded instances which are extraordinary almost to the point of being incredible, strokes of lightning have effected amputations. Sycyanko quotes a case occurring in Russia, in which a boy of 12, who had had a flexed and ankylosed right knee for some years, was struck when riding on horseback. He was thrown to the ground and rendered insensible. At the same time the lightning amputated his right leg just below the knee-joint, leaving the patella and the cartilaginous upper end of the tibia intact. The boy made a good recovery; the amputated limb was afterwards found near the spot where he was struck. Vincent refers to a case in which an arm was amputated by lightning, but he did not see it himself. Dunscombe-Honeyball records the fact that he has known lightning to amputate a man's fingers. There seems no reason to doubt that such amputations might be the results of local developments of heat by the passage of the lightning through the tissues, with the sudden production of steam or other hot gases in sufficient quantity to blow the limb off. The alternative explanations that these amputations are due to "electro-caustic action," or to violent electric repulsion, appear to me unsatisfactory.

Rapid putrefaction of the bodies of persons killed by lightning has occasionally been recorded, but is not of common occurrence. Rigor mortis, on the other hand, partial or of the whole body, may appear in a few minutes, and seminal emissions are not rare.

### *Evidence Derived from Deaths Produced by Sudden Electric Shocks.*

It seems likely *a priori* that electrocution by the sudden and violent discharges of Leyden jars, condensers, and induction coils—that is to say, by discharges of high voltage and very brief duration—is more likely than electrocution by industrial electric currents to resemble death by lightning-stroke. The experiments on death by these sudden discharges have already been laid before you; it is not necessary to do more than summarize them here, and to say that such deaths may be due either to primary arrest of the respiration, or to primary arrest of the heart's action by ventricular fibrillation. These discharges seem to produce a profound degree of nervous shock.

### *The Mode of Death by Lightning.*

It would seem as if sudden death by lightning might occur in at any rate three different ways—by failure of the heart, by failure of the respiration, and by failure of both together. In the vast majority of cases the senses are lost at once, and in most death takes place very rapidly if at all. The extreme suddenness with which it must have occurred, as proved by the natural position of the corpse and its placid expression, has often been noted. As is the case in non-fatal strokes, there is reason to suppose that the nervous system is profoundly affected, though no microscopic lesions may be demonstrable.

1. *Death by failure of the heart*, which may be supposed to be thrown into a state of fibrillation, is assumed to be the commonest mode of death by lightning; in man it is probably final and irremediable, although the respiration may continue for a short time. The face in these instances is pale, free from congestion.

2. *Death by failure of the respiration* from Brown-Séquard's inhibition, while the heart continues to beat until asphyxia stops it, would explain why so many of those killed by lightning present all the *post-mortem* appearances of death by asphyxia. Such deaths might be averted by artificial respiration, continued until the respiratory centre in the bulb has had time to recover from the injury inflicted on it by the stroke. In non-fatal cases it has been noted that the patients' symptoms were those of asphyxia or the breathing of irrespirable gases[44], [92]; Nick records an instance in which gradual failure of the respiration became complete in about four hours. Apparent death may last for three-quarters of an hour, yet be followed by recovery (Sahut). Kelly has described an instance where the heart was still beating ten or fifteen minutes after the stroke, though respiration

had ceased; but in this instance artificial respiration did not restore life.

3. *Death by Failure of the Heart and Respiration together.*—It is probable that this form of death occurs after lightning-stroke, just as it may after the passage of industrial electric currents; but I do not know of any evidence to prove that it does.

4. In a very few cases, mentioned already, gross lesions of the brain have been found *post mortem*, and may well have been the cause of death in these instances. The older *post-mortem* examinations very generally failed to bring to light any pathological changes in the central nervous systems of the victims of lightning-strokes. It is possible that the more delicate modern methods of investigation would not give such negative results here.

### *Prognosis.*

Unless sudden death follows, the probability that a person struck by lightning will recover is large; Dechambre collected 365 instances in which the immediate effects of the stroke were survived, and found that only 15 of these victims died subsequently from late effects of the lightning. It seems to be very generally assumed that immediate treatment would improve the prognosis considerably, and that many of the people killed by lightning are only apparently dead, and still capable of recovery if properly treated during the next few minutes. I do not know of any statistical evidence to prove this point.

### *Prophylaxis.*

The ancient Greeks and Romans protected themselves against lightning by the use of incantations and amulets, and by wearing the skins of animals like the seal, hippopotamus, and hyaena (Fougères) that were supposed to be immune to lightning-stroke; they also had the good sense to take refuge in caves or cellars during thunderstorms. An Etruscan—Tages—protected his landed property by setting up an ass's head as tutelary deity, suitably enough. In the Middle Ages flight to England was advised, as that country was supposed to be free from lightning—a view sadly contradicted by Müller in 1690.

At the present day only general advice can be given, as the accumulated records have shown that no place is completely protected against lightning. It is certainly safer to be indoors than out, and a large house is much safer than a shanty. The windows and doors of the room in which one is should be shut, and one should keep away from the walls, and particularly from the fireplace, because, when a chimney-stack is struck, the contents of the chimney and the fireplace are often blown out into the room and cause bodily injuries. A great many people have been struck in sheds and barns, especially when they have been near doors or windows, or in currents of air. Turley recommended the centre of a railway carriage at a distance from the engine as the securest place of all; Schefcik, a feather bed. To take refuge in the cellars merely to avoid a thunderstorm is not necessary as a routine, though in exceptional cases it may be advisable.

The advice given by various authors to persons caught out of doors in a thunderstorm is contradictory. It is probably unwise to take shelter in a shed unless one can get out of the way of doors, windows, and draughts while one is in it. A shed containing domestic animals is certainly more dangerous than the open. If one has to remain in the open, there are certain things that should be avoided at any cost. The first of these is the proximity of wire fences, because when such a fence is struck the electric discharge may be carried along the wires and cause death at a distance from the place actually struck. The second is proximity to such things as hedges, ponds and streams, isolated trees, crowds of people and herds of domestic animals. Crowds of people or animals seem to have a mild attraction for lightning, very possibly by virtue of the warmth and dampness they impart to the atmosphere immediately round them. Certain varieties of trees are less dangerous than others; in similar conditions the beech is much less often struck than any other tree that is common in Europe, while the oak is very many (perhaps forty or fifty) times more liable than the beech to be struck and injured. This may be because the electric conductivity of beech trees is low at all times of the year, beech wood being always rich in fat and poor in starchy matter.[26] Hence, if one has to take shelter under a tree, that tree should be a beech,[*] and one should not be near its trunk. But to take cover in a forest or wood is quite safe, as trees *en masse* are rarely struck. If one is in quite open country, there is nothing to show whether it is better to be on high ground or in a valley; it seems to be agreed that to lie or sit down is safer than to stand up, that umbrellas should not be hoisted, and that riders and drivers should dismount and not stay near their horses or conveyances. It has often been said that to have had the clothes thoroughly wetted by rain and rendered conducting gives some protection to people who are struck by diverting the path and violence of the lightning from the body to the clothes. I have found seven well-recorded instances in which the effect of the stroke was to blow all, or practically all, the wetted clothes off the body, by the generation of steam, as I believe. There can be no doubt that a part of the energy of the lightning was expended on the clothes in these cases, but three of the seven victims were killed notwithstanding. So the protection of wet clothes cannot be considered at all complete.

Vincent makes an ingenious practical suggestion—perhaps too ingenious. It has long been known, he says, that animals are more liable to be struck than men;

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[*] Compare the German proverb:

Vor den Eichen sollst Du weichen,
Vor den Fichten sollst Du flüchten,
Doch die Buchen sollst Du suchen.

hence one should always take a dog out walking in order that if a thunderstorm comes on, the dog, already the friend of man, may also serve as his lightning conductor. In these days, when vaccine therapy is so widely employed, it is not without interest to note that in South Africa both the Zulus and the Caffres inoculate themselves against lightning by rubbing into cuts the flesh of animals (bullocks) killed by lightning (Frazer).

### *Treatment.*

Persons struck and apparently killed by lightning should at once be given plenty of fresh air, their clothes should be loosened, and artificial respiration by Schäfer's or Sylvester's method should be applied and should be continued until either recovery occurs or cooling of the body and *rigor mortis* show conclusively that death has taken place. In the medical writings of from fifty to two hundred years ago one often sees bleeding recommended, and this might well be of service in those cases of lightning stroke in which the heart goes on beating while the respiration stops. If it were immediately—within a few minutes—available, to give strong electric shocks to the praecordia would be well worth trying in desperate cases. As regards other remedies—such as stimulants in all forms, hot or cold applications, the inhalation of pungent vapours—very many have been recommended, but none seem to have met with any success.

In conclusion, I may say that it is very highly improbable that any one of us will be struck by lightning. But to the attention of those who are struck and survive may be recommended the French superstition that such people have for forty days the power of curing all kinds of disease by "touching." I may quote for their encouragement the case[18] of a girl of 8 who was struck at Douai, and afterwards "touched" over 600 persons in this way; and, as it is recorded that the parents did not refuse the modest offerings presented by the visitors, one may assume that the girl "touched" their pockets as well as their persons. As regards those who are fated to be killed by lightning, the only consoling thought I have been able to find for them is taken from the recently published diary of Queen Victoria. On June 1st, 1838, the Queen wrote:[162]

"I told Lord Melbourne I never could forgive him for having stood under a tree in that violent thunderstorm at Windsor last year; he said, 'It's a hundred to one you're not struck,' and then added, smiling, 'It's a sublime death.'"

### LITERATURE.

[1] Abildgaard, P. C.: *Soc, med. Havn. collectanea*, 1775, ii, 157.
[2] Arago, F.: *Meteorological Essays*. London, 1855.
[3] *Arch. de l'anthropologie crim.*, Lyon, 1900, xv, 116.
[4] d'Arsonval, A.: *C. R. Acad. des Sciences*, Paris, 1885, c, 239.
[5] Idem, *C. R. Soc. de Biol.*, Paris, 1887, 8me sér., iv, 95.
[6] Idem, *C. R. Acad. des Sciences*, Paris, 1887, civ, 978.
[7] Idem, *Bull. de l'Acad. de Méd.*, Paris, 1892, xxvii, 424.
[8] Idem, *Arch. de physiol. norm. et path.*, Paris, 1893, 401.

[9] Idem, *C. R. Acad. des Sci.*, Paris, 1894, cxviii, 1139.

[10] Idem, *Bull. Soc. internat. des Elect.*, 1910, 355.

[11] Aspinall, F. B.: *Lancet*, 1902, i, 660.

[12] Auzouy: *Schmidt's Jahrbücher*, 1858, c, 78.

[13] BRITISH MEDICAL JOURNAL, 1861, ii, 98.

[14] Banham, G. A.: *Vet. Journ.*, 1881, 243, 297.

[15] Barnes, G. R.: *Med. Times and Gaz.*, London, 1868, i, 671.

[16] Battelli, F.: *Rev. méd. Suisse Rom.*, Geneva, 1899, xix, 605.

[17] Idem, *Congrès Internat. d'Elec.*, Berne, 1902, 583.

[18] Idem, *Richet's Dict. de Physiologie*, Paris, 1904, vi.

[19] Becher: *Aerztl. Rundschau*, München, 1897, vii, 529.

[20] Benjamin, P.: *The Intellectual Rise in Electr.* London, 1895.

[21] Bennett, H. C.: *Amer. X-ray Journ.*, 1897, i, 127; 1898, ii, 141.

[22] Bidermann, J. G.: *Caussas subitae mortis fulmine tactorum.* Lipsiae, 1768.

[23] Biraud, F.: *Thèse de Lyon*, No. 780, 1892.

[24] Bordier et Lecomte: *C. R. Acad. des Sciences*, 1901, 1295.

[25] Boruttau: Nagel's *Handbuch der Physiologie*, 1909, i, 239.

[26] Bourrot: Reported by Grange.

[27] Brauchbar, R.: *Über Unfälle durch hochgesp. elektr. Ströme.* Leipzig, 1901.

[28] Brodie, B. C.: *London Med. Gazette*, 1828, i, 79.

[29] Brouardel: Reported by Grange.

[30] Brown, H. P.: *Med.-Legal Journ.*, New York, 1888–1889, vi, 276.

[31] Brown-Séquard: *C. R. Soc. de Biol.*, Paris, 1850, i, 154.

[32] Buchanan, W.: *Lancet*, 1892, i, 629.

[33] Carpi, A.: *Lo Spallanzani*, Modena, 1874, xii, 551.

[34] Cipriano, C.: *Il raccogl. med.*, Forlì, 1892, 5 s., xiv., 274.

[35] Claes, E.: *Journ. de Méd. Chir. Ph.*, Paris, 1856, xxiii, 340.

[36] Clark, R. O., and Brigham, J. K.: *Lancet*, 1872, ii, 77.

[37] Colladon, D.: *C. R. Acad. des Sci.*, Paris, 1887, civ, 1136.

[38] Corrado, G.: *Arch. d'Électr. méd.*, Bordeaux, 1899, vii, 5.

[39] Idem, *Atti della R. accad. med.-chir. di Napoli*, 1898, 242.

[40] Coulter, F. E.: *Med. Herald*, St. Joseph, 1899, xviii, 483.

[41] Crile and Macleod: *Amer. J. Med. Sci.*, 1905, 417.

[42] Crossland, J. C.: *Columbus Med. Journ.*, 1892–1893, xi.

[43] Cunningham, R. H.: *New York Med. Journ.*, 1899, lxx, 581, 615.

[44] Darling, Frier, and Pedlow: BRIT. MED. JL., 1905, ii, 1522.

[45] Davies, J.: *Lancet*, 1838–39, xxxvi, 681.

[46] Daxenberger: *Aerztl. Rundsch.*, München, 1897, 289.

[47] Dechambre, A.: *Dict. encycl. d. sci. méd.*, 1880, vi, 272.

[48] Dillner, F.: *Ueber die Wirk. des Blitzes*, etc. Leipzig, 1865.

[49] Donlin, P. E.: *Medico-Legal Journ.*, New York, 1889, vii, 470.

[50] Dunscombe-Honeyball, O.: BRIT. MED. JL., 1900, i, 1153.

[51] Durand, J. J.: *Thèse de Paris*, No. 232, 1894.

[52] Dürck, H.: *Münch. med. Wchnschr.*, 1895, xlii, 716.

[53] Durrbach, F.: *Daremberg and Saglio's Dict.* Art. "Neptune."

[54] Dutt, O. C.: *Indian Med. Gaz.*, Calcutta, 1867, ii, 152.

[55] Eggleston, W. G.: *Med. Record*, New York, 1885, xxvii, 120.

[56] *Elektrotechn. Ztschr.*, Berlin, 1911, xxxii, 354.

[57] Emde, F.: *Electrotechn. Ztschr.*, Berlin, 1910, xxxi, 675.

[58] Farkas, E.: *Ungar. Arch. f. Med.*, Wiesb., 1894–95, iii, 320.

[59] Fischer: *Med. Ztg.*, Berlin, 1837, vi, 1.

[60] Fischer, J. G.: *Disp. physica de fulmine.* Jenae, 1665.

[61] Fougères, G.: *Daremberg and Saglio's Dict.* Art. "Fulmen."

[62] Franque, J. von: *Memorabilien.* Heilbronn, 1866, xi, 33

[63] Frazer, J. G.: *The Golden Bough*, Pt. V, vol. ii, 161. 1912.

[64] Free, J. E.: *Med. and Surg. Reporter*, Phila., 1887, lvii, 102.

[65] Gardé, P.: *Thèse de Paris*, No. 81, 1895.

[66] *Gaz. des Hôp.*, Paris, 1911, lxxxiv, 1237, 2028.

[67] Gem, W.: *Lancet*, 1909, i, 34.

[68] Gibbons, P. J.: *New York Med. Journal*, 1895, lxi, 482.

[69] Goelet, A. H.: *Atl. Med. Weekly*, Providence, 1895, iii, 241.

[70] Grange, E.: *Thèse de Paris*, 1884, No. 383.

[71] Idem, *Ann. d'Hyg. publ.*, 1885, 53, 303.

[72] Haberda, A.: *Wiener klin. Wchnschr.*, 1891, iv, 588.

[73] Hankel, E.: *Volkmann's Sammlung*, 1897-1900, No. 208.

[74] Hann, J.: *Lehrb. d. Meteorologie*, 2te Aufl., Leipzig, 1906.

[75] Harting: *Med. Ztg.*, Berlin, 1856, xxv, 249.

[76] Hedges, K.: *Modern Lightning Conductors.* London, 1905.

[77] Hedley, W. S.: *Lancet*, 1893, ii, 427; 1894, ii, 437, 655.

[78] Idem, ibid., 1895, i, 281; 1895, ii, 281.

[79] Idem, ibid., 1896, ii, 1630.

[80] Heffernan: Reported in *Lancet*, 1877, ii, 266.

[81] Henry, A. J.: *Loss of Life in the United States by Lightning.* Washington, 1901.

[82] Heusner: *Arch. f. klin. Chir.*, Berlin, 1884–85, xxxi, 659.

[83] Hoest, G. L': *Bull. Assoc. des Ingén. Élect.*, 1910, x, 9.

[84] Hoffa u. Ludwig: *Ztschr. f. rat. Med.*, 1850, 107.

[85] Hoffmann, C. F.: *De morte in fulmine tactis.* Halae Magd., 1766.

[86] Hoffmann, J. A.: *Quaest. phys.*, etc. Wittemberg, 1703.

[87] Hofmann, G. von.: *Eulenburg's Real-Encyclop.*, 1894, iii, 522.

[88] *Hospitalstidende*, Copenhagen, 1862, v, 61.

[89] Jack: *Allgem. med. Central-Ztg.*, Berlin, 1857, xxvi, 418.

[90] Jacobsthal, P.: *Der Blitz in der orient. u. griech. Kunst.* Berlin, 1906.

[91] Janichius, P.: *De fulmine disp. physica.* Dantisci, 1606.

[92] Jellinek, S.: *Elektropathologie*, Stuttgart, 1903 (Literature quoted); *Virchow's Archiv*, 1902, clxx, 56.

[93] Idem, *Lancet*, 1903, i, 357; *Wien. k. Wch.*, 1905, 1139, 1184.

[94] Idem, *Atlas der Elektropathologie.* Berlin u. Wien, 1909.

[95] Jenks, W. J.: *New York. Med. Journ.*, 1892, lv, 542.

[96] Jones, H. L.: British Medical Journal, 1893, i, 1318.

[97] Idem, ibid., 1895, i, 468.

[98] Johnston, J. W.: *Indian Med. Gaz.*, Calcutta, 1873, viii, 213.

[99] *Journal of the Royal Agricult. Soc.*, London, 1900, 3. s., x, 608.

[100] Kelly, B.: *Journ. Am. Med. Assoc.*, Chicago, 1903, xli, 1273.

[101] Kennelly and Alexanderson: *L'Ind. élect.*, Paris, 1911, 79.

[102] Kisling, J. J.: *De tactis fulmine.* Kiliae Holsatorum, 1673.

[103] Knaggs, R. H. E.: *Lancet*, 1894, ii, 1216; British Medical Journal, 1894, ii, 1236.

[104] Kratter, J.: *Wien. klin. Wchnschr.*, 1894, vii, 379.

[105] Idem, *Der Tod durch Elektricität.* Leipzig, 1896.

[106] Kronecker, H.: *Deutsche med. Wchnschr.*, 1884, x, 364.

[107] Lane, J. R.: British Medical Journal, 1872, ii, 114.

[108] Lauffer, C. A.: *Electrical Injuries.* New York, 1912.

[109] Lawson, R.: *Quart. J. R. Meteorol. Soc.*, 1889, 140.

[110] Liman: *Deutsche med. Wchnschr.*, 1885, xi, 529.

[111] Lodge, O. J.: *Lightning Conductors and Lightning Guards.* London, 1892.

[112] Lucas, C.: British Medical Journal, 1905, i, 134.

[113] McAdie, A. G., and Henry, A. J.: *Lightning and the Electricity of the Air.* Washington, 1899.

[114] MacDonald, C. F.: *New York Med. Journ.*, 1892, lv, 505, 535.

[115] Macintosh, D.: *Lancet*, 1864, ii, 118.

[116] McWilliam, J. A.: *Journal of Physiology*, 1887, viii, 296.

[117] Mache, H., und von Schweidler, E.: *Die atmosphärische Elektrizität.* Braunschweig, 1909.

[118] Mally: *Rev. de chir.*, Paris, 1900, xxi, 321.

[118a] Mangin, M.: *Ann. des sci. psych.*, Paris, 1897, vii, 213.

[119] Mann, J. D.: *Med. Chronicle*, Manchester, 1885, ii, 1.

[120] Marherr, P. A.: *Weiz's Neue Auszüge*, Leipzig, 1776, v, 22.

[121] Milham, W. I.: *Meteorology.* New York, 1912.

[122] Müller, A.: *De astrobolismo.* Francof. ad Viadrum, 1690.

[123] Münnich, J. A.: *Gründl. Bericht*, etc. Halberstadt, 1732.

[124] Nick: *Med. Corr.-Bl. des Würt. Aerztl. Ver.*, 1857, xxvii, 76.

[125] Niederheitmann: *Bericht Rhein. Med. Coll.*, 1833, 125.

[126] O'Neill, J. A.: *Atl. Med. Weekly*, Providence, 1898, x, 184.

[127] Oesterlen, O.: In Maschka's *Handb. ger. Med.*, 1881, i, 795

[128] Oliver, Sir T.: *Lancet*, 1911, i, 363.

[129] Oliver, T., and Bolam, R. A.: Brit. Med. Jl., 1898, i, 132.

[130] Ouvrard: *Nouv. Journ. de Méd. Chir. Ph.*, Paris, 1821, xii, 312.

[131] Pélissié, J.: *Thèse de Lyon*, No. 59, 1896.

[132] Penfold, O.: *Austral. Med. Journ.*, 1880, n.s., ii, 120.

[133] Phayre, T.: *Dublin Med. Press.* 1842, viii, 22

[134] Pla, E. F.: *Consideraciones medico-legales acerca de la muerte por la electricidad industrial.* Habana, 1891.

[135] Pockels, F.: *Meteorolog. Ztschr.*, Wien, 1901, xviii, 40.

[136] Prevost, J. L.: *Rev. méd. Suisse Rom.*, 1898, xv, 545.

[137] Prevost, J. L., et Battelli, F.: *Rev. méd. de la Suisse Romande*, Geneva, 1899, xix, 545.

[138] Idem, *C. R. Acad. des Sci.*, Paris, 1899, cxxix, 651, 1267.

[139] Idem, *Journ. Phys. et Path. gén.*, Paris, 1899, i, 1085, 1114.

[140] Priestley, J.: *The History of Electricity.* London, 1767.

[141] Rasbach, J. C.: *De eo quod medicum decet circa fulmine tactos.* Erfordiae, 1737.

[142] Richardson, B. W.: *Med. Times and Gazette*, London, 1869, i, 511, 595; ii, 183, 373.

[143] Robinovitch, L. G.: *Sommeil électrique.* Nantes, 1906.

[144] Röser, C. J.: *Disp. phys.-med. de fulm.* Regiomonti, 1704.

[145] Roy: *Rec. de mém. de méd. chir. pharm.*, 1864, xii, 231.

[146] Sahut: *Soc. des Sci. Méd. de Gannat*, Moulins, 1874, 40.

[147] Schefčik, J.: *Wiener med. Presse*, 1877, xviii, 814, 847.

[148] Schmidt, K. E. F.: *Meteor. Ztschr.*, Wien, 1905, xxii, 362.

[149] Schmitz, W.: *Deutsche Med.-Ztg.*, Berlin, 1887, viii, 821.

[150] Schneider, S. A. J.: *Deutsche Ztschr. f. d. Staatsarznk.*, Erlangen, 1870, n. F., xxviii, i, 161.

[151] Schottin, D.: *Med. Convbl.*, Hildburghausen, 1831, i, 1.

[152] Schumacher, E. D.: *Unfälle d. elek. Starkströme.* 1908.

[153] Sheild, M., and Delépine, S.: BRIT. MED. JL., 1885, i, 531.

[154] Shettle, R. C.: *Lancet*, 1895, ii, 694, 809.

[155] Sonrier: *Gaz. des Hôp.*, Paris, 1872, 833.

[156] Stanton and Krida: *Med. Record*, 1910, 896.

[157] Stock, J. C.: *De fulmine*, etc. Jenae, 1734.

[158] Sutherland, W. G.: *Lancet*, 1893, ii, 1033.

[159] Swinton, A. A. C.: *Lancet*, 1893, ii, 957.

[160] Sycyanko: *Berl. klin. Wchnschr.*, 1868, v, 227.

[161] Tatum, E.: *New York Med. Journ.*, 1890, li, 207.

[162] *The Girlhood of Queen Victoria.* London, 1912, i, 337.

[163] Thomson: *Trans. Amer. Electrotherap. Assoc.*, 1894, iv. 261.

[164] Thys: *Ann. de la Soc. de Méd. Prat.*, Malines, 1851, ix, 389.

[165] Trotter, A. P.: *J. Inst. Electr. Eng.*, 1902, xxxi, 762.

[166] Trowbridge, J.: *Mem. Amer. Acad. of Arts and Sci.*, 1908, xiii, 185.

[167] Turley, E. A.: *Med.-Chir. Review*, London, 1844, xl, 177.

[168] Verhoogen, R.: *Journ. de méd. de chir. et de pharm.*, 1894, 729.

[169] Vincent, F.: *Gaz. des Hôp.*, Paris, 1885, lviii, 724, 755, etc.

[170] Idem, *Gaz. des Hôp.*, Paris, 1892, lxv, 928, 958, etc.

[171] Vollmar, J. G.: *De fulmine tactis.* Argentorati, 1765.

[172] Weber, L.: *Schr. d. Naturwiss. Schleswig-Holst.*, 1878, 99.

[173] Weiss, G.: *Bull. Soc. Inter. des Électr.*, Paris, 1911, i, 417.

[174] Wheeler, W. M.: *Med. Brief*, St. Louis, 1896, xxiv, 1177.

[175] Wilks, G., *Lancet*, 1879, ii, 655.

[176] Witz, A.: *Ann. de psych. et d'hypn.*, Paris, 1893, n.s., iii, 193.

[177] Zacon: *Bull. Soc. Internat. des Électr.*, 1911, i, 437.

[178] Zwaluwenberg: *Journ. Amer. Med. Assoc.*, 1903, 967.