death, in these animals, the production of asphyxia by the use of high-pressure currents would be necessary.

In determining the action of a strong, continuous current upon the cranio-cervical portion of the nervous system, Cunningham placed the contacts directly upon the exposed brain and spinal cord, thereby minimizing the resistance and acting directly upon the nerve centres. The passage of a current of 1.1 amperes for one minute directly through the cerebrum, medulla, and upper cord resulted in the usual deep inspiration followed by expiratory standstill, while the current was still flowing. If the current was not kept applied for too long a time, the respiratory movements generally recommenced a few moments after its removal. At first these movements were feeble, but gradually they resumed their normal rhythm, if the electrode had not been pressed with undue force against the brain. Even when the dose was 1.6 amperes, after the current had been on for several seconds, respiratory inhibition was overcome and pronounced respiratory movements began while it was still flowing. As a rule, however, inhibition of the respiratory centre during contact was maintained by a current of 1.5 amperes.

The blood pressure behaves differently when the contacts are directly against the brain and spinal cord, from what it does when they are placed simply against the head and chest;—*i.e.*, after a slight rise coincident with the general tetanic spasm of the muscles, produced always by the closure of the circuit, the pressure falls slightly; it then rises to a considerable height, often twice or thrice its original height, if the circuit is kept closed for fifty seconds. If the current is broken at this time it may or may not continue to rise for a few moments, but after this it quickly returns to the normal. On the other hand, if the flow of the current is continued for four or five minutes the blood pressure slowly diminishes, the cardiac action becomes progressively more labored and slower, and finally ceases. If artificial respiation is maintained, this enormous rise in the pressure does not take place. If the current is discontinued after the lapse of a minute, the inhibited heart action gradually disappears and respiratory movements, at first slow, soon become natural.

The asphyxia from inhibition of the respiratory centre appears to be mainly responsible for the increased blood pressure.

These experiments demonstrated the ability of a strong, continuous current passed through the brain and upper part of the cord to kill; but that the mode of death is quite different from that which takes place when the heart lies in the conducting path and is traversed by the current. In the former the lethal effect is plainly the result of asphyxia due to a respiratory inhibition, while in the latter the lethal result, even from moderate currents continued for a short period, is due to the permanent stoppage of the heart's co-ordinated action, the central nervous system dying from anæmia.

Cunningham's experiments, in common with all others in which these points have been observed, show that a greater amperage is necessary to produce death when the current traverses the supreme nerve centres than when it traverses the heart. In his experiments, the relations were 1.1 to 1.6 in the former as against 0.3 to 0.65 ampere in the latter instance. His conclusions are embodied in the following summary:

"1. Industrial electric currents which traverse the whole body transversely or longitudinally in sufficient intensity kill because fibrillar contraction of the heart is produced and not, as has been hitherto surmised, by producing a total paralysis of that organ or killing it outright.

"2. Such currents neither kill the central nervous system outright nor paralyze it instantaneously. Death of the nervous system from such currents is due to the total anæmia following a sudden arrest of the circulation.

"3. In rare instances, when an electric current traverses only the cerebro-cervical portion of the nervous system in considerable intensity and for a considerable length of time, it may kill by asphyxia consequent to more or less complete inhibition of the respiratory movements, which occurs chiefly during the passage of the current. No existing facts warrant the conclusion that the medullary respiratory centre is paralyzed or killed in such conditions.

"4. Industrial currents are practically non-lethal to frogs and turtles, as the condition of fibrillation quickly and spontaneously disappears from their hearts after the current has ceased to pass. Such animals, of course, can be killed by the very prolonged application of a current of moderate intensity, or by one of enormous voltage and large intensity.

"5. Strong electrical currents applied to the surface of the skin affect the heart in the same manner as currents of less strength do when they are applied directly to the exposed heart.

"6. It may be possible for an electric current of enormous intensity and electromotive force to produce instantaneous death either by its disruptive action or by producing an instantaneous heat coagulation of the cellular constituents of the body. Industrial currents do not kill instantly, although as a result of their action death rapidly occurs. The experience of individuals who have recovered from severe electric shock indicates that such a mode of death is not a painful one.

"7. Spontaneous recovery of the dog's heart from fibrillation produced by strong currents is rare. Spontaneous recovery of the dog's heart from fibrillation and restoration of the arrested circulation after the external application of a strong current for two or three seconds appears not to exist.

"8. Artificial recovery of the fibrillating heart of the dog, with restoration of the circulation and recovery of the nervous system, can be accomplished by the method described in this paper, provided the duration of the shock is short and the procedure is begun immediately after the cessation of the current."

Clinical Manifestations in Electric Shock.—As the result of electric shock in both animals and man there are distinguished five stages of effects: Muscular contractions; clonic convulsions; tonic convulsions with momentary stoppage of respiration; general inhibition of respiration and of the nervous system, but without convulsion; and lastly complete stoppage of the heart's action.

When a strong current is brought to bear upon the subject there is a strong tetanic contraction. Sometimes, not always, when the circuit is broken, a deep respiration takes place followed by an expiratory cry. In the tabulated list of accidents it is noticed in but one instance (Case 4).

Cunningham describes the clinical manifestations in a case of electric shock of which he was a witness. An electrician who was on the point of removing a defective brush from the motor of a trolley car was partially beneath the car, with his right hand on the brush, when he inadvertently rested his left hand on a live rail; immediately his muscles became tetanic and he was thrown backward in an instant, thus severing his connections with the live contacts. Syncope occurred in a few moments, and during its continuance the respirations were at first rather rapid, later possibly a little slower and shallower than normal. His pulse was very soft, rapid, and slightly irregular, but soon consciousness returned. He then vomited once and was able to get up by himself, though he complained of feeling extremely weak. The next morning he stated that the prostration had persisted for about two hours and then disappeared, leaving him as well as ever. The pressure of the current in this instance was 500 volts, but, by reason of the position and nature of the contact (hand-to-hand, dry skin), the resistance was so great as to minimize the current so that probably not more than a small fraction of an ampere passed through him. These effects, Cunningham concludes, are produced as follows: As the accidental contact with the live wires, rails, brushes, etc., is made, more or less pronounced general muscular contractions occur. Respiration may be inhibited after a deep inspiration and expiration, but is quickly resumed. From the moment the shock begins there is temporary inhibition of the heart's action accompanied by a fall in the blood pressure. After exposure to a non-lethal current of brief duration, both normal heart beat and blood pressure are soon recovered. Consecutive to diminution of the blood pressure and disturbance of the cerebral circulation, more or less syncope frequently occurs, but this is gradually recovered from and normal circulation is re-established. When a large portion of the current traverses the brain (head and back of neck contact, for example) the underlying sensory-motor centres of the brain may be stimulated to such a degree that in a few moments one or more general convulsions, quite similar in many respects to an epileptic fit, may be produced. If syncope had not been induced previously by the cerebral anæmia resulting from the lowering of the blood pressure and disturbed heart action, the onset of a general convulsion in all probability would be accompanied by complete loss of consciousness. Loss of consciousness is not confined to fatal cases, and the longer it continues the less danger there is to life. It rarely persists longer than a few minutes, but may be followed by headache for several days—possibly by vertigo. In Cases Nos. 2 and 8 (see tabulated list of accidents) loss of consciousness was prolonged, and in No. 8 not completely recovered from for twenty-four hours. It is very rare that sensory or motor paralysis appears as the result of an electric shock. In Case No. 2 (see tabulated list of accidents), there was slight sensory disturbance; in Case 10 motor paralysis, and in Case 21 both sensory and motor paralysis. Convulsions sometimes occur and seem to bear a relation to the contacts. If the energy is expended upon the supreme centres they are more apt to appear. In Case No. 2 (tabulated list of accidents), the man was blind for forty-five minutes, delirious for several hours, and for several hours unable to speak. In No. 7 the pupils were observed to be dilated —a condition often noted.

In most cases no permanent ill effect appears to follow an electric shock. On the other hand, Case 10 (tabulated references) claimed to "feel better in general health" than before. This is not an unreasonable statement in view of the physiological action of an electric current in a therapeutic dose.

The following case, however, suggests the possibility of the development of traumatic neuroses from electric shock in common with other forms of injury: A workman while at work on an electric transformer, standing on a perfectly dry floor, received a shock of 3,000 volts, with 100 interruptions per second. He lost consciousness for twenty or thirty minutes, and then he was able to get up and walk to the carriage. For about two months he was treated for burns which he had received, and recovered sufficiently to resume his work. Soon afterward he developed a neurosis associated with hysteria and neurasthenia. He presented a concentric narrowing of the field of vision, clonus of the patella, irregularity of the pulse, increased reflex action and muscular irritability, vaso-motor disturbances and weakness of the extremities. In other words, this was a typical case of traumatic neurosis developing several months after the injury.

The patient finally recovered under bromides, massage, and electricity.*

Post-mortem Findings.—The post-mortem findings in death from electricity present fairly uniform conditions:

1. Rigor mortis is always quickly established. Tatum found it generally established in the second or third hour, but it occurred in fifty minutes in one instance. It was established in every instance without any relation that could be traced to the strength of the current. It was never absent where it was sought for, and presented nothing noteworthy in its character save promptness of appearance.

2. The extent of injury to the skin in electrical injuries and fatalities varies greatly. The points of penetration of the current are always evidenced by burns of greater or less degree. The place of exit is less frequently marked by burning than is that of entrance. The evidences of burning may be very well marked or they may be, on the contrary, very slight; and they are by no means proportional to the gravity of the accident,—depending as they do upon the condition of the skin, whether moist or dry, as well as upon the nature and duration of the contacts. In Case No. 6 (see tabulated list of accidents) —pressure not given, death instantaneous—a small blister only was found on the left index finger, while in Case 14 (contact with a 2,000-volt continuous current) the thumb of the right hand with a portion of the joint was burned off. Intense cutaneous congestion and patches of ecchymosis are often found (see Cases 5 and 6, tabulated references).

3. As to the heart, Tatum found that if the body was opened immediately after a sudden death the heart was always found to be in a lax condition, both ventricles distended with blood, and both auricles pulsating rhythmically. If the examination was delayed a quarter of an hour or more, or if it followed a less rapid death, the left ventricle was sometimes found empty and more or less firmly contracted. The observations of other experimenters point to practically the same condition of the heart,—that, namely, which follows death by apnœa.

4. Blood-vessels and blood: The arteries are often contracted to their smallest calibre and the blood is crowded into the very large veins of the trunk and head. There is sometimes rupture of the blood-vessels (see Case 11, tabulated references, and also twenty-fourth electrocution). Tatum found the blood in the arteries bright red if the body was opened at the end of a minute or so after death; but if the examination was delayed for a few minutes the blood was quite black. On free exposure to the air it turned scarlet as promptly as other venous blood and clotted quite normally. There is an absence of hæmoglobin from the blood in death due to electricity, as in apnœa. Great fluidity of the blood and absence of clots are marked features in death from industrial currents. Cases 6, 7, and 15 of the tabulated references are excellent illustrations of this post-mortem condition.

5. Viscera: The viscera are frequently found congested and sometimes engorged with blood (see Cases 7 and 15 of the tabulated references).

6. The nervous system does not present any gross lesions, nor have any microscopic evidences of changed conditions been found. That molecular changes which are not determinable by present methods may be found is very possible. On the other hand, there may be gross disorganization of the brain, with destruction of the peripheral cortex and intracranial effusion of blood. The latter, with rupture of blood-vessels, was a marked feature in the twenty-fourth electrocution in the State of New York. Slight hemorrhages in the walls of the fourth ventricle and in the meningeal coverings are not rare.

Prévost and Battelli never found intracranial hemorrhage when elevation of the temperature had been avoided, although there was sometimes hyperæmia of the meninges. In Case No. 5, of the tabulated references, there was hemorrhage into the common sheath of the carotid and the vagus nerve on both sides of the neck, and there were also symmetrical hemorrhages along the spinal cord.

The post-mortem findings in Nos. 5, 6, 7, 11, and 14 of the tabulated list of accidents—in which cases the examination was made at times varying from ten hours to three days after the occurrence of the accident—may be summarized as follows:—In every instance there were marked rigor mortis and great cutaneous congestion, with patches of ecchymosis; the heart was uncontracted and empty; the blood was markedly fluid and would not coagulate; there was but little blood in the large blood-vessels; the viscera were engorged with blood. In some instances there were ruptures of small blood-vessels, and burns of greater or less severity were found on different parts of the body. In Case No. 7, the vessels of the

*Brustein, S. A.: "On the Action of the Electric Current of High Tension (Pressure) on the Human Body." Vratch, April 21st, 1901, vol. xxii., No. 16.

scalp, meninges, and brain were congested and full of liquid blood, and so also were the lateral sinuses. This accident from a 2,000-volt current seems to have affected the brain instantaneously, as the subject fell as in a fit; but the heart and respiration did not stop until five minutes later.

Is Death Instantaneous and Painless?—The conclusions of Houston and Kennelly, whose experiments were undertaken to answer the above question, are as follows:

"1. That the passage of a sufficiently powerful alternating current through the body of an animal is followed by instantaneous, painless, and absolute death.

"2. That consequently where electrocution is properly carried out there is not even a remote possibility of subsequent resuscitation of the criminal.

"3. That in case of accidental contact, where the current passing is not excessive, it is quite possible that death may be apparent only, and that the method of artificial respiration suggested by Dr. D'Arsonval should invariably be followed."

In the analysis which the writer has made of all the data at her command, and in the evidence furnished by experiments upon animals, by accidental contacts of man with industrial currents, or by electrocutions, there is nothing which contradicts the conclusions just stated. There may be a difference of opinion as to what is meant by instantaneous death, although the experiments of these authorities showed immediate and absolute arrest of the cardiac function.

So far as the ego is concerned, death is no doubt instantaneous, but from the physiological point of view this need not necessarily be true. Physiological death is not, judging from the evidence in many instances, established until some time after conscious death. The results of Cunningham's experiments show that all the tissues of the body, the nervous system and the heart included, are not killed instantaneously, and that the respiratory centre continues to act more or less perfectly for some moments after the cessation of a lethal current. On the other hand, in the experiments of Houston and Kennelly, the dogs, with the exception of the one in which the current was passed through the head, died instantly —*i.e.*, no cardiac movements nor respiratory effort occurred after the application of the current.

From an analysis of nineteen cases the subject of severe but non-lethal shocks, Cunningham concluded that there was ample time before loss of consciousness for the recipient of the shock to become aware that he was or had been in contact with an electric current. Every one of the nineteen individuals experienced some sort of sensation (for description of sensations and conditions produced from an electric shock experienced by a physician, see Case 21, tabulated references of accidents) before consciousness was lost,—a sensation which was described by them as similar to that produced by catching hold of the electrodes of a small but strong medical induction coil. Usually a sensation of tremendous pressure is felt across the chest. It does not follow, however, that a lethal would be accompanied by as much sensation as a non-lethal shock. Indeed, to the writer's mind, the question of physical pain from electrocution is not only not proven by the evidence, but disproved. "With the nearly instantaneous extinction of the cerebral circulation, such a rapid and complete cessation of the functions of the cerebral cortex occurs that no time remains for sensations other than those of an electric current to be felt before the cerebral perceptive nerve centres have ceased to act." The suffering must be the mental anguish and consequently of the same character as that experienced by the condemned criminal, no matter how death is to be brought about.

When the enormous pressures used in the industries are considered, it does not seem difficult to believe that death may be instantaneous, even from accidental contact. Continuous currents of 10 kilo-volts are sometimes used in series arc lighting—ordinarily only 3 kilo-volts are used. The ordinary limit, however, in the case of a continuous current is but 600 volts. In the case of alternating currents the pressures are very much greater and go up to 40 or even 60 kilo-volts in the long-distance transmission of power.

In the writer's opinion, based upon an analysis of experimental work, accidents from industrial currents and electrocutions, as well as upon the experience of those who have suffered from electric shocks of varying severity, there seems to be no good reason for doubting that death from an electric current, so far as consciousness is concerned, is instantaneous and unaccompanied by any pain save the possible cerebral perception of an electric shock.

As to Spontaneity of Recovery.—Many instances of spontaneous recovery after accidental contact with industrial currents of high pressure are a matter of record. In these cases, as has been pointed out, but little—possibly none—of the current has traversed the heart, by reason of the position and the nature of the contacts. Therefore, the co-ordinate contractions of the heart are not stopped. Or if the current has traversed the heart, it may not, for some reason inherent in the individual, as suggested by Prévost and Battelli, have established well-defined ventricular tremulations; and consequently, in such a case, after the flow of the current has ceased, recovery takes place. Whether the recovery is spontaneous or is influenced by artificial respiration, depends no doubt upon the degree of inhibition of the respiratory centre and the consequent asphyxia. If the nervous system has suffered profoundly before the current is stopped, spontaneous recovery is extremely doubtful, just as it is in profound asphyxia from other causes. In some instances, apparent death from lightning is but a condition of suspended animation, and it is, therefore, well always to practise artificial respiration in all cases of lightning stroke. But where the electrical energy has expended itself in producing a disruptive action, or mechanical lesions of vital organs, efforts of resuscitation are useless.

In Case No. 10, of the tabulated references, recovery was spontaneous; in Nos. 3 and 8, artificial respiration was practised; while in No. 2, morphine, brandy, and sinapisms to the præcordium were used. It is possible that spontaneous recovery might have taken place in all four instances.

On the other hand, when a strong current has passed through the heart—Cunningham places it at from 1 to 8 amperes—the organ goes at once into a condition of fibrillar contraction. He considers it most improbable that, after the brief passage of such a strong current, spontaneous recovery of the highly organized heart, with complete restoration of the extinguished circulation, would ever take place. As a matter of fact, he concludes, from his experiments upon fibrillating excised dogs' hearts (with artificial perfusion of blood), that such recovery would never take place spontaneously in the brief interval which exists before the vitality of the central nervous system has become so reduced as to be incapable of recovery. After the arterial blood pressure has disappeared, "I have never seen," says Cunningham, "a single instance, in a series of more than thirty experiments on dogs, in which spontaneous recovery of the co-ordinated contractions of the heart, with restoration of the general circulation, occurred. The simpler the heart the more rapid the recovery; therefore, the spontaneous recovery in frogs after a severe shock."

In electrocutions, Cunningham believes that if the autopsy is deferred for one hour and no signs of recovery are then manifested by the executed criminal, one may rest assured that recovery could not take place either spontaneously or by artificial means. He points out, however, that the excised heart would probably be made to beat again co-ordinately if it were perfused with blood.

Resuscitation.—As to resuscitation after electric shock, an analysis of the work of the different experimenters instanced in this paper points very clearly to the inefficiency of artificial respiration when there has been a purposed application of a lethal current; and an analysis

of the accidents occurring from electric currents points to the same conclusion.

D'Arsonval, in 1887, and later in 1894, voiced the opinion that after an electric shock the individual should be treated by means of artificial respiration, as in the case of the drowned, "since the condition after the shock is one of suspended animation, in which the respiratory function is suspended."

In the light of the experiments quoted in this paper, such a procedure can be regarded only as unphysiological and ineffective. In those cases in which the heart happens not to be in the direct conducting path of the electrical current (as in brain and spinal-cord contacts), and consequently feels the influence of the latter in a diminished degree, it is quite possible that the establishment of artificial respiration may be found useful. In accidents in which there is but a momentary contact with a current of high pressure artificial respiration is always indicated. But when the current has exerted its power mainly upon the heart and the latter has ceased to beat, artificial respiration will do no harm, but we can scarcely expect that it will do any good. Finally, in those cases in which there has been an actual mechanical and disruptive action, death is absolute and artificial respiration valueless.

It has been shown that after a brief application of an electric current to the exposed heart of a dog, a brief period of fibrillation may be followed by the reappearance of a few co-ordinated heart beats (Herbst and McWilliams). "Should this occur," says Cunningham, "before the general blood pressure has become greatly diminished, it is possible that the disturbed circulation might be restored. Once, however, it has fallen to zero the right heart becomes so overdistended with venous blood, which may coagulate in a few moments, that even though one or more feeble, co-ordinated beats occur, the overfilled right heart cannot empty itself with sufficient rapidity through the lungs so that the left ventricle can produce enough pressure in the aorta for the necessary blood to be forced through the coronary circulation rapidly enough for the spontaneously restored co-ordinate contractions to be maintained."

In those cases in which artificial respiration is indicated, inhibition of the respiratory centre (Laborde's method), which Laborde called the physiological treatment of death (*i.e.*, rhythmic traction of the tongue), should be practised.

When the action of the electrical current has been upon the heart, the indication is to restore the circulation—not only of the nervous system, but also of the heart—as quickly as possible, in order that the latter may quickly recover its co-ordinated contractions. There is but one way in which this may possibly be accomplished, viz., by the establishment of a temporary circulation of a fluid which will feed the heart and nervous system until the former has sufficiently recovered to perform its function. "Of all the various fluids recommended for intravascular injection, the defibrinated blood from another animal of the same species is the only one capable of maintaining the circulation. The mere arterial injection of warm, defibrinated blood would not answer, for the injected blood, after passing through the capillaries, accumulates in the venous system and in the distended right heart until finally the veins rupture or the general vascular pressure equals the pressure of the blood being injected. The overdistention of the heart prevents the re-establishment of the coronary circulation, an element of great importance in establishing the co-ordinated heart beat.

"This enormous increase in the pressure could be prevented only by the establishment of an outlet in the right ventricle for the injected defibrinated blood. With such an outlet the oxygenated blood would circulate through the coronary arteries and the nervous system, but naturally there would be no pulmonary circulation. Under these circumstances artificial respiration would be of no avail, save possibly to assist the outflow from the heart."

Owing to these very serious obstacles the matter of resuscitating the heart's action by perfusion of defibrinated blood becomes at once absolutely impracticable. The solution of the problem as a mere laboratory experiment is a totally different matter.*

The observation of the fact that the employment of oscillatory currents of high potential favors the recovery of a fibrillating dog's heart, and of the results obtained by the use of such currents in therapeutic work, suggests the possibility that a similarly favorable effect may be produced in the human being in cases in which the heart has not been too profoundly affected. Experimental work in this direction could not fail to be of value, no matter what might be the conclusion reached. Further experimental researches into the mechanism of death are also desirable. However, if we are to obtain further knowledge as to when an attempt at resuscitation is likely to prove successful, we must not only extend our experimental researches, but we must also observe with greater care and with more scientific accuracy the phenomena resulting from accidental contact with industrial currents, and we must study more closely the post-mortem conditions. It is also desirable that accurate observations and records should be made of all the conditions of the conducting circuit, of the character and pressure of the current, of the current strength or amperes, of the position and nature of the contacts, and also of the duration of the contact. Such accumulated evidence should be of value in establishing the fact of death and determining its mechanism, or in indicating, in cases of apparent death, the phenomena which warrant the hope that efforts at resuscitation will prove successful.

The following table of accidents from electric currents has been largely made up from cases described in medical and electrical journals. In all accounts of accidents, whether mortal or not, the data given have been found to be very meagre, and the table, though very incomplete, is as full and exact as the data furnished would admit of. There is also in both medical and electrical literature a striking dearth of detailed cases and even of any mention of accidents, which leads to the assumption that they are comparatively rare.

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* For a detailed account of the apparatus to be used in the laboratory for the recovery of animals the subject of experiment, see Cunningham's article, New York Medical Journal, October 21st, 28th, 1899.