

be far worse than even the results attendant upon the passage of such momentarily great currents.

In Table IV, column 1 gives the size in B. & S. gauge of the copper wires; column 2 gives the circular mils; column 3 gives the minimum fusing current as determined by Preece's law, $C = 10244 d^{\frac{3}{2}}$, and column 4 gives the fusing currents on 500-volt short-circuits as determined by the law, $C = 470,000 d^2$, enunciated by the writer. Fig. 2 graphically illustrates the pronounced disparity of the two laws, showing the curves of currents for diameters: Curve A for Preece's law, and curve B for the law as discovered by the writer. The natural conclusion arising from a knowledge of the above data is that fuse metals are under no circumstances to be considered in the light or nature of a protection.

DISCUSSION.

DR. LEONARD WALDO:—There is one matter that might be commented upon here. Aluminium is coming to play a more and more important part in electrical work, and a word of caution ought to be uttered in regard to the accurate use of the term. If you take a table such as given here, it is of great importance to know just exactly what that aluminium is. Assume that it is commercial aluminium and has a purity of 98 per cent., and that the balance of the ingredients are iron and silicon, which they probably are, and have a resistance about three times as great as that of pure aluminium under the same conditions, while the melting point is only slightly increased. You have, therefore, in questions of fuses, a very marked change in the relations of your aluminium. And aluminium wire that is sold is very often strengthened by the addition of small percentages of copper or nickel, or some of the other metals which are used to give strength to pure aluminium, and those wires pass also in the market under the term "aluminium" wire. I offer this comment as a caution in the use of the term "aluminium," and the use of aluminium wire under such conditions. If Mr. Harrington could furnish an analysis, or in some way define the term "aluminium wire," it would take its place then in terms with copper, which is pretty well understood, and with commercial lead and tin; but even in the case of lead and tin it would be well to indicate the brands, because they vary quite a good deal; and in all questions of resistance, the purity of the metal is of the first consequence.

MR. CHARLES P. STEINMETZ:—In listening to this paper I must confess that I have not quite understood what the writer intends to prove, and, therefore, I beg to be corrected if I am mistaken in my conclusions. But as I understand it, the writer connected

fuses of various diameters and of various metals into a 500-volt circuit, closed the circuit through the fuses, and observed by means of a magnetic circuit breaker the maximum current which would flow through the fuse at the moment of closure of the circuit, before the fuse is blown.

Assuming even that the magnetic circuit breaker is a suitable means by which to determine instantaneous flow of current—which it is not, because the magnetic circuit breaker is like the fuse, an integrating apparatus, reacting upon the total amount of power passing through, and thus allowing a much larger current to pass for a very short time—assuming even this, then what do we have in reality? We have a 500-volt circuit closed by a fuse, and also by the leads which, compared with the fuse, may or may not be of negligible resistance. In such a circuit, as in any other circuit, the current flowing is equal to the E. M. F. divided by the resistance, and what the writer has observed is merely Ohm's law.

In consequence thereof, if the cross-section of the fuse is half as large, and the leads negligible, the resistance is twice as high, and thus the current half as large, and if a different metal of higher resistance is used, the current will be different also. But the constants derived in this way do not mean anything whatever. If, for instance, the writer had happened to use fuses of twice the length, all the currents, and thus all the constants given in the paper, would have been entirely different. So I do not see how any conclusions can be drawn from this investigation. It merely demonstrates Ohm's law, and that, we all knew before, holds true.

Another incidental remark I may make as to the proposition that a copper fuse is superior to any other fuse. This statement, I think, is based on a misunderstanding of the object of the fuse. A fuse is not in circuit only to open the circuit at a dead short-circuit. It is not even the best means for this. A magnetic circuit breaker, or any other circuit breaker, is far superior to guard against short-circuits, because fuses will not always open on dead short-circuit with unlimited power behind. The object of a fuse is to open the circuit, if the loads exceeds the carrying capacity of the lines, or the rated load. In this case, where the fuse is used in its proper place to guard against excessive load by cutting out the circuit at, say, 50 per cent over-load, the comparison between copper and lead fuses leads to quite different conclusions. Neither of these fuses will blow with such an explosion as on dead short-circuit. Both will be perfectly safe to open the circuit, but as soon as the load approaches fusing point, the copper fuse will be red hot, due to the high melting point of the copper, and thus liable to ignite dust or other combustible material, and set the building on fire. Thus the lead fuse is preferred to the copper fuse, not because it behaves better under a dead short-circuit, but because it opens the circuit and blows a

a temperature below that which will ignite combustible material, and for this reason copper or any other metal with a high melting point is absolutely unsuitable for fuses, except in particular instances where the conditions are such that it can ignite nothing.

DR. F. B. CROCKER:—I had taken somewhat the same view of this subject that Mr. Steinmetz has given, only in a different way. It strikes me, as Mr. Steinmetz says, that this is simply an investigation of the maximum current reached under certain conditions, and it is not exactly what the author intended it to be. Any fuse would carry an infinite current for an infinitesimal period of time, or, to put it a little more practically, it would carry a very great current for a very short time. Now, if the author had closed the circuit for a definite period of time, that might have given certain results. Perhaps the circuit breaker acted in that way and gave a definite time, although, as Mr. Steinmetz says, that would depend on the amount of electrical energy, or the integral of the current which passed.

Furthermore, the question of exactly what a fuse is intended to do is another point to be considered. This "short-circuiting point" is a matter of some practical importance, although I do not think it is the definite and scientific quantity that is implied in the paper, because we want to protect coils of wire on dynamos or other apparatus from the effects of short-circuiting under certain conditions. If the fuse does not blow—and presumably the fuse is of lower current capacity than the wire of the machine to be protected—then it stands to reason that the wire will not be injured. Therefore, after all, in a practical common sense way, perhaps this test is a useful and important one. And often this is the object of the fuse after all.

But looking at the matter as a physical problem, it seems to me the questions involved are these:—that a fuse has a definite capacity for heat, and requires a certain number of calories to raise it to its fusing point; that amount being the product of its weight, specific heat and the temperature of fusion. That is the amount of heat required to raise it to fusing point, assuming that the action is so rapid that no heat is lost, which I think would be approximately true in this case. It is practically instantaneous, and the loss, I think, would be almost negligible. Now, a certain amount of electrical energy is required to produce that amount of heat, and that amount of electrical energy is just as definite as anything can possibly be. It is simply the electrical equivalent of that amount of thermal energy. We have a certain E. M. F. and a certain impedance to overcome, due to the resistance and the self-induction, and a certain time during which that current flows. Consequently, as a physical problem, we can investigate it by calculation. We can tell beforehand what current and what time would be required.

MR. C. J. REED:—It seems to me that from a physical standpoint I cannot agree with Dr. Crocker that it simply depends on

a certain amount of heat generated, but the element of time and the surrounding conditions have all to do with it. The question as to whether the fuse will melt or not, appear to depend on whether there is a generation of heat in the wire at a rate exceeding that at which it is dissipated. If so, the temperature will continue to increase until the melting point is reached. If the conditions are such that with any given current, whether great or small, the heat is dissipated more rapidly than it is produced in the wire, then it will never reach fusion. It will reach a certain temperature and will not go beyond that. On the other hand, it is perfectly evident that if there is no opportunity for energy to dissipate, even an infinitesimal current would in the course of time fuse the largest wire. That seems to me very evident. If no heat can escape, even an infinitesimal current, theoretically, would in time heat the wire to its melting point; and, therefore, it seems to me that the only way any formula could be applied, would be under conditions in which the radiation must be absolutely the same for all temperatures of the wire, and in which no heat could escape through the terminals. That limits us practically to considering the central portion of a very long fuse, and one situated in a vacuum, or under other conditions, where the temperature of the surrounding space could be kept perfectly uniform. Then, as the temperature of the fuse rises, the difference between its temperature and that of the surrounding medium could be determined for any given temperature. But under ordinary conditions the most uniform that I can conceive of would be that of an exposure to air of uniform temperature. But this is impossible to get. If we compare, for instance, a fuse wire of very small diameter, say .001 inch, and another of a diameter of one inch, the small wire heating to its melting point, say for instance 2,000 or 1,500 degrees, if it is a wire that melts at that temperature, will heat only a very small amount of the surrounding air, whereas a wire one inch in diameter would heat a considerable thickness of the surrounding air, and consequently reduce its rate of cooling much more than a small wire would. It seems to me, then, that any formula we can get will be valueless unless we take into consideration the surrounding conditions.

So far as the comparison of copper wire and lead wire fuses is concerned, I cannot entirely agree with Mr. Steinmetz. I remember in the early days of electric lighting, when I did not know any better, I put up a plant in which I used copper wire fuses for electric lights on a 100-volt circuit. I used a No. 36 copper wire fuse about two inches long on every lamp. Later, when we got the Edison lead wire fuses in their cut-out boxes, I always noticed that the copper wire fuses when they went out never made any fuss, not the slightest noise of any kind, and only a very minute spark; while the lead wire fuses would invariably make a loud report and send a lot of melted metal around, which was likely to do damage; and I came to the conclusion that for

this particular service the best kind of a fuse is one which will give the least amount of melted metal, and not the one that melts at the lowest temperature. It does not matter whether the metal melts at a low temperature or not, as the arc is very sure to heat it up to about the same temperature. Hence, the more metal the more danger.

PROF. W. A. ANTHONY:—There was one point in this paper that I did not fully understand. If I understood correctly, these experiments were all made with the same circuit connection, the same connection from the switch-board, and with the magnetic circuit breaker in circuit; and if I understood correctly, the experiments were made some 30 feet or so distant from the switch-board, and therefore leads of that length were necessary in order to reach the fuse. Now, under such circumstances, I can hardly see how the resistance of the connections could be negligible in comparison with the fuse. It would seem to me that the connections under such circumstances would be quite large, that the fuse would not be a large percentage of the whole resistance, and, therefore, that the amount of current that would flow would depend perhaps as much upon the connections, instruments, contacts, etc., in circuit, as upon the fuse itself, and that if these experiments were to be made with entirely different connections, with larger or shorter wires, that entirely different results would be reached, that a larger current would flow through the same fuse, because the amount of current that flows in this case, as Mr. Steinmetz says, is determined by Ohm's law; that is, by Ohm's law excepting the self-induction or impedance that comes in. And if we had a less resistance as a whole, no matter whether the fuse itself were of less resistance or not, then a much larger current would have passed through the same fuse. Now, unless the conditions were such that the connections were extremely small in comparison with the fuses, I cannot see why the result should not be as I have stated, and cannot see that the results given really show us anything of importance.

PROF. ELIHU THOMSON:—It seems to me that the question under discussion resolves itself into a question of what is the proper function of a fuse, whether it is to save the apparatus from an overload, or whether it is to save it only in the case of a short-circuit. It is conceivable that if the fuse is not to give any relief to an overload of say 50 per cent, but is merely to be active on short-circuit, then the copper fuse might perhaps be the best. But if the fuse is to act on, say, 50 per cent. overload, or some definite proportion of the normal load, then it strikes me that tin, lead, or fusible metal is undoubtedly the best, because we must not neglect the economy of the fuse. If, for example, we use a copper wire for a fuse, we must make it longer than the fuse metal in order that the heat of the fuse will not be conducted back to the terminals. Copper being such an excellent conductor of heat, it will, of course, if made short, deliver its heat rapidly

to the terminals, and to get rid of any effect on the terminals, we would have to enlarge or lengthen out the copper. At the same time, if we lengthen it out and run it on a normal load at a considerable elevation of temperature so that it may fuse on, say, 50 per cent. overload, then we are wasting energy. We will have a great number of fuses which are running hot, and we know that a small wire, if of some length, can get rid of a considerable amount of energy. Again, with the tin and lead fuse, the conductivity for heat is low and the fuse runs at comparatively near normal temperature unless the overload comes. At that time it is ready to melt at a moderate elevation of temperature. If the function of the fuse is to save the apparatus in case of overload, then a soft metal must undoubtedly be the best.

Now what is the function of the fuse in the railway motor? Certainly not to save the apparatus in a case of short-circuit, because you cannot have a true short-circuit. You have a drop in the trolley line, you have a drop in the returns, and you have all through the connection a drop which, of course, would limit the current and remove any liability of any such values being reached as are stated in the paper. If the current did reach those high values for an instant, there would not necessarily be any bad result to follow, if the instant after, say .1 second or .01 second, all things are righted. Then it does not matter if we have just that momentary high flux of current. Now the fact is, that a car may be upon a grade, and for some reason or other it may be slipping down the grade. The motorman puts on the current rather briskly, and he may get for the moment 150 to 200 amperes. I have known that to occur. I have been on cars when tests were made, when the motors took that current for a time, when rotating slightly in the opposite direction current was suddenly put on. The fuse, which might have blown at, say, 50 or 60 amperes, did not, of course, blow under the conditions, but if the conditions had existed for any considerable time, the fuse would have blown and saved the apparatus. In other words, the motor could stand a high value of current for a short time without sustaining any harm. It seems to me that the practical question is the one which you have to consider in this connection.

MR. GEO. W. BLODGETT:—I take it the object of an investigation of this sort is one of two, either to establish a law, or to furnish a practical application. It seems to me that no formula can be devised in which a single constant would embrace all the conditions which are to be met, because, as has been said, the length of the fuse and the duration of time are both factors which determine to a degree the point at which it will melt. Perhaps I have overlooked it, but I see nowhere stated the length of the fuse which Mr. Harrington employed. Nor does he state definitely the time which elapsed between the closing of the circuit and the blowing of the fuse. Perhaps he does that in one or two cases, though I did not have an opportunity to read the

paper beforehand. I think the experiment, to be complete, should state exactly the length of fuse employed and the time during which it was in circuit. A formula to be applicable to all cases should bring in those two factors, and it is rigidly true only when the exact conditions under which the test was made are reproduced. But we never have in practice exactly the conditions which we impose in the laboratory for an experiment of this sort, and if the object is to determine a law under theoretical conditions, then it should be distinctly stated what the conditions were, under which the test was made. But if it is to furnish a practical application, then as nearly as possible the conditions which exist in average practice should be reproduced, and it should be definitely stated what the conditions are under which the practical application is made in the test. I am sorry that Mr. Harrington did not state the length of the fuses and the composition of the alloys which he used, because varying the proportions of lead and tin, for instance, in the fuse which he employed, would vary quite considerably the melting point of the fuses. Some experiments made by the American Bell Telephone Company I believe developed this fact, that a current which was perfectly harmless for a short time, if continued through the coils of a telephone bell, for instance, for a considerable time, would destroy it. Therefore they found it necessary to provide against what they called "sneak" currents, that is, currents which for a short time will do no damage, but which continued a long time will do harm by a gradual rise of temperature, because, owing to the density and the number of turns in the coil of wire, the energy can not be dissipated as fast as it is communicated to the coil, and, therefore, a dangerous temperature results; and that should be taken into account in the application of a fuse to a particular purpose, how long the current can be continued without injury to the apparatus.

MR. ALLAN V. GARRATT:—What I was about to say was precisely what Prof. Thomson has said, and he has said it so much better than I could, that I will not go over the same ground. But I wish to say just this one thing more. It seems to me the most criticisable point of the whole paper is contained in the very last sentence, which I will read. "The natural conclusion arising from a knowledge of the above data is that fuse metals are under no circumstances to be considered in the light or nature of a protection." That is not a conservative statement. If the words "under no circumstances" were changed to "under some circumstances," it certainly would meet the approval of us all. There is probably not a man here who has not many times in his own experience seen fuse metals do precisely what they were intended to do. The point, I think, that is brought out in this discussion by Dr. Crocker, that we must first make up our own mind what we want fuse wire to do before we can find fault with it, is a very important one. We know in every machine designed

what the bare wire will carry, and we are familiar with what will happen in the machine if an excessive current passes through it; and the machines are so designed that under the service for which they are intended they will dissipate the heat as fast as they are likely to get it under commercial conditions, and under most abnormal conditions the fuse acts.

Hence, although there is a great deal of value in this paper, yet its conclusion, I think, is erroneous, and not perhaps of the practical utility that its author intended.

MR. HARRINGTON:—As to the matter of the length of fuse, I think I mentioned in the paper its being three inches long, and the time of opening the circuit in these instances approximated .01 second. As to the use of fuses in railway work, where the fuse is intended to carry current for the jumps, and where you are liable to have the current as tabulated under short-circuit column on account of low line resistance, I think the law true in the majority of instances. It is a very noticeable fact in connection with railway work, that in climbing grades fuses very frequently blow when they are least wanted to blow; and yet if you put in a fuse large enough to carry the currents for that service, on a "ground" or "short-circuit," the current, while it may not rise to the quantity tabulated, still it will rise to such quantity as will by the torque or shock produced, cause a great deal of damage, which the protection of a circuit breaker will unquestionably prevent, as practice has proved.

That the use of fuses as a means of protection is not satisfactory is demonstrated by the use of magnetic circuit breakers on the Metropolitan railway in Chicago, and other large railways.

As to the conclusion concerning the non-protection that fuses afford, it is the occasional arising of this phenomenon that leads to their not being depended upon. For instance, very recently at the Broad Street station of the Pennsylvania Railroad, in Philadelphia, having Westinghouse generators, and using very large fuses, a short-circuit took place. The fuse did not blow. The generator was very badly injured and the crank-shaft broken, and considerable damage occurred. In the report that the engineers made, they recommended the use of magnetic circuit breakers, although before that time the same engineers had never considered circuit breakers as being advisable. It is the liability of these things to happen, owing to the properties that fuses have, that seems to point to their lack of reliability.

In the matter of the refinement of the law as enunciated, while it might have been conducted on a finer basis and results obtained which would be rigorously true, yet knowing that such a condition would not be attained, I was very careful to state all the facts as far as I was able to obtain them, aiming to bring out prominently the point that fuses have properties which have very seldom, if ever heretofore, been noticed and provided for. It has been my effort simply to bring these phenomena before you.

MR. REED :—I would like to ask the gentleman if I understood correctly that the time in these experiments was .01 second.

MR. HARRINGTON :—Approximately that.

MR. REED :—In all cases?

MR. HARRINGTON :—Approximately that, yes ; very closely.

MR. REED :—In that case it does not seem to me, then, that this formula could be expected to apply in any way, because this is a formula which is intended to show the relation between the diameter of the fuse metals and the minimum currents required to fuse the metals when sufficient time elapses for fusion to occur. Now it is very evident that if you take two fuses of different diameters, under different conditions, and of the same metal, and if your current is just sufficient under those conditions to fuse the wire, it will not generally fuse both of them in the same time, being of different diameters ; and hence to expect that they would all fuse in .01 second would be expecting something that certainly could not take place.

MR. HARRINGTON :—You are probably thinking about the law enunciated by Preece, where sufficient time elapses for fusion to occur. That law is : $C = a d^{\frac{3}{2}}$.

MR. REED :—Any time which you are going to allow for a given current to fuse the metals will not be the same for the fusion of different diameters, even of the same metal. The time will be such as is required for the increase of temperature to come up to the fusing point. You must remember that energy is being dissipated all the time and being developed all the time. The time when the fusing temperature will be reached will depend upon how much faster energy is being developed than it is being dissipated.

MR. HARRINGTON :—That is true, but in the law, as shown by Preece, time is eliminated. In fact, time drops out of the question when developed, and since time is ignored there, the actual conditions obtained in the tests were such that I have ignored the time. But I happen to know from other tests that it was about .01 second.

MR. STEINMETZ :—I wish to refer to what I believe is a misunderstanding of a statement made by Professor Crocker. Professor Crocker stated that the blowing of a fuse was merely a question of calories. Obviously that means the calories accumulated in the fuse, and this is the calories impressed upon it, in case of an excessive current, where the fusing takes place so quickly as to allow no time for noticeable radiation. Otherwise it is the difference between the calories impressed and the calories radiated by the fuse.

Now, with regard to the formula given in the paper, we can draw conclusions from the numerical values which plainly show their fallacy. It is stated there that the fuse in the Westinghouse car equipment allows 2,000 amperes to flow, and in the General Electric Co.'s equipment 3,600 amperes on a short-

circuit. Now that means that at 500 volts impressed and by series parallel control, with the two motors of the car in series, the resistance of each Westinghouse motor is $\frac{250}{2000}$, or $\frac{1}{8}$ of an ohm, and the resistance of a General Electric Co.'s motor only $\frac{1}{15}$ of an ohm. Although both companies claim that their motors are very efficient, I do not think that either of them makes any claim to such low resistance as that.

MR. CARL HERING, Philadelphia:—In connection with the subject of fuse wires, a specimen which I have here may be of interest. It is a portion of the fuse wire of the high-tension, overhead lines of the famous Lauffen-Frankfort transmission plant, and was handed to me just now by Dr. Lobach, one of the engineers of that plant, and which he now presents to the INSTITUTE. It is a copper wire 0.1 mm. in diameter. The fuses were two metres long, stretched overhead between two poles, and consisted of two of these wires in multiple in each of the circuits of that three-phase system. 200 H. P. at about 20,000 volts were transmitted through these fuses. It will be remembered that the center point of this three-wire system was grounded, and that these fuses acted as a cut-out to kill the line in case one of the three wires became grounded; an official test demonstrating their efficacy in a satisfactory manner was made before the plant was allowed to be operated.

MR. BLODGETT:—The shape of the fuse has also an important bearing on the temperature at which it will melt. If it is in the form of a flat strip, it will carry a higher current than if it is in the form of a solid rod or circular wire, particularly if it be intended to carry a large current. I saw an illustration of the conditions existing very nicely shown by the Electric Forging Company, in some experiments with their apparatus, in which an iron rod about one inch in diameter was heated to a bright red heat, and by regulating the current carefully it could be maintained at a constant temperature. That temperature was brought so high that while the outside of the rod was in a stable condition, owing to the dissipation of the energy into the surrounding air, the interior was melted, and would after a little time find for itself a vent through the outside shell, and the interior of the rod which was then fluid would run out, leaving a tube, while the outside would remain at a temperature sufficient to preserve its shape and integrity, showing that the dissipation of the energy under such conditions bears an important relation to the temperature at which destruction will occur. So in a large fuse, we should get a decidedly greater carrying capacity in the shape of a flat thin strip than we would if it were a solid circular or rectangular section.

CAPT. WM. BROPHY:—Nearly every point in this paper has been covered and discussed, except the concluding paragraph. I must say that I am nearly in accord with the writer in what he there says. I would simply amend it in this way: "The natural

conclusion arising from a knowledge of the above data is that fuse metals are under *most* circumstances," etc. It has been my province to deal with fuse metals for the last twelve years. The functions which are required are prevention of an abnormal flow of current over the wires, thereby increasing their temperature to a dangerous point. I have only very recently tested commercial fuses—sent out and bought them—and I find that none of them come anywhere near doing what they are advertised to do. The current that they carry varies from 50 per cent. to 250 per cent. above what they are marked. Many of them have the same property as copper wire,—they heat; and I have maintained them in a red hot condition for five or ten minutes, or longer, if I so desire. I would like to see something substituted for the present commercial fuse, for a great many reasons. The men in charge of plants are apt to use fuse metals that are entirely too large, even if they did what they are supposed to do, protect the wires in which they are inserted. As they age, I find that their carrying capacity increases very rapidly. In fact, there are innumerable objections that could be stated to the use of fuse metal for the protection of wires and prevention of overheating the same, if time permitted.

MR. CHARLES P. STEINMETZ then read the following paper :