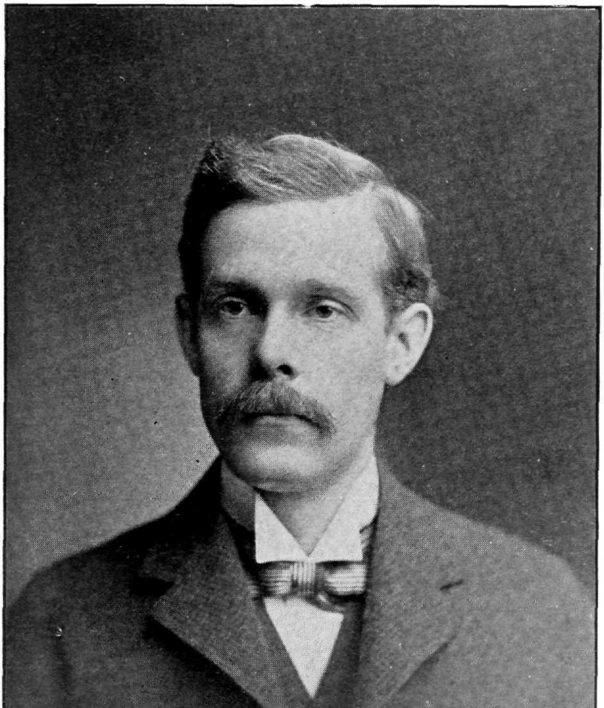
THE DISTRIBUTION OF ELECTRICITY IN COAL MINES.

BY CHARLES A. PRATT, E. E.

The application of electricity to the various industries has in every case passed through a developmental period, not only in the particular apparatus used, but also in the methods and practices of distributing the current. If we turn to the telegraph, the telephone, the electric light, the electric street car, or to power transmission, we find the same story repeated. In each case, in its early days, the one thought was to get the current to the machine, and little attention was directed to the hazard, the loss in transmission, the permanency of the circuits or to the relation between first cost and expense of maintenance. In each case, also, as the particular industry has grown in importance, its development has been accompanied by an ever increasing amount of attention given to current distribution, and this has always culminated in rigid rules, laid down by the insurance companies and municipal authorities, to which the users of electricity are compelled to conform.

In applying electricity to coal mining, it may be safely predicted that history will repeat itself in regard to circuits, and to a careful observer it will be apparent that we are, even now, passing through the era of the change. Up to within the last twelve or eighteen months, but little attention had been paid to this subject, and within an equal period in the future, we may expect to find the matter fairly well crystalized. During the years embraced between these limits, various systems and methods are being, and will be, tried. Some of these will doubtless be proven entirely unfit for the purpose and will pass into oblivion, while some will be found best suited to particular circumstances and conditions, and others, to other circumstances; and all will be found to have their limitations, their advantages and their disadvantages.

The alleged use of two hundred and twenty volts at the motor became prevalent, and in fact, all but universal, almost from the beginning; this being due, no doubt, to the fact that most stationary motors were, at that time, built for this voltage. This established a precedent, which was very naturally followed by the



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pioneers in electrical mining work. The pressure, however, actually received at the motor was a widely varying and extremely uncertain quantity, due to inadequate wiring, bad joints, poorly bonded tracks and the use of simple shunt wound dynamos, instead of over-compounded machines. I remember about three years ago being in an Illinois mine where there was a considerable electric plant, operating, along with other machinery, some electric pumps. As the workings advanced it became advisable to move one of the pumps farther out; and the pit boss told me, in all seriousness, that the pump did not run very fast since it had been moved. A closer inquiry revealed the fact, that while a small wire had been led from the main line to the pump, the only return provided was a connection to a track that was not even fish-plated. The peculiar feature was that the pump would run at all, for there was several hundred feet of this track; and, if the mine had been dry, it probably would not have run. As the matter stood, it might have proven an interesting example of an automatically regulated electric pump, for, when it had cleared the mine of water, it would stop running, since the circuit would be broken at every rail joint; and when the water again accumulated along the track, the circuit would be again completed and the pump started up. Whether this actually occurred, I cannot say, but I have a distinct recollection of walking very carefully along the top of the rail to keep from getting in water over my ankles, so it is safe to say that the pump did not stop that day.

Mine circuits, consisting of a piece of copper wire of almost any size for an outgoing conductor, and a poorly bonded track, or second piece of copper wire for a return, have been all too common in the past, and mine operators who have anything to do with electric plants are coming to appreciate that just as the steam piping in the power house must have a capacity depending upon the horse power of the engine, and the distance from the boiler to the engine, so the circuit must have a capacity, depending, similarly, upon the horse power of the motors to be operated, and their distance from the generator.

The use of from two hundred and twenty to two hundred and thirty volts at the motor is, at present, the rule; there are, however, a few instances in which a pressure of from two hundred and eighty to three hundred volts is maintained at the motors, and others, where from four hundred and fifty to five hundred volt pressures are used, but these are the exception.

In the plants operating on two hundred and twenty volts, the dynamos usually generate a normal electro-motive force of two hundred and fifty volts and are over-compounded to raise the voltage to two hundred and seventy-five at full load. This permits a drop of fifty-five volts on the line, and results in an efficiency of transmission of eighty per cent. This practice has gone into such extensive use, especially during the past year or two, that with perhaps the exception of increasing the percentage of over-compounding on the generators, it will probably remain in favor, in coal mines of ordinary extent, for many years to come. It has the advantage of unquestioned safety as far as electric shocks are concerned, therefore bare wires may be used for the distribution; and the amount of copper required, in mines of moderate size, is not excessive. The use of bare wire, aside from its smaller first cost, is a distinct advantage over insulated wire, for insulation, underground, is very hard to maintain. It is always soaked with moisture, and is frequently subjected to abrasion, and wire which was originally insulated is sure to be continued in use (being taken down and put up, time after time), long after its insulating qualities have ceased to exist, even though it still maintain the semblance of insulated wire, and a conductor appearing to be insulated while in reality it is not, is a double menace, especially in the case of high voltage currents.

The use of the rails for a return conductor very greatly increases the scope of the two hundred and fifty volt plant, making its use possible in mines where otherwise the extent of the workings and their distance from the power station would render it impractical. For example; a properly bonded track of thirty pound rails is the equivalent in current carrying capacity of about five No. 0000 copper wires. That is to say, if a plant were of such a size that a return circuit of five No. 0000 wires were necessary to transmit the current; the use of a thirty pound track would save half the wire, and, if the distance were a mile, this would amount to nearly seventeen thousand pounds of copper. But if the plant were of such size that a circuit of two No. 0000 wires were necessary, the use of a thirty pound track would save not only the return wire, but also one-third of the outgoing wire; two No. 00 wires and the track constituting the circuit, instead of two No. 0000 wires. And 804 pounds of copper per thousand feet would be used instead of 2560 pounds per thousand feet; a saving of over two-thirds. The expense of bonding must be deducted from the saving, but this is not a serious item. It is apparent, however, that it would not be economical to bond a light track if it were expected soon to replace it by a heavier one.

With the continued increase in the use of electrical machinery in coal mines, there is sure to arise, now and then, a case in which the two hundred and fifty volt system is unsuited to the work on account of its requiring a prohibitory amount of copper. The most obvious solution of such a problem is to raise the voltage, and there are, even now, a few plants operated on five hundred volts. The use of this pressure effects a saving of about three quarters of the copper, and this feature is certainly very attractive, especially when the wiring bill is a large one. But the system has its limitations in another direction; for it becomes necessary to use a large amount of rubber covered wire, instead of bare copper wire, and in No. 0000 wire, for instance, this costs 15 cents a foot, whereas bare wire of the same size costs but 9.6 cents per foot. In smaller sizes the disparity is even greater. Furthermore, in mines where both locomotives and under-cutting machines are operated at a pressure of five hundred volts, it has been found desirable to run two independent circuits; one grounded circuit for the locomotive and the other a complete wire circuit, entirely insulated from the ground and using rubber covered wire. In this case the machine circuit loses the advantages of the rail return, and therefore requires from two to three times the amount of copper, and besides this, the wire must be rubber covered. In such a case it is apparent that the machine circuit may cost more for a five hundred than for a two hundred and fifty volt circuit. If, however, there is a long pole line outside of the mine, on which bare wire would be used in either case, the five hundred volt transmission may result in a material saving.

In mines where current is used for locomotives only, and where the distance is considerable, the five hundred volt system is liable to come into favor, to a greater or less extent, especially in dry mines where the haulways are reasonably high. But for the purpose of operating under-cutting machines, the system has to contend with a serious disadvantage in the danger incident upon the use of the high voltage. The conditions under which an electric circuit exists in a coal mine are, at best, unfavorable. The timbers that support the insulators are frequently soaked, and with acidulated water at that, and the insulators themselves are often covered with water that trickles down from the roof and then runs along the wire until it finally drops off to the floor. Nor is it at all uncommon for a fall of rock to carry a wire down, thus grounding the circuit, and this is especially true in the rooms, in "breakthroughs" and in the irregular places that occur in every mine, so that even in case it were supposed to be entirely insulated, there is constant danger of the circuit becoming grounded. The use of a grounded five hundred volt circuit for under-cutting machines involves an unwarranted risk to the lives of the men operating them, for there can be little doubt but what a current of electricity at five hundred volts pressure administered for half a minute will kill; on the other hand, an instantaneous shock at five hundred volts has never, I believe, as far as recorded, killed anybody. This is the reason why there has never been a person killed by a shock from a five hundred volt street car circuit. A shock will almost inevitably knock a person down but this very act knocks him away from the wire.

The elevated electric road in Chicago is operated by a third rail, which is within a few inches of the track. A few months ago an employee of the road while on the track, in some way or other, received a shock and was thrown so that he lay across both the third rail and the track. He was unable to get up and was killed by the current before help reached him. An exactly similar accident might happen with an under-cutting machine. The whole affair is low, and the runner is directly over it, and frequently in a cramped position, and a shock might easily throw him onto the machine and this might result fatally or might not; depending largely upon whether his helper became scared and ran away, or stayed by and helped him.

It is with the idea of combining the advantages of the high voltage, for transmission with the safety of the low voltage at the machine, that the use of alternating currents, both two phase and three phase, has been proposed. By this system a very high primary pressure may be used, and through the intermission of transformers, brought down to a suitable voltage for use at the machines. By this method of operation the size of the main wires may be reduced to a mere fraction of what would be necessary for a two hundred and fifty volt transmission, and when the power house is, of necessity, at a great distance from the workings, an enormous saving may be effected in the expense of the circuit, and transmissions are made possible in which, otherwise, the cost of copper would be quite prohibitory. This feature renders alternating currents invaluable for power transmissions, in cases where fuel is expensive and a distant water power may be developed. For coal mine use where fuel is both plenty and cheap, the system, of necessity, loses its most attractive element, although there are occasionally mines in which the underground workings are so extensive that a very material reduction will be effected in the total weight of the copper used,

Throughout the underground circuits, the primary wires, of which there are three or four, and which carry the high pressure current, must be carefully insulated from one another and from the ground, and this insulation must be carefully maintained. This involves a heavy expense which goes far toward eliminating the saving due to a smaller amount of copper, so while the total expense for circuits is not, perhaps, far different in the two cases, the operator has his money invested largely in insulating material in one case and almost entirely in copper in the other case. Money invested in copper is unquestionably much better invested than when tied up in insulating material, for the insulation deteriorates in value and when taken out of the mine is practically worthless, whereas copper is always copper and will at any time bring a large percentage of its original cost.

The circuit must also bear the expense of the transformers which might, or might not be a large item, depending upon the particular mine.

There is an element of danger connected with the use of a high pressure alternating current, where transformers are depended upon to reduce the voltage, in the possibility of the transformer insulation breaking down and permitting the high voltage current to get to the low voltage wires and so, directly to the machine. Accidents of this nature are not uncommon on electric lighting circuits using alternating currents and transformers, and occasionally a fatality has resulted. In coal mine work where the transformers would of necessity be placed in disadvantageous positions subject to dripping, acidulated water and falls of rock, it would be fair to expect that they would fail more frequently than when placed on electric light circuits where there is every chance to place them advantageously.

The fact that there has, as yet, been no alternating current locomotive put on the market, is a serious drawback to the system; for in case both cutting and hauling is to be done, it becomes necessary to put in two sets of generating apparatus; one alternating and the other direct current, or else to resort to the use of a rotary transformer and this involves complications and a multiplicity of machines.

There is still another system for the transmission of current to a considerable distance, which is admirably adapted to use in mine work. For want of a better name I shall designate it the Three Wire Motor System. It differs from the ordinary Edison three wire system, only in that the load is distributed less evenly between the two sides and therefore special means must be taken to maintain a given pressure at the machines.

By virtue of this system a large part of the saving in wire effected in five hundred volt transmission is retained, and at the same time the motors operate on two hundred and fifty volts pressure. This result is accomplished by connecting two two hundred and fifty volt dynamos in series; the positive brush of one to the negative brush of the other and then running three wires; one from the two brushes that are connected together, which will be a neutral wire, and one from each of the outside brushes; one of these latter being the positive and the other the negative conductor.

The difference of potential between the outside wires will be five hundred volts, while from either of the outside wires to the neutral wire there will be but two hundred and fifty volts. This neutral wire is then to be connected to the track and thereby becomes the "ground." The machines will be operated from one or the other of the wires to the ground, using only two hundred and fifty volts; in this respect, as is customary with the regular two hundred and fifty volt circuit.

The two wires will run down opposite sides of the main entry, and the butt entries and rooms on one side of the mine will be fed from one wire and those on the other side, from the other wire, so that there will never be more than two hundred and fifty volts between any wire and the ground, and the two wires between which there is a pressure of five hundred volts, are in entirely different parts of the mine. The saving of wire by this system results from the fact that the same current flows through two machines before returning to the dynamos. It leaves the dynamo over the positive outside wire, flows through the machines that are being run off that wire to the ground wire or track and, following this to the machines on the opposite side of the mine, flows through them to the negative outside wire, by which it returns to the dynamos. So if a certain mine is running ten machines, only as many amperes of current will be used as five machines would call for, and further, since the current is transmitted at five hundred volts instead of two hundred and fifty, the same percentage of drop of pressure on the wires will permit the loss of twice as many volts as ordinarily. Therefore, since the system requires but one-half the current and permits double the drop, the main wires need have but one-fourth of the cross section, and therefore one-fourth of the weight necessary with the two hundred and fifty volt system. At the same time, the advantage is retained of operating the machines at two hundred and fifty volts. The third or neutral wire carries current back to the dynamo only when the power demanded by one set of machines is in excess of that demanded by the other set.

There are at present two distinct practices in wiring rooms. One, is to string wires in every room, and the other, is to supply each machine with a reel of double conductor, flexible cable of sufficient length to reach from the entry wires to the ultimate face of the room. This latter method is cheaper in first cost because one reel and cable are substituted for the wire that would be required for eight or ten rooms, while the former is cheaper in the long run, since the life of the cable is quite limited, whereas the room wire may be taken down and replaced in new rooms, time after time. The use of the cable, however, has an advantage over wiring the rooms, in that when the machine is out, there are no live wires to interfere with the mules or to be carried down by falls, so short circuiting the line.

This advantage is largely offset by the practice, now in quite extensive use, of leaving the positive room wire detached from the entry wire at the mouth of the room, so that it is normally "dead." When a machine goes into a room the runner makes the connection between the room wire and the entry wire and when he has finished the room he again breaks the connection.

It is probable that both of these ways of taking current from the entry wires to the machines will continue to be used, some operators preferring one, and some the other. And it is also likely that a third method, a cross between the other two, will sooner or later come into use. This third method would involve stringing a bare ground wire in every room, or perhaps, simply laying it back of the props, and then furnishing each machine with a reel carrying the necessary length of a single conductor flexible, insulated cable, which would be used for the live wire. This method would be intermediate in first cost between the other two and also intermediate in expense of maintenance. It has an advantage over the double conductor cable in that a much smaller reel could be used and the cable when worn out would be much cheaper to replace. And it has the advantage over entirely wiring the rooms of keeping them free from wires when the current is not being used.

The value of the utmost simplicity in everything about a coal mine can hardly be overestimated, and this principle is as applicable to circuits as to machinery. Therefore, we may expect to see the two hundred and fifty volt direct current system grow in favor, from year to year, among the great majority of coal mines. It is perfectly simple; the ordinary extensions involve nothing more than lengthening the wires; it is unnecessary to maintain a high standard of insulation, and it involves no danger to life. In those mines where the amount of copper required by this system becomes a serious item of expense, the Three Wire Motor System, as outlined, will doubtless prove itself capable of solving the problem of transmission, for it combines much of the advantage of the higher voltage transmissions with the safety and a large measure of the simplicity of the two hundred and fifty volt circuit.

It is clearly to the interest of the operator to encourage uniformity in mining machinery and to discourage the multiplication of "systems." If, after a mine has been equipped with a power plant, any standard machine can be operated from it, it is a distinct advantage to the purchaser when the time comes for increasing the capacity. Whereas, if some system is used from which only particular machines can be run, the operator is confined to a limited market and therefore is at a disadvantage. It is in view of this fact that the two systems, the two hundred and fifty volt and the three wire motor, mentioned, acquire a special significance, for the same machines may be operated from either system and between them they fulfill all ordinary coal mine requirements.

PRESIDENT ORTON: The paper we have just listened to is what I expected it would be, a most able exposition of the knowledge now available on the subject of mine wiring. It has certainly brought new ideas to me, and doubtless has to many of you here. I now call for a discussion of the paper, and desire it understood that the discussion is not limited to members of the Institute, but we will be glad to have any who are interested in the subject to express themselves.

MR. HUGHES: As long as there seems to be reluctance on the part of my fellow members to discuss this subject, and the time is slipping by, I want to express my hearty approval of the paper. The author has referred to the fact that the bonding of the rails is an important factor, and as he has so well exhausted other and more important features, perhaps that has been skipped more than was intended. In other words, if to-day we were to abandon the bonding of the rails of street railroads, every water pipe would be leaking. In mines we find that a great difficulty. The bonding of the rails is no more or less than making perfect conductor of the current back to the generator. The gentleman said that good riveting would cover the case. Now, copper being a soft metal and the steel rail being hard, you very often drive up a tight rivet connection and in less than three months have a leakage. Three months ago a superintendent said to me, "How do you account for this?" He showed me the return wire connection at the generator had not a diameter of more than an eighth of an inch, which was originally three eighths of an inch. It took little time to find he had a leakage at each joint, and also mine water running over the return wire. The sulphur, or mineral water in mines is ten times worse than anything the street railway has to contend with. Within the past eighteen months there have been at least fifty different patents issued for special rail bonds. That the gentleman spoke of having an absolute copper contact at the fish-plate of the rails, is a good one. I think perhaps it would be also good for the copper contact at the rails to have one-seventh of the cross section of the rails. I think this is a vital point, to make your connections absolute at the fish-plate. I hope you will pardon these remarks, which were drawn out by the paper, in which I was deeply interested. I only inject them to impress upon my fellow members that this is one of the most important subjects yet discussed.

MR. PRATT: I would like to second everything which has been said about this factor being most important. It is especially important to have good contact in railroads. It is apparent that where there are two contacts in every thirty feet of rail, in a half mile there are a large number of contacts. The only point I would take exception to, perhaps, is the inference I drew that the gentleman intended that bonds should have the cross section of the outgoing conductor. It is frequently necessary to use a large cross section outgoing conductor in order to keep the voltage at the face at a reasonable pressure.

MR. KANE: At the opening of Mr. Pratt's paper, he spoke of some system safer than other systems, or some plan which gives a maximum of safety. I did not quite understand it and would be obliged if he would repeat that.

MR. PRATT: The pressure ordinarily used in coal mines at present in undercutting machines is two hundred and fifty volts at the generator and two hundred and five at the machines. This is perfectly safe. There has been no case recorded of a person being seriously injured by that pressure, whereas five hundred volts has done it.

MR. ———: In England it is considered safe to use five hundred volts, and it is used for locomotive and mining machines in this country. I see no reason why five hundred volts can be used in street railroads with overhead wires which might fall at any time and kill persons, and not be used in mines. The miners are very careful, as they have been taught that the wires are very harmful. A miner in Kansas not many months ago was killed by two hundred and seventy-five volts; and if two hundred and seventy-five volts could do it, I do not see why two hundred and fifty could not. This question of the voltage which is safe for an operator to operate machines is an old question. It is the same old story, just as that of ventilating mines. It has been talked over again and again and no final decision arrived at. It is a matter of opinion, and I believe that five hundred volts can be used in the three wire svstem with safety. Then, for concentric cables: that is another question. For years it was considered that by concentric cables was a very satisfactory way of conducting electricity from the engine to the machines. It might be a little more expensive at first cost, but safer in every way. I think the speaker did not emphasize that point sufficiently. They were first introduced by ———————— and he was laughed at, but they were later adopted. The main idea in mine insulation is to save first cost, because fuel is cheap and labor is expensive; consequently if five hundred volts is safe, why not use it?

MR. PRATT: The gentleman has referred to cheap first cost being the primary element in mine insulation. I think it is so to a very unhappy extent—too much so. As time passes, mine operators will come to appreciate the fact that they will save money in the long run by spending a little more at the start. In regard to the danger or safety of any voltage, it certainly is an open question and probably always will be. It is a matter of opinion as to what is and what is not safe. It will probably be a matter of legislation, as to what is safe and what not, in the not distant future. It is a matter of legislation in all big cities now as to what is safe or allowable. The reason why I specify five hundred volts as being dangerous when used on mining machines, is because the men are at a disadvantage and in a cramped position. There is great liability of their being so thrown that they cannot get away from the current, so that the shock is not instantaneous, but constant. I think it has never been questioned that five hundred volts will kill a man if applied for any appreciable length of time. I doubt if he could stand three hundred, unless it was raised gradually. I know he could stand three hundred volts if the voltage is gradually increased so that it does not come as a shock. If a man gets a shock from a five hundred volt street car system and is thrown under the circuit so that it becomes continuous, there is no question but it would kill him. If he were knocked off a repair wagon by the shock, the fall might kill him, but I do not think the shock would do it. As to placing transformers under ground, the statement was made that it is as advantageous under ground as over ground. That is a matter of judgment. In my judgment it is not as well. The acidulated water in mines will eat most anything. Whether it will eat up the outside cover is a question. There is also the question of the transformer being injured by falling rock; whereas the transformers on the outside are placed so as to be kept clean and no chance to be knocked down; and even in these cases occasionally the transformer gives out and some are killed.

PROFESSOR CALDWELL: In regard to the injurious consequences of five hundred volt current, some experiments made in our laboratories last spring by the professor of physiology may be interesting. The experiments were made on two large dogs, and they were killed in a few seconds, I think in ten seconds, with fifty volts. The current was applied in the most effective way, one on the temple and the other in the back. Time contacts of five hundred volts would certainly kill.

PRESIDENT ORTON: I will ask whether in Mr. Platt's judgment it would require higher power current to kill a man than a large dog? The experiment was upon a large dog and he was killed by fifty volts in ten seconds.

MR. PLATT: Well, I would not want to try it in the small of my back; but I think probably it would take more to kill a man than a dog. I do not know exactly why, either; for in the case of horses, they certainly seem to be more susceptible than man. There are a great many horses killed by five hundred volts. Most cases it occurs where the trolley wire falls on the horse and the horse is knocked down. It lies on the horse and the people around are afraid and will not take steps to get the wire off. If somebody would take a stick or a cloth and take it off the horse, it might be saved.

MR. PRATT: I think there is no question about the greater sensitiveness of the lower animals. A two hundred and fifty volt current will kill a mule in short order; but a man can take a two hundred and fifty volt wire and hold it, whereas at fifty volts he would have to wet his fingers to know there is anything there.

MR. KANE: Some time ago I read a newspaper article on electricity. I anticipate you will say that you cannot put much trust in newspaper articles on scientific subjects, but I will mention it. The man interviewed said he had permitted two thousand volts to pass through his body. It was a curiosity to me.

MR. PRATT: Was it not fifty thousand?

MR. KANE: I think it was two thousand.

MR. PRATT: I think the statement was entirely correct. But you must add to it the fact that it was not a current of electricity as the term is commonly used. In that case, it was an alternating current of very high frequency; an alternating current, alternating with extreme rapidity. When it gets to alternating with extreme rapidity, what is ordinarily a conductor becomes a non-conductor; and non-conductors become conductors.

MR. HUGHES: I wish to confirm what Mr. Pratt has said. Mr. T——— said he did not fool with five hundred volts, but fifty thousand was safe.

MR. KANE: I move a vote of thanks to Mr. Pratt for his extremely interesting and valuable paper on the Distribution of Electricity in Mines. (Seconded; carried.)

MR. PRATT: I wish to thank the Institute for the kind attention and interest shown.

PRESIDENT ORTON: The next feature of this afternoon's program will be a paper by Captain Morris, the poet laureate of this Institute. Before Captain Morris takes the floor, I want to state to the Institute that it came very nearly undergoing a very severe loss this year. You are all aware that the position of poet laureate to to the British crown has been vacant for some time past and a great deal of agitation has existed among English speaking people on account of that fact. When some months ago Secretary Haseltine and myself received a letter from Captain Morris, stating that he wished credentials from this Institute before going abroad, you can readily understand what our misgivings were. But I am happy to state that the blandishments of the English crown were not able to take the captain from us and I now introduce him to you. (Applause.)