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Telegraph-Engineers and Electricians.

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The One Hundred and Fiftieth Ordinary General Meeting of the Society was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday evening, January 28th, 1886—Mr. C. E. Spagnoletti, M. Inst. C.E., late President, in the Chair.

The minutes of the Annual General Meeting of December 10th, 1885, were read and approved.

The names of new candidates for admission to the Society were announced and ordered to be suspended.

The following transfers were announced as having been approved by the Council:—

From the class of Associates to that of Members—

Robert O. Bourne. | Charles H. Sharples.
Hugh Erat Harrison. | H. D. Wilkinson.
O. E. Woodhouse.

From the class of Students to that of Associates—

F. B. O. Hawes. | Eugene J. Moynihan.
Frederick Worsley.

Donations to the Library were announced as having been received from the Colonial Office; the Smithsonian Institution; Professor E. J. Houston; G. M. Whipple, Esq.; A. Andersen, Member; W. Lynd, Associate; C. Mourlon, Foreign Member;

and Willoughby Smith, Past-President; to all of whom the thanks of the meeting were unanimously voted.

The LATE PRESIDENT: Gentlemen,—One of the most pleasing duties in connection with my Presidency devolves upon me this evening. It is that of presenting the premiums which have been awarded by the Council to those who have contributed the best papers during the year ending June last. I may perhaps be allowed to say, in the presence of our younger members, that I consider the honour of receiving a premium from a Society like this is very great indeed; because, if the papers are not really of true value, no premiums are given, and therefore for the author to obtain a premium the paper must necessarily possess considerable merit. The ability and reputation of our Council are well known, and it is a very great honour indeed for the author of a paper to have it selected by such experts as worthy of a premium among the productions that have been brought before the Society. I hope that many of our members will endeavour to gain a premium during the ensuing year, and will contribute papers the excellence of which may be rewarded by the Council of the Society.

The first premium, being "the Society's Premium," value £10, has been awarded to Professor Oliver Lodge for his excellent paper—which brought forth two evenings' discussions—"On the Seat of the Electro-motive Force in a Voltaic Cell." Professor Lodge has chosen Ruskin's Works, and the volumes are here ready to be presented to him, but unfortunately his duties in Liverpool do not permit of his being present to-night, and he has commissioned Professor Perry—who, as you will recollect, crossed steel with him in scientific argument very closely—to receive the books for him; but unfortunately Professor Perry is also lecturing to-night, and cannot attend here until later in the evening, so that the books must remain on the table for the present.

The second, being the "Fahie Premium," value £5, has been awarded to Captain H. R. Sankey, R.E., Associate, for his paper on "Some Experiments in Electrotyping with a Dynamo-electric Machine." You will all recollect that his paper was very interesting, possessed great merit, and was well received by the Society. Captain Sankey has selected an aneroid barometer, a "Boucher's circular calculating machine," and "Gordon's Electricity," which I now have the pleasure of handing to him.

The next is the "Paris Electrical Exhibition Premium," value £5, awarded to Mr. W. H. Snell, Associate, for his paper, "On the Calculation of Mains for the Distribution of Electricity." I am very sorry, indeed, that on the occasion of that paper being read —which was at an Extraordinary General Meeting devoted to the purpose—I had not the pleasure of being present. It is the only occasion on which I was absent during the past year; but I have read the paper, and can support the selection of the Council in awarding this premium to Mr. Snell, to whom I now have the pleasure to hand these ten volumes of electrical works which he has himself selected.

Now, having performed the routine duties of the office, it only remains for me to express the great pleasure I have in introducing to you my successor, Professor Hughes.

The President, Professor D. E. Hughes, F.R.S., then took the chair.

Professor G. FORBES: Might I ask, before we listen to your interesting remarks, Professor Hughes, for a few moments to perform what is a right and graceful act towards our late President. We know that the success and interest of our meetings depends very much upon the manner in which our President conducts his duties in the chair, and the way in which he introduces the subject and invites discussion upon it. Further, the position of the Society depends a great deal upon the dignity of the chair, in having a President who has a thorough business-like and regular habit; and I may say that we have seldom had a gentleman more suited to that double capacity than Mr. Spagnoletti. He has happily introduced subjects and invited discussions at every meeting at which he has been present, and has conducted the duties of the chair in so methodical and business-like a manner that I am confident of the support of the members present when I propose a hearty vote of thanks to Mr. Spagnoletti for the manner in which he has fulfilled the duties of President.

Mr. W. T. ANSELL: I beg to second the proposition, and can say that from the bottom of my heart I cordially endorse the sentiments expressed by Professor Forbes in reference to my old friend Mr. Spagnoletti, our late President. I have known him for very many years—from his earliest career in telegraphy—and have been intimately associated with him in very many of the early undertakings which were the pioneers of the magnificent telegraph system which now exists, not only in England, but throughout the world, and, in my old age I am proud to say, in which I have been one of the foremost workers. I am an old man now, and I remember my old friend Sir W. Fothergill Cooke once saying, "We cannot hold a candle to the young ones, there is no mistake about it, and we must give place to younger and better men;" but it has always been to me a matter of great pride that we have been the starters and the pioneers of a science which has grown to the great position in which it now stands throughout the civilised world.

The PRESIDENT: My first duty is an extremely agreeable one, and that is to put to the meeting the vote of thanks which has been proposed by Professor Forbes and seconded by Mr. Ansell.

I am sure that no one can appreciate more than myself the noble way in which Mr. Spagnoletti has fulfilled all the numerous and arduous duties of President of our Society during the past year; and in putting this motion I ask you to carry it unanimously, so that we may all testify our sincere thanks to and highest regard for our past President, Mr. Spagnoletti.

The resolution was unanimously carried.

Mr. C. E. SPAGNOLETTI, in reply, said: I feel exceedingly obliged and gratified at the very kind way in which Professor Forbes has expressed himself, and also to my old friend Mr. Ansell for the way in which he seconded the proposition. As Mr. Ansell said, we have worked together for a very great many years, and it will always afford me much pleasure in looking back to the time when he was my chief. Perhaps it is somewhat due to his attention and training in my early days that I have been qualified for the position in which I am placed to-night. I am obliged to Professor Hughes for his kind expressions, and I assure

you it is most gratifying to me to find that the meeting has so cordially endorsed the proposition.

I would detain you just to say that I feel extremely happy that the Society during my term of office has come a little out of its shell. In regard to electric lighting, a committee of the Society was appointed to consider and bring to the notice of the Government the shortcomings of the regulations in force under the Act of 1882, and, I think, did its work well, giving that branch of the science the support it so much needed. Also, as you know, a committee was formed to consider electrical nomenclature and notation, and that committee has been working hard; but the subject requires much time and great care, and it will not do to hurry its deliberations by pressing for too early results. It is still at work, and I hope that Professor Hughes may be able shortly to report progress. A third committee has been formed to consider the best means by which the standardising of electrical apparatus can be practically carried into effect, the result of which I hope will be of great assistance in remedying many of the defective instruments in existence, and give us a mode of testing and proving instruments that will render reports on tests of real value to all concerned.

I take this opportunity of thanking the Council most sincerely for the kind way in which they supported me during my term of office. Important duties have frequently occupied the Council until late hours on many evenings, but they have always willingly given their time and ability to all questions connected with the Society in the most thorough manner, and my thanks are deeply due to them for their kind support on every occasion. I should also like to express my thanks to our Secretary, Mr. F. H. Webb, who has always, and most willingly, afforded me every assistance in his power, and helped and supported me in every way he could in the office.

The PRESIDENT said it would facilitate the reading of his inaugural address if Mr. Spagnoletti would take the chair *pro tem.*

Mr. Spagnoletti took the chair.

The PRESIDENT then read the following

INAUGURAL ADDRESS.

Before commencing the subject of my address this evening, I desire to express my sincere thanks to the Members of the Society of Telegraph-Engineers and Electricians for the great honour they have conferred on me by electing me as their President, and to assure them that I will do all in my power to aid and promote the interests of our Society, which are those of Applied Science in one of its highest branches.

It is the custom in our Society, that the elected President should open the Session by an address containing a general review of the present state of Electrical Science, or researches in some special branch which may be of interest. I have chosen the latter, as it enables me to present to you some researches which I have not yet published, and I propose to present these in the form of a paper rather than an address, in order to allow our members the opportunity of a full discussion on the subject, which I hope may bring forth many new facts in their possession.

The subject which I have chosen is—

THE SELF-INDUCTION OF AN ELECTRIC CURRENT IN RELATION TO THE NATURE AND FORM OF ITS CONDUCTOR.

Induced or secondary currents in a near but independent circuit were discovered by Faraday in 1831; and the phenomenon of the self-induction of an electric current in its own wire was observed by Henry in 1832, and traced to its cause in 1834 by Faraday, who proved that on sending a current through a wire a momentary induced current in the opposite direction is evoked in its own wire; also that, on the cessation of the primary current, a second induced or "*extra-current*" is excited in the direction of the primary. The effect is greatly augmented when the wire forms a coil, as we then have in addition the reaction of superposed currents; but the effect exists to a great extent even when the wire forms but a single loop, or a straight wire with the earth forming the returning portion of the loop, as in all telegraph lines.

It has been generally supposed that the nature or the molecular condition of the metal through which the primary current passed exerted no influence upon the extra-currents except that due to its resistance. I have previously pointed out* that for induced currents "the rapidity of discharge has no direct relation with the electrical conductivity of the metal, for copper is much slower than zinc, and they are both superior to iron." This led me to make a study of these extra-currents, for which purpose I constructed a special Induction Bridge, in order to measure both the primary and its extra-currents separately at the instant of action.

INDUCTION BRIDGE.

This instrument† is a combination of a portion of my "Induction Balance," with a "Wheatstone Bridge." The resistance of the wire is measured and balanced by the bridge; the induced or extra-currents are measured and reduced to zero by an equal opposed induced current from the induction balance.

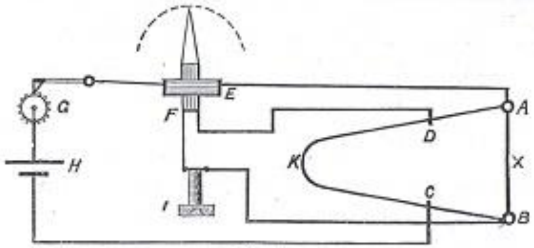

FIG. 1.

The above diagram shows the electrical communications. The bridge consists of a single German silver wire (0·25 mm. diameter, 1 mètre in length, of 4 ohms resistance) running from A to K, returning to B. The wire is stretched and sustained upon two wooden arms articulated at K, by means of which the terminals A B can be more or less separated as desired. The wire to be tested, X, is joined at A and B, thus completing the closed circuit of the bridge.

* "Induction-Currents Balance," *Proc. Roy. Soc.*, vol. xxix., p. 56, 1879; "Molecular Electro-magnetic Induction," *Proc. Roy. Soc.*, March 7, 1881.

† Manufactured by Mr. William Groves, 89, Bolsover Street, Portland Place.

The external communications are shown, A being connected to the primary coil of the sonometer E, and through it to the spring of the interruptor or rheotome G, the interrupting wheel being connected to the battery H, and thence to the bridge at C. The wire from B passes through the telephone I to the secondary coil F, returning to D.

Great care has to be taken in the construction of the bridge, so that it shall be as free as possible from induced or extra-currents; and for this reason we cannot employ or introduce resistance coils. The resistance of the wire X is balanced by sliding the communications D and C. It is evident that if all the arms of this bridge are equal in resistance and inductive capacity, there will be silence on the telephone; but if A B be slightly stronger or weaker in inductive capacity, then we may be able to balance its resistance, but not its induction, as we shall then have a slight or a loud continuous sound due to the differential extra-currents in the arm A B. These are compensated by the introduction in the circuit of the telephone of an equivalent but opposed induced current from the secondary coil of the sonometer F, the degree of angle through which this coil has turned to produce silence being the degree of force of the extra-current. The induction sonometer* consists of two coils only, one of which is smaller and turns freely in the centre of the outside coil. The exterior coil being stationary, the centre coil turns upon an axle by means of a long (20 cm.) arm, or pointer, the point of which moves over a graduated arc or circle. Whenever the axis of the interior coil is perpendicular to the exterior coil no induction takes place, and we have a perfect zero; by turning the interior coil through any degree we have a current proportional to this angle, and in the direction in which it is turned. The value of the induction current for each sonometric degree was $\frac{1}{2500}$ of the primary current which passed through the wire under observation, the latter being variable at will from ·001 to ·250 ampère. There is also a reversing key (not shown in the diagram), in order to place the interruptor on the telephone circuit and close the battery current from H to A; the conditions then

* *Comptes Rendus de l'Académie des Sciences*, Paris, Dec. 30, 1878, and Jan. 20, 1879; *Proc. Roy. Soc.*, vol. xxxi., p. 527, 1881.

being the usual method of testing, except using the telephone in place of a galvanometer—a well-known method. The telephone, being exceedingly sensitive and rapid, is most suitable, whilst a galvanometer would be too slow, and its use, in fact, impossible for the researches I have been making.

Numerous details have been necessarily omitted in this rough sketch of the instrument. Suffice it to say that it is perfectly adapted for the object sought, viz., the investigation and measurement of the self-induction which takes place in all wires.

By all previous methods the measurement of the resistance of a wire is taken when the current has been already some time in action, or, to use an expression of M. Gaugain, when the electricity has arrived at its "stable period." In telegraphy, electric lighting, and all applications using rapid electrical changes, another period has to be considered, viz., that during the rise and fall of the current; this he named "the variable period," and it is in this period that all the phenomena of induction take place.

To observe the *stable* period, the current is continuously passed through the bridge (and consequently through the wire under observation), and the interruptor being placed in the telephone circuit allows us to find the exact resistance of the wire, free from all induction or change in the wire itself.

To observe the *variable* period, the interruptor or rheotome (making at will from 10 to 100 contacts per second) is placed on the battery circuit, the telephone being joined as shown in the diagram.

By means of a switch or reversing key these changes are made as rapidly and often as desired.

If there were no static or self-induction, no loss of time, or change of resistance, then the result from these two periods would be equal; but this is never the case, for we find that when the resistance is balanced to a perfect zero for the stable period, loud sounds are given out in the variable period, requiring a fresh adjustment or balancing of the resistance of the wire, as well as a compensating opposing induction current from the sonometer to balance the self-induction. If we balance the resistance or the extra-currents alone there is no possible zero, but when both are compensated we find at once a perfect zero for the resistance of the wire, and for its extra-currents. [*Professor Hughes here explained in detail the electrical communications of the experimental apparatus used by him, which was arranged for demonstration on the table before the meeting.*]

Inductive Capacity of Metals.

The results of the following experiments prove that the force and duration of the extra-currents depend upon the kind of metal employed as a conductor, its molecular condition, and the form given to the conductor, independent of its resistance or the electro-motive force of the primary current. The increase of force by increased length is proportional to the length of wire less its additional resistance, but with wires of the same length increased cross section or diminished resistance does not produce a corresponding increase in the electro-motive force of the extra-currents.

The time of charge and discharge of the wire is independent of the electro-motive force of the extra-currents; for, if we compare currents of equal electro-motive force obtained from copper and iron, it will be found that the duration of these currents in wires of 1 mm. diameter will be seven times slower in iron than in copper, and a still greater difference will be found in larger wires. The longest or slowest charge and discharge take place in the purest soft iron, and have a constant ratio of increase with increased diameter of the wire; my experiments giving for wires of double the previous section, or for wires of four times less resistance, a mean increase of three times its previous duration.

The electro-motive force of the extra-current in different metals will be seen in the following table, and in order that the values obtained from the sonometer may be clearly understood I have reduced the results to comparative values.

The table of values were obtained on wires of similar length, having been repeated on a similar series of lengths ranging from 10 cm. to 5 mètres. The instrument is sufficiently sensitive for pieces only 10 cm. in length, and the results from the short lengths were as pronounced and accurate as those for greater

lengths. I may add that the instrument shows no effects or traces of static charge for the lengths mentioned.

Table I.

Wires 1 mm. in Diameter, 30 cm. in Length.

Soft Swedish iron	100	Copper...	20
Soft puddled iron	78	Brass	13
Swedish iron, not softened ...	55	Zinc*	12
Soft cast steel	41	Lead	10
Nickel*	34	German silver	7
Hardened cast steel	28	Mercury*	2
Cobalt*	24	Carbon*	1

* Being unable to procure wires of these metals, they were tested in the form of strips, and compared with similar strips of copper. Mercury was in a glass tube 2 mm. in diameter; carbon tested in the form of electric light carbon from 3 mm. to 10 mm.

The above table is only true for wires of 1 mm. diameter, as the effect depends on the size of the wire in relation to the nature of the metal. In soft Swedish iron a diminution in the electromotive force of the extra-currents takes place with each increase in its section, and this has been partially foreseen by Maxwell,* who said: "The electro-motive force arising from the induction of the current on itself is different in different parts of the section of the wire, being in general a function of the distance from the axis of the wire as well as time."

From this I expected that the increase of electro-motive force by an increased section would not increase directly as its sectional increase; but I was not prepared to find, as my experiments prove, that after a certain maximum diameter of wire has been reached a marked decrease in electro-motive force takes place with each further sectional increase, and that this maximum is variable with each metal.

* "Electricity and Magnetism," vol. ii., p. 291.

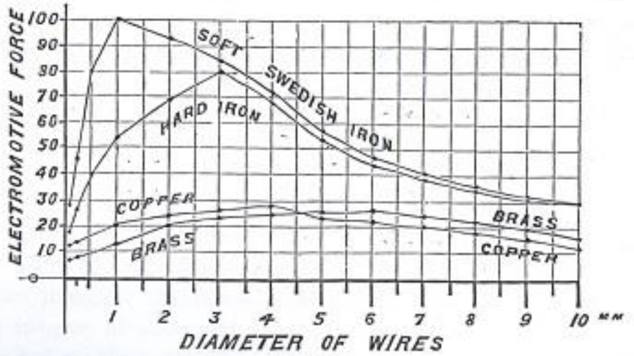

Fig. 2.

The diagram shows a rapid rise of force in soft iron from an extremely fine wire of 0·10 mm. section to a maximum at 1 mm., from which point there is a slow but continued decrease of force with each increase in the size of the wire, until at the comparatively great diameter of wire of 10 mm. the force is but a fraction more than in the extremely fine wire.

Hard Swedish iron has a less initial force in the fine wire, and does not arrive at its maximum until the wire has 3 mm. diameter, being then nearly of the same force as soft iron of the same diameter; the fall from this point is somewhat similar, but less than soft iron until at 8 and 10 mm.; soft and hard iron have absolutely the same values.

A curious change of values at different diameters will be seen in copper and brass. Copper, having nearly double the initial force in fine wires, arrives at its maximum at 4 mm.; but brass creeps slowly up, passing copper at 5 mm., arriving at its maximum at 6 mm., and finally, in the large section 10 mm., it has more force than copper, their positions being completely reversed.

I have been unable to obtain wires of different diameters of other metals; but zinc rods of 10 mm. gave a still higher rate than brass, whilst in small diameters its force was less. For non-magnetic metals it is probable that the greater the specific resistance of the metal the greater will be the diameter of the wire before the fall commences. There is no change in the relative positions of the different metals when using weak or strong

currents. The diagram shows the critical diameter of wires 30 cm. in length, but the critical diameter varies with the length, due to the increased resistance of the wires.

Carbon is remarkably free from self-induction, and although there is a rise of force in rods of 3 mm. to 10 mm., it is so small as to be hardly measurable. German silver rises with comparative rapidity, indicating that with wires of 20 mm. its force would equal that of copper. Carbon therefore seems peculiarly adapted as a resistance when used in the variable period of electric currents.

Influence of Parallel Currents.

The instrument being well adapted for showing the slightest change in the self-induction by the reaction of one portion of the current upon the other when in the same direction, as in a coil, or in the opposite direction, as in a parallel return wire, I made a series of experiments in order to observe the influence of different metallic conductors in this respect.

Two silk-covered iron and copper wires of similar diameter and length (1 mm. diam., 2 mètres in length) were each formed in a single loop of 66 cm. diameter. The extra-currents from iron were, as usual, six times stronger than those from a similar loop of copper. On closing the loop by bringing the opposite sides in close proximity and thus making a parallel return wire (the current ascending on one side and descending the other), I found that the reaction of currents in opposite direction was very different with different metals, the results depending more upon the nature of the metal than upon the proximity of the wires.

There was a reduction of the previous force of the extra-currents in iron, when forming a parallel return wire, of 15 per cent., whilst the reduction in copper was 80 per cent. Thus the currents in copper are far more influenced by an external wire than those in iron; consequently a telephone line having its return wire in close proximity should invariably be of copper, as not only is its specific inductive capacity less, but this is again reduced by the return wire, so that its self-induction is far below that of iron.

In order to observe the influence of currents in the same direction, the same wires were formed into a close coil of twelve turns of 2 cm. diameter; and from the known effects of parallel currents in the same direction we should expect a greatly increased effect. It was so in the case of copper, but iron was far less under the influence of an external parallel current; the strength of current in iron when formed into a coil being 57 per cent. greater than that of a single wide loop, whilst in copper the increase was 404 per cent., or seven times the increase of iron; and although iron when in a single wide loop had six times the force of copper, the comparative strength was reversed when the wires were wound as a coil, the extra-currents from the copper coil then having 14 per cent. greater strength than that from iron, and this difference could be rendered more evident by employing longer wires.

Thus copper, as regards extra-currents, is far more sensitive to the influence of external currents than iron, and the true self-induction from its own current can only be obtained by a straight wire, where the return wire is at such a distance that its influence is not appreciable.

Reaction of Contiguous Portions of the same Current.

It is well known that currents in separate portions of the same wire (as in a coil) react upon each other, and I felt convinced from the preceding experiment that self-induction is entirely due to similar electro-magnetic reactions between contiguous portions of the current in its own wire. Let us assume that an electric current consists of a bundle or an almost infinite number of parallel currents, the limit being a single line of consecutive molecules; then each line of current should by its electro-magnetic action react on each of the others similarly to wires conveying separate portions of the current, and the self-induction should be at its maximum when the lines are in the closest possible proximity, as in a conductor of circular section, and far less when separated, as in one of ribbon form, where

the outlying portions are separated by a comparatively great distance: there would still remain, in the latter case, the reactions from the near portions on each other, and these should again be reduced by cutting the ribbon into a number of thin narrow strips separated, except at their junction, to a sufficient distance to prevent any marked reaction.

My experiments prove that this assumption is an experimental fact; for we can reduce the self-induction of a current upon itself to a mere fraction of its previous force by simply separating as indicated the contiguous portions of a current from each other, the results proving that a comparatively small separation, such as is obtained by employing ribbon conductors in place of a wire of the same weight, reduces the self-induction 80 per cent. in iron and 35 per cent. in copper; and if we still divide the current by cutting the ribbon into several, say 16, strips (separating the strips at least 1 cm. from each other), then the combined but separated strips show a still greater reduction, being 94 per cent. in iron and 75 per cent. in copper.

The following table shows the comparative reduction of self-induction by employing ribbons and parallel separated wires:—

Table II.

Flat Strips compared with Round Wire 30 cm. in length.	Copper.	Iron.	Parallel Wires 30 cm. in length.	Copper.	Iron.
Wire 1 mm. diameter ...	20	100	Wire 1 mm. diameter...	20	100
Strips.			Single Wire.		
0·25 mm. thick, 2 mm. wide	15	35	0·25 mm. diameter ...	16	48
Same, 5 mm. wide... ...	13	20	Two similar wires ...	12	30
„ 10 „ „	11	15	Four „ „ ...	9	18
„ 20 „ „	10	14	Eight „ „ ...	8	10
„ 40 „ „	9	13	Sixteen „ „ ...	7	6
Same strip rolled up in the form of wire ...	17	15	Same, 16 wires bound close together... ...	18	12

The resistance of a conductor, or even the nature of its metal, has less influence on its self-induction than the form given to that conductor, the 1 mm. wire in the above table having a less resistance than the strip of 2 mm. wide, and a greater than any of the wider strips; but through all these variations we notice a gradual fall from the wire to the widest strip or ribbon, with a marked return to its previous force when the ribbon is rolled up in the form of a wire.

The reduction is greater in iron than copper, but its increase when rolled up is less than copper, thus agreeing with the previous observations on the difference of iron and copper to external reactions.

A still greater reduction takes place when we separate a current by using parallel wires separated 2 cm. from each other, as shown in the table. We then have a similar reduction to that produced by cutting the strips into several separate conductors; and we again remark that when the wires are brought close together (forming a stranded wire) copper rises in a far greater proportion than iron, the 16 fine iron wires twisted together as a stranded wire having 88 per cent. less induction than a solid wire of similar weight; a remarkable fact being that whilst a solid iron wire has an inductive capacity 80 per cent. greater than a solid copper wire, this is completely reversed when each metal forms a stranded wire of the same weight as the solid, for iron then has 33 per cent. less self-induction than copper. [*Lord Rayleigh, at the request of the President, advanced to the table, and after making with the Induction Bridge a few experiments with various kinds of wire, verified the results as predicted by Professor Hughes.*]

It is not necessary to use extremely fine wires when we desire to reduce the inductive capacity of iron to that of copper, for I have formed stranded wire rope of 16 strands of wire where each wire was 1 mm. in diameter, giving 75 per cent. less induction than a solid wire of the same resistance. I purchased an ordinary wire rope of 6 mm. diameter, having 6 strands of 6 wires, each 0·5 mm. diameter: this gave the best result yet obtained, for, on comparing 3 mètres of it with a similar length of solid iron wire of the same resistance, the 36-stranded wire had only 5 per cent. of the amount of induction shown by the solid wire.

Steel, in the form of ribbon or stranded wires, shows a similar effect to that of iron; and it is a remarkable fact that, whilst the

extra-currents from a steel or iron wire 4 mm. in diameter are extremely slow, and impossible to balance without reducing the time of the sonometer current (by the introduction of an iron core), the ribbon or stranded wire requires no such compensation, for its feeble extra-current is exceedingly sharp, and can be balanced to a perfect zero, being actually quicker than that of a solid wire of copper of the same resistance. This fact I regard as one of great importance for telegraph lines and lightning conductors.

A curious effect takes place if we employ mixed conductors, such as a compound wire of copper and iron. A fine coating of copper reduces the induction in a solid iron wire in a marked degree. This I found to be due to the difference of electro-motive force of the extra-currents in the two metals, for, by employing a fine copper wire parallel with an iron wire, and in contact at the ends, the extra-current was reduced 60 per cent. The copper wire, having a lower electro-motive force, probably acts as a shunt; but if the capacity of the iron has already been reduced, as in a sheet or stranded wires, then the addition of a single copper strand increases the force, as the electro-motive force of the extra-currents of copper is above that of stranded iron.

There has been for many years a discussion as to the merits of the round form as compared with the tape or ribbon form for lightning conductors. Those in favour of the former based their conclusions on experiments which gave a negative or no apparent difference between the two forms of conductors. Those in favour of ribbon conductors, as Sir W. Snow Harris, Professor Guillemin, and many others, based their opinion upon marked differences found when using high charges of static electricity. The latter supposed that there was a difference between discharges of static electricity and voltaic currents of low tension, and that the advantage recognised by almost conclusive experiments was due in a great measure to conduction by surface.

In the year 1864, Professor Guillemin and myself, as members of the Commission de Perfectionment of the French Telegraph Administration, were charged with the mission of testing the comparative merits of the lightning protectors then used upon their lines.

Our method of experimenting consisted in joining an insulated conductor to a short fine iron wire connected directly with the earth return wire. A Leyden jar battery charged by a Rhumkorf coil was discharged through this conductor, burning or deflagrating the fine iron wire. This wire represented the telegraph instrument requiring protection, and by placing the lightning protector connected with the earth in advance of the fine iron wire we could observe the amount of protection afforded. This answered extremely well for feeble discharges, but with the full power of our battery the fine iron wire was invariably destroyed, even with the best lightning protectors which are universally used to this day. Noticing that we could not give absolute protection to the fine wire by lightning protectors, we tried the effect of joining the conductor direct to a separate earth wire in advance of the fine wire, and with powerful discharges the wire beyond the protection was invariably burnt, notwithstanding that we connected the conductor direct to earth by a copper stranded wire of 1 cm. diameter. [*These experiments were more fully described and explained by Professor Hughes by diagrams on the board.*]

Professor Guillemin continued these experiments after my departure for Russia, and he found, by employing a thin sheet of copper as a conductor to earth in place of the copper stranded wire placed in advance of the fine iron wire, that the wire could be perfectly protected. The theory of this action was not understood at the time, and the experiment has not received the attention it deserved; but the mutual reactions of contiguous currents shown in this paper explain the phenomenon in the fullest degree, for we see that a sheet or ribbon conductor has far less self-induction than a wire or rod of the same material.

I am fully convinced from the results of my experiments that an enormous retardation or resistance is evident in all conductors at the first portion of the variable period, and that this is due to self-induction, the current thus arousing an antagonist in its own path sufficiently powerful, when the primary current has a high electro-motive force, to deflagrate or separate the wire into its constituent separate molecules, as shown by Dr. Warren de la Rue.

It is also evident from my experiments—which are easily

repeated, with invariable results—that a flat conductor has far less self-induction than a solid of circular section during the variable period; and even with a constant current, as in the stable period, this form of conductor, as shown by Professor George Forbes, would, from its greater radiation, convey more current with less heating than a wire or rod of the same resistance.

Lightning conductors are intended to convey a current of high intensity during an exceedingly short time, and should therefore be designed so as to convey this current with as little opposition from self-induction as possible; consequently I regard a solid rod of iron as the worst possible form for a lightning conductor. The conductor, if of copper, should be of ribbon form, say 1 mm. by 10 cm. wide, or if of iron, of numerous stranded wires or a wide ribbon of similar conductivity to that of the copper.

Self-Induction of a Telegraph Line.

A telegraph line may be considered as a single loop: the earth taking the place of a return wire can only affect the self-induction by a diminution of its effects, as in the case of a parallel return wire.

Mr. W. H. Preece has lately read a most valuable paper on "The Relative Merits of Iron and Copper Wire for Telegraph Lines,"* in which he shows, by comparative rates of speed with the same instrument, that on a copper and an iron line of 278 miles in length (between London and Newcastle), whose resistance and static capacity were rendered equal, there was an increase of speed in the copper line of 12·9 per cent. as compared with an iron wire.

I have not been able to test the relative speeds obtainable by telegraph instruments on wires of different material. The results in every case would depend very much on the apparatus employed, but I have considered the question from a point of view independent of the instruments.

There is a remarkable difference in the resistance of a wire

* British Association, Aberdeen, September, 1885.

during the stable and the variable period, the measurements taken in the stable period giving no real or approximate idea of what its resistance really is during the rise of the current in the wire.

A curious fact in relation to telegraphy is that all measurements are made during the period of a constant flow of current, whilst all instruments—particularly those requiring rapid changes in the current—work only during the rise and fall of the current, as in the variable period. Telegraph engineers, however, have not made the mistake of assuming that there is no difference in the resistance of a wire in these two periods, as it is well known that electro-magnets and coils have a far higher resistance during the rise and fall of a current, and coils simply augment the effect of a straight wire of a given length.

The present method of testing by Wheatstone bridge has been adopted because we had no practical means of measuring the resistance in the variable period; and I do not believe that this can be accomplished except by a similar method to that which I have used, in which the resistance and self-induction are separately measured and balanced, and by the use of an exceedingly rapid and sensitive instrument of observation, as the telephone, in place of the sluggish galvanometers, no matter of what construction.

The speed of telegraph instruments is greatly influenced by the resistance of the wire. I said in 1883* that a great difference would be found in the resistance of an electrical conductor if measured during the variable instead of the stable period, and I have made numerous experiments with the view of ascertaining to what extent this difference would probably be felt on telegraph lines.

I have already mentioned that the time or the duration of the extra-currents increases rapidly with the section of the conductor; consequently comparisons can only be made between wires of similar section for speed, or wires of similar resistance for differences in their variable period.

* Discussion on the paper of W. H. Preece on Electrical Conductors, *Proc. Inst. Civil Engineers*, vol. lxxv., 1883.

In measuring the resistance of a wire during the two periods, I have found it best to avoid the use of resistance coils, the simplest method being to measure or balance a given length of wire in one period, and then observing how much lengthening or shortening of the wire would produce a similar zero in the second period. Suppose that we commence by balancing the resistance during the variable period, and fix the sliding communications at the point at which we have obtained a perfect zero: we can now change to the stable period by means of the commutator; and as we no longer find a zero, but extremely loud sounds, we gradually lengthen the wire under observation until we have again a perfect zero. The amount of wire added to its previous length shows the difference in resistance between a conductor in which there are rapid electrical changes and that wherein the flow of current is constant.

Amongst numerous experiments I will cite a single example. I measured or balanced the resistance of an ordinary soft iron wire, 1 mètre in length and 4 mm. diameter, during the variable period, and found that it required in the stable period exactly 2 mètres 58 cm. to balance the previous resistance. Similar tests on a sample of best charcoal iron wire, as used on our telegraph lines, gave still more remarkable results, showing 225 per cent. difference between the two periods; for 1 mètre of this wire had, during the rise and fall of the current, precisely the same resistance as 3 mètres 25 cm. in the stable period. This shows that an iron telegraph wire has with rapid currents *more than three times* the resistance during its actual work than that supposed to be its true resistance.

It was difficult on short lengths to find any change whatever in the resistance of copper or stranded iron wires in the two periods; the time of discharge being excessively rapid, I could only estimate the resistance by the electro-motive force of the extra-currents, or by forming the wires into coils (when a remarkably great difference is shown), and then estimating the proportional amount due to its own reaction; by this method I was enabled to detect 10 per cent. difference for a solid copper wire, and but 8 per cent. for the stranded rope of 36 iron wires.

The difference in time of the duration of the extra-currents between solid iron and copper and between solid iron and stranded iron is so great that we may consider a solid iron wire to belong, comparatively speaking, to the class of slow conductors, whilst copper and stranded iron would belong to the rapid.

I have shown a difference of resistance in the variable period between copper and iron of at least 200 per cent.—a difference which will be felt on instruments depending upon rapid changes, such as the telephone; and it is evident that the more rapid the contacts of a telegraph instrument the greater will be the difference between copper and iron. There is consequently a great electrical advantage in those instruments which require only a single current for each letter, as the economy of electrical impulses allows them to work at a comparatively high speed; the duration of the extra-currents would be shorter than the length of their contacts, and consequently they would perceive very little, if any, difference between the two periods, or between iron and copper. If we use three or five currents for each letter, we must necessarily send them faster or closer together; and the difficulty increases in a rapid ratio with the speed of intermittent or reversed currents, until a point is reached (as I have shown in the case of best charcoal iron) where, whilst nominally working through 500 miles, we are practically working through an equivalent resistance of at least 1,500 miles, and this without taking into account the static charge, which would, in addition, from its comparatively extreme slowness of charge and discharge, cause the apparent resistance of the wire in the variable period to be much greater than I have mentioned.

In Mr. Preece's experiments he finds a difference of speed of 12·9 per cent. between iron and copper, which is far less than the difference of resistance during the variable period which I have obtained; and this may be explained by assuming that the speed of the reversed currents which he employed was only near the border land of extra-currents. I am convinced that if Mr. Preece could have increased the speed of the instruments he would have found a far greater difference between iron and copper; and if I regard the results of a solid iron wire alone, I should consider

iron as unsuitable for telegraph instruments requiring extremely rapid currents. Copper would reign supreme if it were not for the fact, which I have discovered, that stranded iron wires have even a greater rapidity of action than copper.

Physical Changes in the Conductor.

Self-induction not only depends on the nature and form of its conductor, but also on the physical state of the metal, as already shown in the case of soft and hard iron. I felt convinced that the higher force in iron was due to its magnetic capacity, and to prove this I tried the effect of heating the wire to a bright red heat. It is well known that iron loses its magnetic properties at bright red heat, and I found that its self-induction then fell to less than that of copper. This would have been conclusive had it not been for the fact that a different result takes place when the capacity of the iron for self-induction has already been reduced, as in the case of thin flat sheets of iron: in this case there is no disappearance or further decrease of induction except that due to the extra resistance caused by the increased temperature of the strip. Now, as the strip was highly magnetic when cold, and lost this property at red heat, there should have been some change in its self-induction if this were due to the magnetic nature of the iron alone. This requires further researches before a probable explanation can be given.

Iron is peculiarly sensitive to all physical changes. Mechanical strain of all kinds hardens the wire, and its influence on its self-induction can at once be detected. An iron wire under a moderate longitudinal strain loses 40 per cent., and its capacity is then less than unstrained cast steel.

Iron well annealed has much less resistance than the same iron when hard drawn, and soft iron is generally employed for telegraph lines; but during the variable period a curious reversal takes place, as then soft iron has a higher resistance than hard iron. This apparent anomaly is easily explained if we compare the far higher self-induction of soft iron. Work is done at the expense of electrical energy, and the apparent higher resistance is due to the greater electro-magnetic action in soft iron.

An iron wire shows traces of remaining circular magnetism after the passage of a continuous current, reducing the following extra-currents 10 per cent.

Magnetising the wire, or subjecting it to mechanical vibrations, when used separately, produce no apparent change in its inductive capacity, but a remarkable change takes place if either of these is used in conjunction with a constant current. Let us pass a constant current and heat the wire to red heat, allowing it to cool with the current on; or, in place of heat, magnetise the wire; or, in place of magnetism, give the wire mechanical vibrations: the result of either of these being a strong internal circular magnetism, due, I believe, to the loosening of the magnetic molecules, allowing them to rotate with greater freedom under the influence of heat, mechanical vibrations, or magnetism. A wire thus treated has no longer its previous self-induction, which has fallen 60 per cent.; and as the circular magnetism becomes fixed when the vibrations cease, this molecular structure remains a constant as long as we employ intermittent currents in the same direction, but the structure disappears the instant a reverse current is sent; and this explains why we have more than double the amount of self-induction from reverse currents, as each reversal destroys any remaining magnetism due to the previous passage of the current.

If we compare the electro-motive force of self-induction on a given length of wire with the secondary currents generated in a second but independent circuit, we find that the self-induction is the most powerful, the secondary currents generated in a close independent copper wire being 20 per cent. less than its own wire. There is no difference between the self-induction of a current and the secondary currents; they are, as proved by Faraday, part of the same phenomenon, the self-induction being evidently due to the electro-magnetic reactions of the primary current, and as magnetism permeates space, the separation of the wires only serves to insulate the primary, but does not affect its magnetic influence; and, as I have shown in the reactions of contiguous portions of the same current, so the magnetic reactions perpendicular to the axis of the current continue through the wire to all surrounding wires; and if we call the currents in the independent wire secondary, they are still secondary whilst enclosed in the wire of the primary; and as the reaction will ever be the strongest in the axis of the current, so will these currents be necessarily stronger than those induced in independent wires. For this reason we should be able to obtain extra-currents of far higher electro-motive force than would be possible from a secondary wire of the same length.

It was my intention, on the reading of this paper, to demonstrate by practical experiments some remarkable properties of extra-currents of high electro-motive force; but I find that the subject and apparatus employed require a longer description than the limits of this paper allow. I must also leave aside for the present my experiments upon coils of different forms with cores of different metals. These, as well as other results obtained, indicate that there is a large field of useful research in many directions, each, however, requiring special studies according to the object we may have in view.

The record of numerous experiments, of which this paper is only an abstract, shows that the nature of the metal as well as its physical condition has an important influence upon the self-induction of an electric current, and by a study of the reactions produced by the contiguous portions of a current, and by application of the results, we may, as in the case of iron, transform an extremely slow conductor into one of the greatest rapidity; I therefore hope not only that these researches may be of interest from a scientific point of view, but that the results obtained may be of practical utility in some of the numerous applications of electricity.

Mr. C. E. SPAGNOLETTI: Gentlemen,—As Professor Perry is now present, I will take this opportunity of presenting to him the books for Dr. Oliver Lodge, and ask him to kindly convey to that gentleman the pleasant assurance that the meeting had at the proper period manifested its expression of approval of the award of the Council in regard to the presentation.

Professor PERRY: Will you allow me on my own behalf to thank you very much for having inconvenienced yourself so much