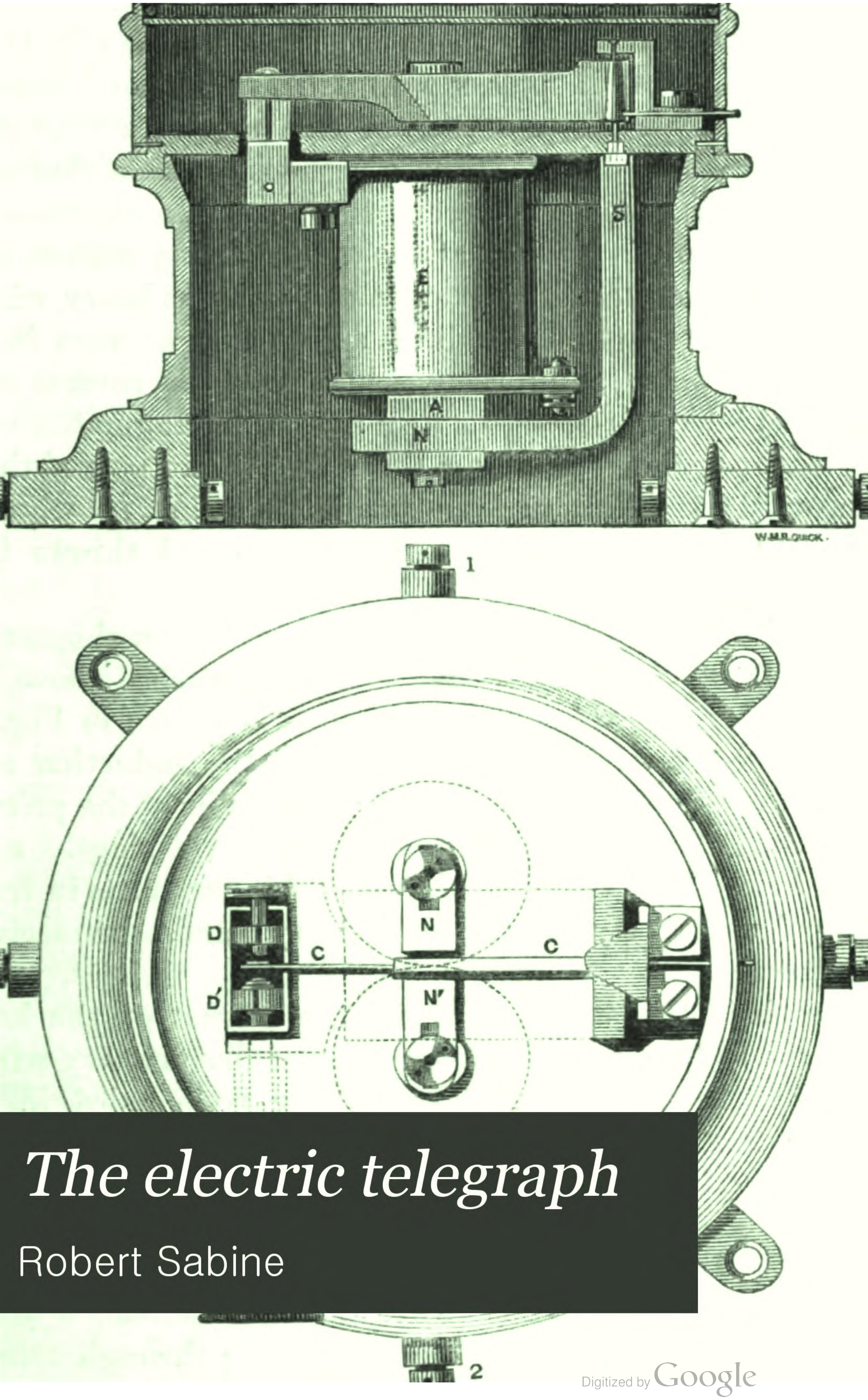

The electric telegraph

Robert Sabine

THE

ELECTRIC TELEGRAPH.

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ELECTRIC TELEGRAPH.

BY

ROBERT SABINE,

FEL. SOC. ARTS, MEMB. BRIT. ASSOC., ETC. ETC.

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TO

C. W. SIEMENS, ESQ.,

F.R.S., Memb. I.C.E., Memb. I.M.E., Etc. Etc. Etc.

My dear Sir,

Allow me to dedicate this little Book to you. There are two reasons which urge me to do so: first, that there is no name more intimately associated with the progress of Telegraphy, both in England and on the Continent, than your own; and secondly, that it gives me an opportunity of showing you how sensible I am of the many instances of kindness which I have experienced at your hands in affording me facilities for prosecuting my studies in this and other branches of applied science.

Believe me,

My dear Sir,

Very sincerely yours,

Robert Sabine.

London, January, 1867.

PREFACE.

THIS book was commenced with the intention of making it a purely Elementary Treatise. As he proceeded with his work, however, the Author became convinced that, in our language, the want is much more felt of such books as Schellen's, Dub's, Moigno's, Blavier's, and others, than of such as he had proposed to make his. He has therefore endeavoured to make it sufficiently elementary to come within the comprehension of every educated man, and, at the same time, sufficiently technical to be useful to electricians. The work is divided into Two Parts: the First being confined to a short history of the Electric Telegraph, and descriptions of many of the past and existing methods and apparatus; the Second Part being confined exclusively to the more scientific matter relating especially to Cable Work. No new theories are started, nor has anything been introduced which experience has not confirmed as having merits to recommend it.

In conclusion, the Author begs to tender his most hearty thanks to Mr. Varley, Professor Hughes, Mr. De Sauty, and others, for advice or information they have given him on points on which he was either doubtful or ignorant, and to Sir Charles Bright for the valuable curve of the resistance of gutta-percha at different temperatures. At the same time he has much pleasure in acknowledging the aid he has gleaned from the excellent works of Wiedemann, Dub, Schellen, Moigno, Blavier, De Castro, and others.

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THE ELECTRIC TELEGRAPH.

PART I.

SKETCH OF THE HISTORY AND PROGRESS OF THE ELECTRIC TELEGRAPH, WITH DESCRIPTIONS OF SOME OF THE APPARATUS.

I. Early Observations of Electrical Phenomena.

1. The phenomenon of electrical attraction produced by friction of bodies was, in some instances, known to the ancients. It was first noticed about six hundred years before the Christian era, by Thales, the founder of Ionic philosophy. He observed that when amber was subjected to friction it acquired the power of attracting light substances, such as bits of feathers. On this account he was led to attribute to amber a species of vitality. The next mention we find is that of Theophrastus, who, three hundred years later, observed that a hard stone (supposed to be tourmaline), when rubbed, attracted straws and little pieces of sticks in its vicinity. Pliny, as well as other naturalists, both Greek and Roman, remarked, at different dates, the same phenomenon, which they regarded, in the spirit of the times, with superstitious reverence.

2. No systematic inquiry into the subject was undertaken until Dr. Gilbert, towards the close of the sixteenth century,

at the expense of much pains, arranged and published a list of all those bodies in which he had observed the same property.

Towards the middle of the seventeenth century Dr. Wall discovered the electric spark on rubbing a cylinder of amber with a piece of flannel. On approaching the cylinder with his finger, he obtained, for the first time, the spark, and noticed the noise which always accompanies it.

Boyle and Otto Guericke added to the little stock of knowledge then in hand, as well as Hawkesbee; but their discoveries are a little out of the reach of Telegraphy.

3. The first discovery which we have on record of the power of transmitting the electric fluid to a distance through an insulated wire, is that of Stephen Grey, pensioner of the Charter House. Grey, having succeeded in electrifying a glass tube open at both ends, was desirous of finding out whether he could obtain the same result if he stopped up the ends with corks. This shows how at random the experiments were conducted at that date, and how little system had been introduced into these inquiries. But Grey's experiment succeeded, and he was surprised to find the corks also highly electrified. On presenting the corked ends of the tube to a feather, he found that the feather was first attracted and then repelled. This led him to infer that the electricity which the tube had acquired by friction passed spontaneously to the corks. From the communication of electricity from tubes to corks Grey was led to transmit it through strings and wires; and in 1727 we find him employing a wire 700 feet long, suspended in the air by silk threads, to one end of which he brought his excited glass tube, whilst another person at the other end observed the electrification.

4. After Grey, the subject was taken up by Desaguilliers, who instituted inquiries into the different conductibilities of bodies. The discoveries of Grey had caused the bodies operated on to be assorted into two classes, which Desaguilliers proposed to distinguish by the names of "electrics" or non-conductors, and "non-electrics" or conductors.

5. On making experiments on the attraction of any light

substance by an electrified body, it had been observed by Grey that the former was repelled from the moment that it was itself electrified by contact. It was further remarked that when the electrified body was a rod of glass, the light body would be strongly attracted by a stick of resin also electrified by friction. It is not a settled question whether Symner it was, or Dufay, who in 1733 concluded, from the combination of these facts, the existence of two electricities. It was supposed that all bodies in their natural state contained an equal amount of each of these electricities in equilibrium; but that from the moment this equilibrium was upset, and until it was re-established, the elements would divide themselves between the rubber and the rubbed body—those identical with the electricity of a glass rod showing themselves in some bodies, and, in others, those of the same nature as the electricity of a piece of resin. This occasioned the former to be called *vitreous electricity*, and the latter *resinous electricity*.

6. Benjamin Franklin believed, however, in the existence of only a single fluid, and explained the phenomena by supposing that on exciting any substance till the equilibrium of the electricity was destroyed, an excess of it would be deposited on one side, and a deficiency, necessarily to the same amount, would occur on the other. Hence he gave the name of *positive electricity* to that which Dufay had called vitreous, and *negative* to that called resinous.

Dufay, without the remotest idea of the transmission of signals for practical purposes, and with the pure curiosity of a physical experiment, made some capital attempts to ascertain the distance to which the electric attraction could be observed in an insulated wire.

7. Winckler, in Leipsic, and Lemonnier of Paris, in 1746, and Dr. Watson, Bishop of Landaff, in 1747, took up the same inquiry.

8. The discovery of the Leyden jar by Muschenbrœck, of Leyden, in 1746, came very opportunely for the experimenters in the transmission of electric power.

Muschenbrœck, struck by the escape of electricity into the air, which he attributed to the vapours and effluvia suspended in it, had determined on an experiment by which he sought to preserve some of the mysterious fluid, to keep it out of contact with the air. For this purpose he selected water as the recipient of the fluid, and a glass bottle as the best means of imprisoning it. On one occasion, happening to hold the bottle in his right hand, whilst he was charging the water contained in it by a wire leading to the prime conductor of a very powerful electrical machine, Muschenbrœck removed the wire with his left hand, and received a shock which his imagination probably led him to regard as much more terrible than it really was; for, in a conversation with Réaumur, he is reported to have said that he felt himself struck in his arms, shoulders, and breast, so that he lost his breath, and was two days before he recovered from the effects of the blow and the terror. "For the whole kingdom of France," added Muschenbrœck, "I would not take a second shock."

9. The Leyden jar—such was the name given to it thenceforth—was soon endowed with a more convenient form and

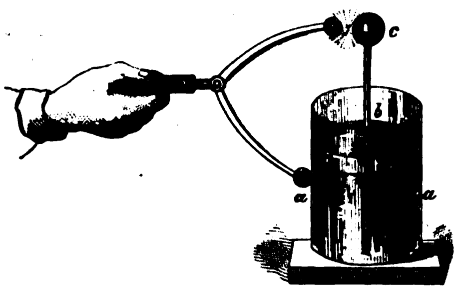


Fig. 1.

became one of the chief instruments in the hands of the students of electricity.

The form given to it by Watson resembled that shown in Fig. 1, in which *a a* is a coating of tinfoil upon the outer surface of a glass jar, *b b* an inner coating of the same material, and *c* a knob attached to a wire in connection with the inner coating. On charging the knob and inner coating of the jar with, for example, positive electricity, the charge acts upon the natural electricity of the outer coating, which, during the operation, should be connected by a conductor with the earth, decomposes it, and repels the positive element, attracting and retaining the negative element on the outer coating. If the communication between the knob and the source of electricity be broken, the charge will remain accumulated on the inner coating of the jar; and if a connection be then made between the knob and the outer coating by means of a wire or of a discharger, as shown in the figure, the opposite electricity accumulated on the coatings of the jar will rush towards each other through the conductor, producing, on its approach to complete communication, a spark of brilliant light.

Suppose that, instead of the short discharger, a wire of several yards' length were employed, the effect would be the same. And it was virtually to ascertain the maximum length of this wire that formed the purpose of those researches of Grey, Desaguilliers, Watson, and others, to which we are indebted for the first suggestion of a telegraph.

10. Watson, in 1747, stretched a wire across the Thames, over old Westminster Bridge. One end was fixed to the exterior coating of a Leyden jar, the interior coating being connected to earth through the body of the experimenter, and the other end held by a person who grasped an iron rod. The moment the latter dipped the rod into the river, both felt a shock.

Subsequently, in the same year, Watson transmitted an electric discharge through 2,800 feet of wire and the same distance of earth at Stoke Newington; and on the 14th of August, in the same year, repeated his experiments on a considerably larger scale, transmitting the electric impulse through 10,600 feet of wire suspended between wooden poles erected on Shooter's Hill.

Franklin made similar experiments in 1748 across the Schuylkill, at Philadelphia, and Du Luc, about the same date, across the Lake of Geneva.

But up to this time the experiments had been conducted without a suspicion of the glorious results to which they were leading. And even in the hands of the ingenious and original Franklin, we do not find that the idea suggested itself to him to apply the power he found capable of being felt at the end of a wire of considerable length, to the communication of intelligence.

II. Telegraphs by Frictional Electricity.

11. In the *Scot's Magazine* for 1753 * is a letter to the Editor, from a correspondent signing himself "C. M.," to whom we must give the credit of being the first who published the idea of applying electricity to the telegraph.

This interesting communication is as follows :—

"*To the Editor of the 'Scot's Magazine.'*

"Renfrew, Feb. 1st, 1753.

"Sir,—It is well known to all who are conversant in electrical experiments, that the electric power may be propagated along a small wire, from one place to another, without being sensibly abated by the length of its progress. Let, then, a set of wires, equal in number to the letters of the alphabet, be extended horizontally between two given places, parallel to one another, and each of them about an inch distant from that next to it. At every twenty yards' end, let them be fixed in glass, or jeweller's cement, to some firm body, both to prevent them from touching the earth or any other non-electric, and from breaking by their own gravity. Let the electric gun-barrel be placed at right angles with the extremities of the wires, and about one inch below them. Also, let the wires be fixed in a solid piece of glass, at six inches from the end; and let that part of them which reaches from the glass to the machine have sufficient spring and stiffness to recover its situation after having been brought in contact with the barrel. Close by the supporting glass, let a ball be suspended from every wire; and about a sixth or an eighth of an inch below the balls place the letters of the alphabet, marked on bits of paper, or any other substance that may be light enough to rise to the electrified ball; and at the same time let it be so continued that each of them may reassume its proper place when dropped. All

* *Scot's Magazine*, vol. xv. p. 73. The page is headed "An expeditious method of conveying intelligence."

things constructed as above, and the minute previously fixed, I begin the conversation with my distant friend in this manner:—Having set the electrical machine a-going as in ordinary experiments, suppose I am to pronounce the word *Sir:* with a piece of glass, or any other *electric per se*, I strike the wire *S*, so as to bring it in contact with the barrel, then *i*, then *r*, all in the same way; and my correspondent, almost in the same instant, observes these several characters rise in order to the electrified balls at his end of the wires. Thus I spell away as long as I think fit; and my correspondent, for the sake of memory, writes the characters as they rise, and may join and read them afterwards as often as he inclines. Upon a signal given, or from choice, I stop the machine; and taking up the pen in my turn, I write down whatever my friend at the other end strikes out.

"If anybody should think this way tiresome, let him, instead of the balls, suspend a range of bells from the roof, equal in number to the letters of the alphabet, gradually decreasing in size from the bell *A* to *Z;* and from the horizontal wires let there be another set reaching to the several bells; one, viz. from the horizontal wire *A* to the bell *A*, another from the horizontal wire *B* to the bell *B*, &c. Then let him who begins the discourse bring the wires in contact with the barrel, as before; and the electric spark, breaking on bells of different size, will inform his correspondent by the sound what wires have been touched: and thus, by some practice, they may come to understand the language of the chimes in whole words, without being put to the trouble of noting down every letter.

"The same thing may be otherwise effected. Let the balls be suspended over the characters as before, but instead of bringing the ends of the horizontal wires in contact with the barrel, let a second set reach from the electrified cable, so as to be in contact with the horizontal ones; and let it be so contrived at the same time, that any of them may be removed from its corresponding horizontal by the slightest touch, and may bring itself again into contact when set at liberty. This may be done by the help of a small spring and slider, or twenty other methods, which the least ingenuity will discover. In this way, the characters will always adhere to the balls, excepting when any one of the secondaries is removed from contact with its horizontal; and then the letter at the other end of the horizontal will immediately drop from its ball. But I mention this only by way of variety.

"Some may, perhaps, think that, although the electric fire has not been observed to diminish sensibly in its progress through any length of wire that has been tried hitherto, yet, as that has never exceeded some thirty or forty yards, it may be reasonably supposed that in a far greater length it would be remarkably diminished, and probably would be entirely drained off in a few miles by the surrounding air. To prevent the objection, and save longer argument, lay over the wires from one end to the other with a thin coat of jewellers' cement. This may be done for a trifle of additional expense; and as it is an *electric per se*, will effectually secure any part of the fire from mixing with the atmosphere.

"I am, &c.,

"C. M."

This is one of the most interesting documents to be found in the whole history of Telegraphy. The writer was, evidently, not acquainted with Watson's experiments, or he would not probably have suggested insulation by "jewellers' cement;" but the suggestion was an ingenious one. The idea which we find of keeping his lines charged with electricity, and giving the signals by discharging them, as well as that of reading signals by sound of bells, both of which, long years afterwards, were brought, with certain modifications, into practice, deserve to be remembered to his credit.

12. To Lesage,* however, belongs the honour of having established, in practice, the first telegraph wire for the transmission of intelligible signals. His system was almost the realisation of the idea of the Scotchman, "C. M." He erected at Geneva, in 1774, a telegraph line of twenty-four metallic wires, insulated from each other. Each wire was connected at the further end to a separate pith-ball electroscope, and corresponded to one of the letters of the alphabet. In this way any letter could be indicated by bringing to the end of the wire corresponding to the letter to be sent, a source of static electricity produced by friction, which would immediately cause the divergence of the pith balls of that particular electroscope.

13. The electroscopes used in these experiments consisted of two small pith balls suspended from a common metallic support, by cotton threads or fine wires. It will, without

* Moigno's "Télégraphie Électrique," p. 59.

further explanation, be evident from what has gone before, that in charging the system, shown in equilibrium at *a*, Fig. 2, the two pith balls, having the same kind of electricity, would repel each other and assume a position similar to that shown at *b* in the same figure. This would continue as long as the charge lasted. The balls would, in course of time, however, approach each other again by their own gravity, the escape of their electricity into the surrounding air diminishing the repelling force. This could, and perhaps was, effected by Lesage suddenly, by discharging his line as soon as he had given a signal; in other words, by letting the line and pith balls reassume their state of electrical equilibrium.

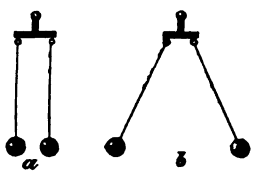


Fig. 2.

14. Lomond, in 1787, by the employment of a delicate electroscope, and combinations of signals, given by the divergence of pith balls, succeeded in transmitting intelligence with the aid of a single line wire.

A short account of this invention is given by Arthur Young,* in the following words:—

"M. Lomond has made a remarkable discovery in electricity. You write two or three words on a paper; he takes it into a room, and turns a machine enclosed in a cylindrical case, at the top of which is an electrometer, a small fine pith ball; a wire connects with a similar cylinder and electrometer in a distant apartment; and his wife, by remarking the corresponding motions of the ball, writes down the words they indicate, from which it appears that he has formed an alphabet of motions. As the length of the wire makes no difference in the effect, a correspondence might be carried on at any distance, within or without a besieged town, for instance, or for objects much more worthy of attention and a thousand times more harmless."

15. In 1794, Reusser proposed, in the *Magazin de Voigt*,† the construction of a telegraph by means of electrical dis-

* "Travels in France," vol. i. p. 979, 4th edition. 1787.

† *Magazin de Voigt*, vol. ix. p. 183.

charges passing over the parts of a broken conductor enclosed in a glass tube, or by letters formed by spaces cut out of parallel strips of tinfoil pasted on square plates of glass. Such letters are shown in Fig. 3. An electric discharge from the interior coating of a Leyden jar, being sent, for instance, through the double strips of tinfoil, from the end marked + to the end marked — connected with the outer coating of the jar, a spark would pass over each of the intervening spaces at the same time, and the letter would appear beautifully illuminated in the dark. This experiment of Reusser forms to this day a very common illustration of tension electricity in lecture rooms.

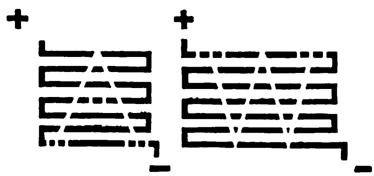


Fig. 3.

Reusser further suggested to call the attention of the observer, at the distant station, by firing an electric pistol by means of the spark.

16. In Spain, about the same time, Don Silva read a paper before the Academy of Sciences of Madrid, on a system of telegraphing with a single wire, by means of continuations of sparks, said, by the *Magazin de Voigt*, to have been carried out, two years later, with no small success, by the Infanto Antonio; and Betancourt stretched a single line in the air, over a space of twenty-seven miles, between Madrid and Aranjuez. He employed a battery of Leyden jars and received signals by observing the divergence of suspended pith balls.

17. Cavallo was the next who strove to attain the perfection of a telegraph by means of frictional electricity. In 1795 he published his "Traité d'Électricité," in which he gives descriptions of his systems of electric signalling and communication. He proposed to transmit letters and numerals by combinations of sparks and pauses. His electric alarm was based upon the explosion of a mixture of hydrogen and oxygen gases or of gunpowder by the electric discharge.

18. It is necessary here to depart a little from historical order, to mention the last and most ingenious invention of a telegraph worked by frictional electricity; this was the

invention of Mr. Ronalds, of Hammersmith. For the purposes of experiment he erected a line, eight miles long, insulated by silk and dry wood, in his garden, and also buried a considerable length of wire, insulated in glass tubes, encased in pitch and wood, in the earth. This was in 1823. For the following description of the invention we are indebted to Mr. E. Highton's* book :—

Ronalds employed an ordinary electric machine and the pith-ball electrometer in the following manner. He placed two clocks at two stations; these two clocks had upon the second-hand arbour a dial with twenty letters on it; a screen was placed in front of each of these dials, and an orifice was cut in each screen, so that one letter only at a time could be seen on the revolving dial. The clocks were made to go isochronously, and as the dials moved round, the same letter always appeared through the orifices of each of these screens. The pith-ball electrometers were hung in front of the dials.

It is evident, therefore, that if these pith balls could be made to move at the same instant of time, a person at the transmitting station, by causing such motion in both those electrometers, would be able to inform the attendant at the distant or receiving station what letters to note down as they appeared before him in succession on the dial of the clock.

This was accomplished in the following manner. The transmitter caused a current of electricity to be constantly operating upon the electrometers, except only when it was required to denote a letter, and then he discharged the electricity from the wire, and instantly both balls collapsed. The distant observer was thereby informed to note down the letter then visible. In this way letter after letter could be denoted, words spelt, and intelligence of any kind transmitted. All that was absolutely required for this form of telegraph was, that the clocks should go isochronously *during the time* that intelligence was being transmitted; for it was easy enough by a preconcerted arrangement between the

* "The Electric Telegraph," by E. Highton, p. 50. 1852.

parties, and upon a given signal, for each party to start their clocks at the same letter, and thus, if the clocks went together during the transmission of the intelligence, the proper letters would appear simultaneously, until the communication was finished. The attention of the distant observer was called by the explosion of gas by means of electricity from a Leyden jar.

Fig. 4 shows an elevation of the apparatus, in which D is an electrical machine, B a pith-ball electrometer, A the screen

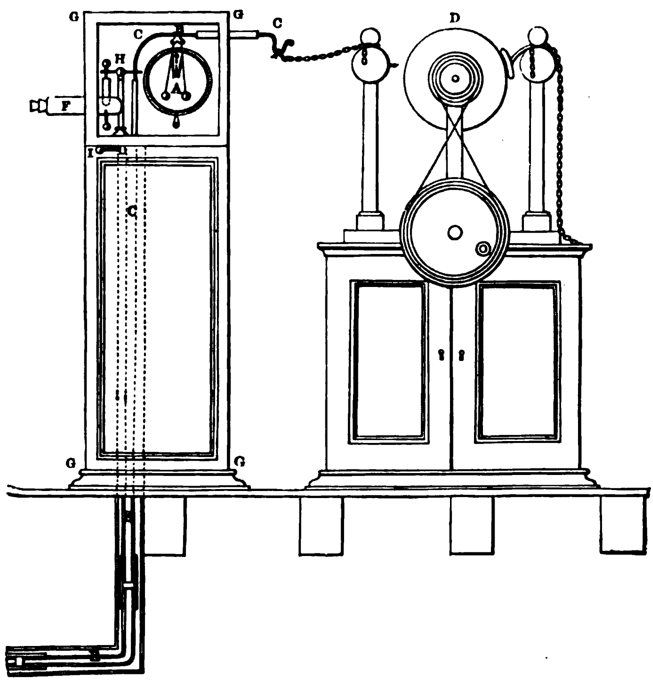


Fig. 4.

hiding the letters on the dial-plate except the one seen through the orifice, F the gas alarm, and E the tube conveying the wires from the station.

Fig. 5 shows the dial; and Fig. 6 the same with the screen before it, and the pith-ball electroscope.

Too much credit cannot be given to all these men for their energy in struggling, with the imperfect means and small experience at their command, to realise an end which the nature of the electricity they employed rendered impossible. And if we can award to none of them the title of the inventor of a practicable telegraph, we must, at least, give them credit for having fully appreciated its importance, and

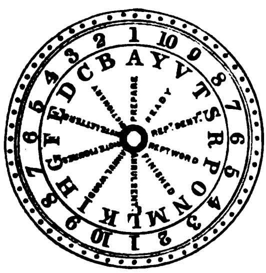


Fig. 5.

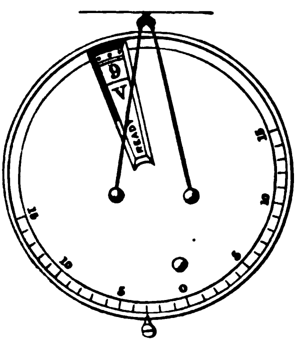


Fig. 6.

for having dedicated their energies to the accomplishment of the task they set themselves, and persevered in the face of many sad difficulties and disappointments.

III. Telegraphs by Galvanic Electricity.

19. A new discovery—that of galvanic electricity—had for some years occupied the attention of the scientific world, and at the beginning of the present century the thoughts of students of electricity were directed to its application for the purposes of Telegraphy instead of the unmanageable frictional electricity with which they had hitherto had to content themselves.

The first mention we find of this species of electricity is in the recital which Sulzer published, in 1767, of the following experiment. On taking two pieces of different metals, and placing one of them (zinc, for example) above, and the other (perhaps copper) underneath his tongue, he found that, so long as the metals did not make contact with each other, he felt nothing; but that when the edges were brought together over the tip of his tongue, the moment contact took place, and during the time it lasted, he experienced an itching sensation, and a taste resembling that of sulphate of iron. If he changed the relative positions of the metals, he experienced a different sensation, which he found difficult to describe.

Sulzer supposed that the contact of the two metals occasioned a vibration of their particles, which, acting on the nerves of the tongue, produced the taste in question.

The next to whom chance afforded an opportunity of making the discovery of galvanism, but who let it pass with as little profit as Sulzer had done, was a student of medicine in Bologna. He was once occupied, we are told, in dissecting a mouse which he held in his hand, when, having touched one of the nerves with his scalpel, he felt a shock resembling that produced by electricity.*

In 1790 Madame Galvani, wife of the professor of anatomy at Bologna, being attacked with a slight cold, her physician prescribed her *frog broth.*

Frogs were provided for the purpose, skinned, washed, and laid upon a table in the laboratory of the professor to await the moment when they were to undergo the culinary operation. Whether this operation was to be performed in the laboratory, is not said; it is certain, however, that Madame Galvani was there with one of the professor's assistants, who was at the moment engaged in some experiments with a large electrical machine which stood upon the same table. Whenever the assistant, in the course of his experiments, took sparks from the conductor of the machine, Madame Galvani was astonished to observe a twitching resembling life in the limbs of the dead frogs.

This circumstance excited the lady's curiosity in the highest degree, and she related her observation to her husband, who immediately repeated the experiment, and found

* "Essai sur l'Histoire Générale des Sciences, pendant la Revolution Française," par J. B. Biot, p. 9.

the convulsions return whenever he took sparks from the machine.*

The professor, who was luckily not more learned in electrical science than in some of the other branches of physics, was unable to give the explanation of the phenomenon, with which he would probably have contented himself, and have let the matter drop, had he been an experienced electrician. But he was struck by the novelty of the new fact, and he determined to follow it up.

Galvani thenceforth prosecuted his studies and experiments on the electricity of animals, with perseverance, and chance rewarded him for his industry by again coming to his aid. In his experiments on the electricity of frogs, he had occasion to separate the lower parts of the bodies from the upper. Having prepared a frog in the ordinary manner, on one occasion he remarked that on hanging it up to an iron balustrade of his house, by a hook of copper wire passed through part of the dorsal column remaining above the junction of the thighs, it all at once underwent a series of lively convulsions.

The professor was more than ever astonished, for there was this time no electrical machine to account for the appearance, and he was compelled to take refuge in the hypothesis of what he called "animal electricity," supposing opposite kinds of electricity to exist in the muscles and nerves of the animal.

In this hypothesis he regarded the muscles and nerves as the charged coatings of a Leyden jar. It is worthy of remark and regret that Galvani should have so thoroughly mistaken the important part played in the affair by the two metals, iron and copper. He regarded these, however, only in the light of a compound conductor, through which the opposite electricities, assumed to exist in the nerves and muscles, discharged themselves.

It is not a rare thing in the annals of science that mere chance has suggested some great discovery. But we seldom

* "Aloysii Galvani de Viribus Electricit. in motu musculari Commentar." p. 2.

meet with chances so favourable to advancement as those which directed the attention of Galvani to the study of animal electricity by a phenomenon of electroscopic sensibility in the nerves of a frog; his fortunate ignorance, which, combined with his ardent imagination, caused him to form hypotheses only excellent because, in being stubbornly supported by himself, he added to the stock of facts, through his many and varied experiments, and in occasioning a discussion in which his views were successfully refuted by the masterly intellect of Alexander Volta.

"In der Beobachtung einer anfangs isolirt stehenden Erscheinung liegt oft der Keim einer grossen Entdeckung," says Humboldt;* and Galvani found it so, and deservedly earned his title of a pioneer in science.

20. Immediately after the publication of Galvani's discovery and hypothesis, Alexander Volta, professor of physics at Pavia, occupied himself with an inquiry into the causes of the frog phenomenon, and was not long in perceiving a want of basis in Galvani's theory. With much penetration Volta recognised the intrinsic elements in the complicated appearance which Galvani had discovered, and sought, with success, to produce the same by substituting other materials for the frogs and other animal bodies. He contended that the two metals, copper and iron, in the experiment of Galvani, were the real electromotors, and that the muscles of the dead frogs only played the part of a moist conductor in completing the circuit. Volta was of opinion that the simple contact of two dissimilar metals was sufficient to develop electricity, and that the strength of the electricity excited depended upon the nature of the metals. This was vigorously opposed by the partisans of Galvani, who held tenaciously to the doctrines of their master, and a scientific war of opinions ensued between the schools of Pavia and Bologna, out of which Volta came victorious even before he had completely verified his sagacious conjectures by experimental proof.

If the tongue be applied to the conductor of an electric machine which is being turned, an acid or alkaline taste

* Cosmos. Einleitende Bemerkungen.

will be perceived according as the conductor is being charged with positive or negative electricity. The similarity of these results with those obtained by Sulzer was an analogy advanced by Volta in support of his contact theory.

Another theory, and that now very generally accepted, was first suggested by Fabroni, and is known in contradistinction as the chemical theory. This theory regards chemical decomposition as necessary to the development of the voltaic current.

A discussion of the arguments advanced in support of these two theories would be out of place here. Müller has devoted an excellent chapter to the subject in one of his books.* The German physicists for the most part hold out for the contact theory, whilst the French and English generally accept the chemical as the most rational and as that affording the most satisfactory explanations of known phenomena.

21. Volta, in 1800, wrote a letter from Como to Sir Joseph Banks, President of the Royal Society, in London, stating that he had found a means of augmenting, at pleasure, the development of galvanic electricity. This he had accomplished by placing upon a plate of glass first a disc of copper, then on this a disc of zinc, and over these a similar sized disc of damp cloth; and by continuing to pile up discs of these materials, in the same order, copper, zinc, cloth, until he had a sufficient number. He then connected wires to the lower and upper plates.

22. This apparatus is known as the Voltaic pile.† Its properties are concisely stated as follows:—

1st. It communicates a charge of positive electricity to a condenser in connection with the wire attached to the last zinc disc, when the last copper disc is connected with the earth.

2nd. It communicates a charge of negative electricity to the condenser when the poles are reversed, that is to say, when the zinc of the upper part is put into contact with the earth, and the condenser with the copper disc at the bottom. These

* "Fortschritte der Physik," vol. i. p. 225.

† The more recent forms given to the pile, as at present employed in telegraphy, are explained in the second part.

experiments may be repeated *ad infinitum* even after the pile has been mounted some hours, provided the cloth retains some moisture.

3rd. It produces chemical effects with an energy proportional to the number of elements accumulated.

The zinc disc which forms one of the extremities of the pile, being that which, in communication with the condenser, gives a positive charge, has been called the *positive pole*, and the copper plate at the bottom of the pile the *negative pole*.

23. Immediately after the receipt of Volta's letter, by the President of the Royal Society, a pile was constructed on this principle by Mr. Nicholson (the conductor of *Nicholson's Journal*) and Sir Anthony Carlisle. A drop of water being, on one occasion, used by them to make a good contact between the conducting wire and a plate of metal with which they were experimenting, Carlisle observed a disengagement of gas from it. Further experiments discovered very shortly the decomposition of water by the electric current. Thus was chance once more on the stage in promoting electrical discovery, and this time the magnificent investigations of Humphrey Davy were the result.

24. In the year 1808, Herr S. T. Sömmering communicated to the Academy of Sciences in Munich his invention of a system of telegraphing based upon the discovery of the British chemists, Nicholson and Carlisle,* that water is decomposed into its constituents of oxygen and hydrogen by the voltaic current.

At the station which was to receive signals were arranged, in a narrow vessel of water, thirty-five glass tubes, each containing a gold point, twenty-five marked with letters of the alphabet, nine with numerals, and one with a zero. From each point an insulated wire was led to a metal terminal at the transmitting station.

To send a signal it was only necessary to bring the two poles of a voltaic pile to two of the terminals in question. The current passing from one terminal traversed its line wire to the voltameter at the receiving station, where it

* "Galvanism," by Sir W. S. Harris, p. 35.

passed between the gold points corresponding to the terminals touched by the poles, and returned through the other line wire to the terminal of the other pole of the pile.

In doing this, bubbles of hydrogen appeared at the gold point in communication with the positive pole, and bubbles of oxygen at the other one. Thus two signals were given simultaneously, to which that of the hydrogen took precedence. When it was desired to indicate only one letter, the positive pole of the battery was brought in connection with zero and the negative with the letter to be transmitted. The con-

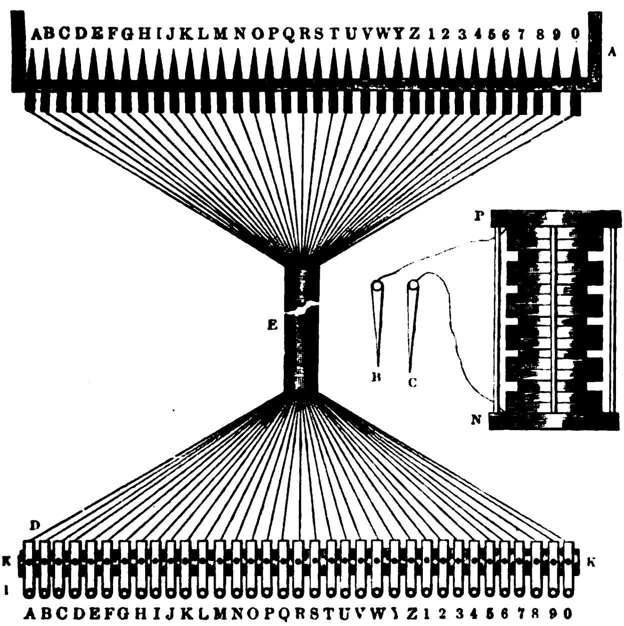


Fig. 7.

nection wires were well insulated, and, at a little distance from the transmitting terminals at one end, and from the voltameters at the other, were bound up in the form of a cable. Sömmering proposed to call the attention of the receiving station by liberating an alarm by means of accumulated gas.

Fig. 7, a copy of that given by Sömmering in his description of this telegraph, will illustrate the foregoing. A A is a sectional view of the glass reservoir. A B C . . . . 8 9 0 are the thirty-five gold points of the voltameter arrangement, passing through the bottom of the glass reservoir. The lower ends of the thirty-five gold points were soldered to insulated copper wires passing through the tube E to the transmitting station. Here the wires, marked with the respective letters and numerals, were insulated on a wooden support, K K. The ends of the terminals were furnished with holes, I, to receive the poles B and C of the voltaic pile P N.

The construction of this telegraph—the first in which voltaic electricity was employed—involved an outlay which, in conjunction with the slowness of working, would have prevented its commercial utility even if the science had not advanced by any of those astonishing strides which marked its progress a few years afterwards.

25. An improvement on the system of Sömmering was published by Schweiger, of Halle, in an appendix to his memoir of Sömmering. He suggested that, for the alarm, it would be possible to employ a pistol by the connection of a battery to the pile. In addition to this, he proposed to diminish the number of wires used in Sömmering's telegraph to two, by using two galvanic piles of unequal power, so that the amount of gas given off in a certain time by the one battery would be much more than by the other, and by varying the time of development of the gas and of the intervals, he proposed to form a code of signals.

26. About the same time that Sömmering invented his telegraph, the same system was suggested by Professor Coxe, of Pennsylvania, and described by him in a paper published in Thomson's "Annals of Electricity," 1810. Coxe had the idea also of telegraphing by means of the decomposition of metallic salts. His systems were, as he described them, considered, however, impracticable.

IV. Telegraphs by Electro-Magnetism and Magneto-Electricity.

27. The power of lightning to weaken the magnetism of the compass needle, and even sometimes to reverse its polarity for a long time, suggested the suspicion of a near relation between electricity and magnetism. The definite discovery was, however, not made until, in 1820, Professor Oersted, of Copenhagen, found that a magnetic needle, suspended in the neighbourhood of a wire in which a current of electricity was passing, was deflected from its position of rest. Ampère made experiments, and found the law by which this influence was governed, and which he briefly expressed as follows :—

"Imagine a human figure in the direction of a conductor through which a positive current is flowing upwards, the figure will have the north pole on the left hand if its face be turned towards the needle."

Thus, if a positive current pass along the upper wire in the annexed figure (Fig. 8) from *a* towards *b*, the magnetic needle N S, suspended in its neighbourhood, will be deflected, and take up a position indicated by the dotted line *n s*, at nearly right angles to the wire. When the current is reversed the poles will be deflected in the other direction, the pole *n* being where *s* is, in the figure. It will become evident on regarding the figure also that, if a similar current pass in the lower wire from *b′* to *a′*, it must produce the same magnetic direction upon the needle as a current in the upper wire would from *a* to *b*. In the case of the upper wire the observer's head is supposed to be near *b* and his feet near *a*, the current passing upwards in the direction of the arrow, and the north pole is found on his left hand when he faces the needle. In the case of the lower wire, however, the direction of the current is reversed, and the

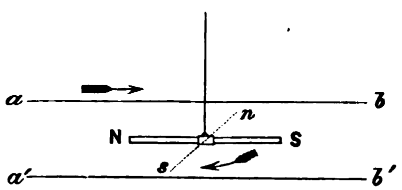


Fig. 8.

position of the observer must be supposed to be reversed also—head at *a′*, feet at *b′*. While he faces the needle the north pole is still found on his left hand. When currents pass, therefore, in both wires at the same time in opposite directions, they act in the same sense on the magnetic needle N S, and, other things being equal, their combined force is double that of a single wire. The same would be reached by joining *b* and *b′* by a wire, and letting a current of equal strength pass from *a* to *b*, *b′*, and *a′*.

28. Professor Schweiger, of Halle, the same who suggested improvements of Sömmering's telegraph, soon after the discovery of electro-magnetism by Oersted, invented an apparatus based on this principle, which he made by coiling a wire several times round a magnetic needle, and found that the deflecting force increased with the number of turns. Such an apparatus, called an electro-magnetic multiplier, is shown in Fig. 9. It has since become one of the most essential instruments for the measurement and indication of galvanic electricity.

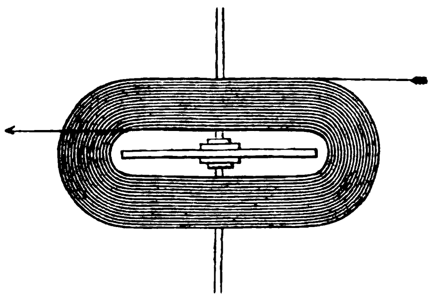


Fig. 9.

29. The brilliant discovery of electro-magnetism* was speedily followed by attempts to employ it for the telegraph, which made, from this time, gigantic progress towards its present state of perfection.

The idea of substituting magnetic needles suspended in multipliers of wire in place of the voltameters of Sömmering

* It is said that the same discovery had already been made in 1802, by Grandominico Romagnosi, of Trent, and made known in a book entitled "Manuel du Galvanisme," published in Paris in 1805. If it be true that Romagnosi discovered the deflection of a magnetic needle by the current, the discovery could have excited no interest whatever, and must have been known within a very limited circle, as the discovery of Oersted in 1820 was immediately hailed as a landmark in science.

seems first to have occurred to Ampère, who explains it in a paper read before the Academy of Sciences at Paris, in October, 1820.*

He says that by means of the same number of magnetic needles and line wires as there are letters of the alphabet, and with the help of a voltaic battery whose poles could be brought in connection, one after the other, with the ends of the wires, a telegraph might be produced by which all possible communications might be made to a person at a distance off, who was charged to observe the needles. If a keyboard whose keys were each marked with a letter of the alphabet were adapted to the battery, so that on pressing down the key of any letter the circuit corresponding to that letter would be closed, correspondence could be carried on with ease, and would only require the time necessary to press down the keys at the one station, and to read off the letters from the deflected needles at the other.

This telegraph, as imagined by Ampère, was, however, doomed to the same fate as that of Sömmering, of never coming into practice, and for the same reasons, principally the number of line wires. Had Ampère combined his system with that which Schweiger proposed of reducing Sömmering's telegraph to two wires, or with any other using a code of signals, the problem of the electric telegraph would have been solved from the year 1820.

But two serious inconveniences—the irregularity of the piles, and, above all, the rapid decrease of their intensity—only permitted the application of this great idea on a small scale.

30. Ritchie, however, carried out a really excellent modification of Ampère's invention by encircling thirty magnetic needles with coils of wire; each needle was furnished with a small screen, so that when it was unaffected by a current, the screen covered over a letter of the alphabet, which was exposed as soon as the needle was deflected.

This telegraph was first exhibited in public, some years later than the date of its invention, by Mr. Alexander, of

* "Annales de Physique et de Chemie," vol. xv., p. 72.

Edinburgh. He divided his thirty wires into twenty-six letters of the alphabet, three signs of punctuation, and one asterisk for indicating the end of a word. The return circuit was formed by a single wire.

31. In 1825, Mr. Sturgeon, of London, discovered that when a soft iron bar is surrounded by a helix of wire, through which a galvanic current is passing, it acquires a considerable quantity of magnetism, which lasts as long as the current continues in the coil. In this way he constructed some powerful magnets. A form which he made, and which acquired an immense lifting power, is shown in Fig. 10. For this purpose, pieces of soft iron were bent in the form of a horse shoe, round the horns of which he wound spirally a length of well insulated copper wire. One end of the magnet so arranged became a north pole and the other a south pole if the spiral wire were wound in the same direction throughout, supposing the horseshoe to be bent straight.

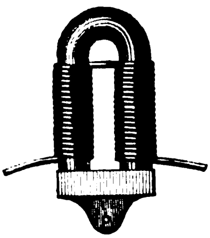


Fig. 10.

The positions of the poles depend, of course, upon the direction in which the spirals are wound, and upon the direction in which the current traverses them, according to the same law as that by which Ampère expressed the positions of the poles of deflected magnets.

In the coil, Fig. 11, for example, the positive current descending between the observer and the soft iron bar, the spiral being right-handed, the north pole would be on the right hand of the observer.

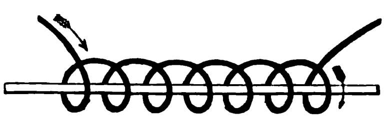


Fig. 11.

In order to increase the power of electro-magnets the wire has to be wound several times round each of the horns. This is generally done by means of bobbins of wire which can be removed at pleasure. Such magnets have been made with iron cores 3 inches and more in diameter, and over a foot in length, which have carried nearly a ton weight. It is strange that this discovery, which has since proved so important in practical telegraphy, was not made use of in any system until some years later.

32. The next important step towards the perfection of present telegraphy was that made in 1832 by Baron Schilling von Cronstadt. In some of the accounts of his system we read that it consisted of a certain number of insulated platinum wires united by a silk cord, which set in motion, by means of a sort of piano, five magnetic needles placed in a vertical position within coils of wire. According to other accounts, he employed only one magnetic needle and multiplier, with two leading wires, and was enabled, by means of a combination of the deflections of this needle to the right and left, by changing the poles of the battery at the ends of the two wires, to give all the signals necessary for a complete correspondence. His call signal was given by means of an alarm. Schilling executed models of his apparatus, which were exhibited before the Emperor Alexander, and still later before Nicholas. He, however, unhappily died before carrying out his invention in practice. The probability is that he suggested both the systems of five and single needle instruments; the latter as an improvement on the former.

33. We owe to the enterprising genius of Michael Faraday the two discoveries not less important in physics than useful in relation to the telegraph—Volta-electric induction, and magneto-electricity.

These were no chance discoveries; and in this they differ from those made by Galvani, who stumbled over his phenomena; they were results of profound consideration; Faraday anticipated his discoveries before he made them. He says, in his "Experimental Researches," * "Certain effects of the induction of electrical currents have already been recognised and described; as those of magnetism; Ampère's experiments of bringing a copper disc near to a flat spiral; his repetition, with electro-magnets, of Arago's extraordinary experiments, and perhaps a few others. Still it appeared unlikely that these could be all the effects which induction by currents could produce. . . . These considerations, with their conse-

* "Experimental Researches in Electricity," 1st series, vol. i. p. 1.

quence, the hope of obtaining electricity from ordinary magnetism, have stimulated me at various times to investigate experimentally the inductive effects of electric currents. I lately arrived at positive results, and not only had my hopes fulfilled, but obtained a theory which appeared to me to open out a full explanation of Arago's magnetic phenomena, and also to discover a new state which may probably have great influence in some of the most important effects of electric currents."

The first successful experiment of Faraday was made with 203 feet of copper wire, coiled in one length on a wooden bobbin, and a similar length interposed on the same bobbin between the turns of the first coil. The wires were insulated from each other by twine. The ends of one of the coils were connected to the two ends of a multiplier with a finely suspended magnetic needle—a galvanometer; and the ends of the other coil with a battery of one hundred pairs of four-inch square plates with double coppers. When contact was made with the battery, there was, says Faraday, a sudden and very slight effect at the galvanometer, and there was also a similar slight effect when the contact with the battery was broken. But during the continuance of the voltaic current through the one helix, no galvanometer appearances, nor any effect like induction upon the other helix, could be perceived.

Faraday began these experiments in 1831 and continued them during following years. He found that not only were currents induced in helices by induction of others in their neighbourhood in which currents were passing, but that on inserting the end of a permanent magnet into the middle of a helix of wire, a current of electricity was generated whose direction depended upon the pole inserted and the end of the spiral with regard to the direction of its windings. He says, "If such a hollow helix as that described be laid east and west, or in any other constant position, and a magnet be retained east and west, its marked pole always being one way, then, whichever end of the helix the magnet goes in at, and, consequently, whichever pole of the magnet enters first, still the needle is deflected the same way: on the other hand, whichever direction is followed in withdrawing the magnet, the deflection is constant, but contrary to that due to its entrance."

34. In 1833 Schilling's proposition of the manner of giving signals with a single needle was carried out in a more complete form by the Göttingen physicists, Gauss and Weber. Their telegraph consisted of a single magnetic needle surrounded by a multiplier of wire, the needle being moved, however, by magneto-electricity instead of galvanism. This was the first employment of Faraday's discovery in the service of Telegraphy.

We read, in relation to this telegraph, in a report of the magnetic observations of these physicists,* the following:—

"There is, in connection with these arrangements, a great, and until now, in its way, novel project, for which we are indebted to Professor Weber. This gentleman erected, during the past year, a double-wire line over the houses of the town (Göttingen), from the Physical Cabinet to the Observatory, and lately a continuation from the latter building to the Magnetic Observatory. Thus an immense galvanic chain (line) is formed, in which the galvanic current, the two multipliers at the ends being included, has to travel a distance of wire of nearly 9,000 (Prussian) feet. The line wire is mostly of copper, of that known in commerce as 'No. 3,' of which one mètre weighs eight grammes. The wire of the multipliers in the magnetic observatory are of copper, 'No. 14,' silvered, and of which one gramme measures 2·6 mètres. This arrangement promises to offer opportunities for a number of interesting experiments. We regard, not without admiration, how a single pair of plates, brought into contact at the further end, instantaneously communicates a movement to the magnet-bar, which is deflected, at once, for over a thousand divisions of the scale."

And further on, in the same report:—

"The ease and certainty with which the manipulator has the direction of the current, and therefore the movement of the magnetic needle, in his command, by means of the communicator, had, a year ago, suggested experiments of

* Pogg. Ann., 32, p. 568; and "Dingler's Journal," 55, p. 394.

an application to telegraphic signalling, which, with whole words and even short sentences, completely succeeded. There is no doubt that it would be possible to arrange an uninterrupted telegraph communication in the same way between two places at a considerable number of miles distance from each other."

The purpose of setting up this aerial line was not for the study of telegraphy, nor for the perfection of telegraph apparatus; but to enable these physicists to institute inquiries into the laws of the intensity of galvanic currents, under different circumstances, on a large scale. At the same time the lines were used for regulating the clocks at the Cabinet de Physique and observatories.

The telegraph apparatus consisted of three parts:—

1. The apparatus for production of the currents;
2. The receiving instrument; and
3. The commutator, or instrument for reversing the currents.

The arrangements used by Gauss and Weber for the production of magneto-electric currents at the transmitting station consisted of two or three large bar magnets, *n s*, Fig. 12, each weighing 25 lbs., fixed together vertically, with their similar poles in the same direction, on a stool, P P. A wooden bobbin, *a a*, supplied with handles, *b b*, and wound with more than one thousand turns of insulated copper wire,* rested on the stool and around the upper ends of the magnet, so that, on lifting up the bobbin by the handles, a current

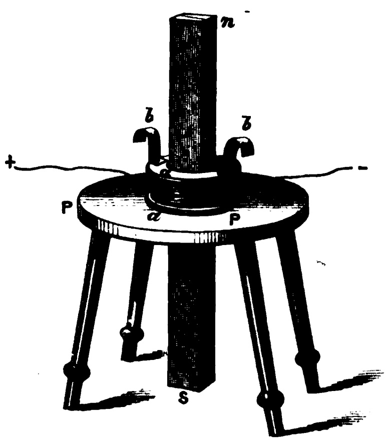


Fig. 12.

* In the apparatus constructed at a later date by Gauss and Weber, they increased the number of turns to seven thousand.

would be induced in the coil in one direction; and on lowering it again, a current would traverse the coil in the opposite direction. The ends + and — were connected to the commutator, and thence to the line wires. The coil *a a* was called the inductor.

The receiving instrument placed at the distant station is represented in Fig. 13. It consists of a large coil or multi-

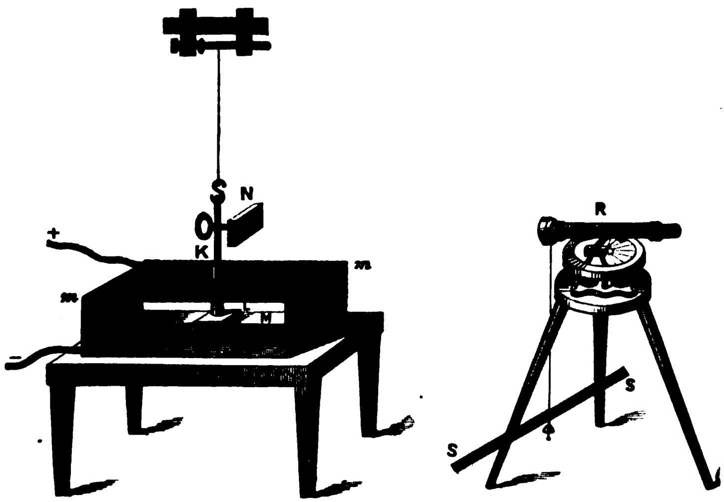


Fig. 13.

plier, *m m*, of insulated copper wire, on a copper frame, the ends + and — being in connection with the line wires.

A permanent steel magnet, M M, 18 inches long and 3″ × 5″ transverse section, was suspended in the middle of the multiplier by a number of parallel silk fibres from the ceiling of the room.

To enable the observer to read off with care the small deflections of the magnet, a mirror, N, was affixed to the shaft K, carrying the magnet, in which was seen, through a telescope, R, at a distance of 10 or 12 feet, the reflex of a horizontal scale, S S.

The commutator, introduced for directing the currents in one direction or the other through the line, consisted of an arrangement for bringing two points alternately in communication with two others. Let *a* and *c*, Fig. 14, be two points in connection with the two poles of a battery, or other electromotive system, and *b* and *d* the ends of any other circuit; if the metal bars *e* and *f* be pressed upon the ends *a b* and *c d* respectively, the current will pass in the direc-

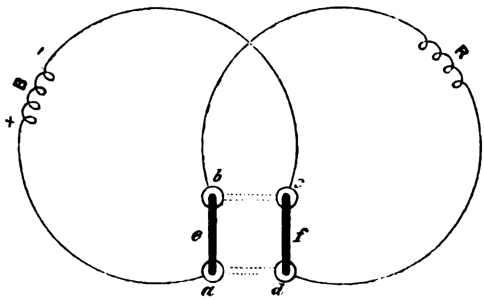


Fig. 14.

tion B + *a e b* R *d f c* — B. But if the bars *e* and *f* be removed from these positions and placed at right angles, that is to say, *e* between *b* and *c*, and *f* between *a* and *d*, as shown by the dotted lines, the current will go through B + *a d* R (in the opposite direction) *b c* — B.

On lifting up the coil *a a*, Fig. 12, from the stool to the top of the vertical magnet-bars, a current was induced in the wire encircling them. This current passed by the commutator, placed as in Fig. 14, from *a* to *b*, through one of the line wires and the multiplier R of the receiving station, deflecting the magnet for an instant in one direction, and returned by the other wire over *c* and *d* of the commutator. When it was wished to deflect the needle of the receiving instrument in the opposite direction, this was attained by simply lowering the coil *a a* again to its original place, and the observer at the receiving station read off one deflection to the right, for instance, and one to the left. But, in constructing a code of signals, it was necessary that two or more deflections to the right or left should frequently follow each other. This was done by means of the commutator.

Thus, on lifting the coil *a a*, if we suppose a deflection of the magnet was produced to the right, by reversing the commutator and then lowering the coil again, another deflection in the same direction would be observed. To produce a third deflection in the same direction it would be necessary, evidently, to reverse the commutator again before raising up the inductor. After this fashion Gauss and Weber were enabled, by an ingenious combination of deflections to the right and left, to form the following alphabet and numerals with a maximum of four elementary signals in a letter :—

r = *a*	*rrr* = *c,k*	*lrl* = *m*	*lrrr* = *w*	*llrr* = 4
l = *e*	*rrl* = *d*	*rll* = *n*	*rrll* = *z*	*lllr* = 5
rr = *i*	*rlr* = *f,v*	*rrrr* = *p*	*rlrl* = 0	*llrl* = 6
rl = *o*	*lrr* = *g*	*rrrl* = *r*	*rllr* = 1	*lrll* = 7
lr = *u*	*lll* = *h*	*rrlr* = *s*	*lrrl* = 2	*rlll* = 8
ll = *b*	*llr* = *l*	*rlrr* = *t*	*lrlr* = 3	*llll* = 9

r represents the swing of the north pole of the magnet towards the right, and *l* the swing of the same pole towards the left of the magnetic meridian.

Various lengths of the pauses between the signals indicated the conclusion of words and sentences.

The copper frame around the needle was necessary in order to prevent the great number of oscillations which the magnet would have made across the meridian had no such check been introduced.

The checking action of masses of metal in the vicinity of an oscillating magnet was discovered by Arago, and has been described by Sir William Snow Harris,* in whose experiments the oscillations of a freely suspended magnetic needle were reduced from 420 without a damper, to 14 with a damper of copper surrounding the needle.

In the case of the magnet used by Gauss and Weber, its mass, and the minuteness of the angle which was necessary for the deflection to be read off with the aid of the telescope and mirror, must have assisted materially in bringing it back to the meridian line.

* "Magnetism," p. 58; "Phil. Trans.," 1831, Part I.

35. Gauss and Weber's line, as has been said, was erected between the Physical Cabinet and the observatories of Göttingen for other than telegraph purposes. It was for this reason that Gauss, unable to afford the time necessary to perfecting the system, which he believed capable, with modifications, of leading to brilliant results, requested Professor Steinheil, of Munich, to simplify the apparatus and endow it with a practical application.

The perfection to which this ingenious inventor brought Gauss and Weber's telegraph has rendered it as much or more his than theirs. He studied thoroughly the subject of magneto-electricity, and made experiments, discoveries, and suggestions which earned for him the name of the founder of electro-magnetic telegraphy.

A description of this telegraph by its inventor is to be found in *Dingler's Journal*, 70, p. 292.

It consists principally of three parts—the inductor, the receiving apparatus, and the line.

The compound permanent magnet employed by Steinheil in his apparatus consisted of seventeen horseshoe magnets, weighing together 60 lbs., capable of lifting about five times its own weight. Two induction coils, of together 15,000 convolutions of insulated copper wire, turned on an arbor, and presented in rotation the axes of the coils to the poles of the magnet, so that when one coil was under the north end of the magnet, the other would be under the south end. The commutator in connection with these coils was so constructed that, in turning them from right to left, the alternate currents, or all those going in one direction only, passed through the line, and, on turning them backwards or from left to right, only those currents in the opposite direction were let into the circuit, the others being cut off.

Steinheil was careful to admit his currents for the shortest possible space of time, and for this purpose, allowed the contact springs of his commutator to make contact with the lines only at the moment when the induced current was at its maximum. Fig. 15 represents the contact plate to which the leading wires from the receiving station were connected. The contact springs to which the ends of the wire coils were attached travelled in the white annular spaces, and made contact only at *a* and *b*, whilst in every other position the circuit was interrupted.

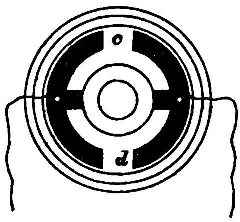
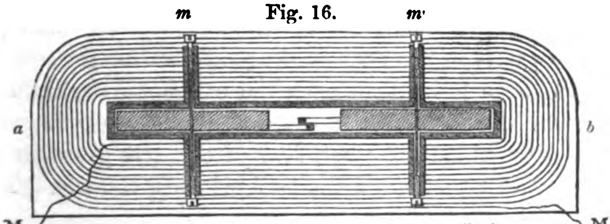


Fig. 15.

The receiving apparatus consisted of an oblong coil of wire or multiplier of 600 turns, in the centre of which were supported, on vertical axes, two magnetic needles, their neighbouring ends having opposite magnetic polarity. Fig. 16 gives a vertical, and Fig. 17 a horizontal section of this instrument. *a b* is the coil of wire, N S and N S, the magnet needles, turning on the axes *m* and *m'*, and

m Fig. 16. *m'*



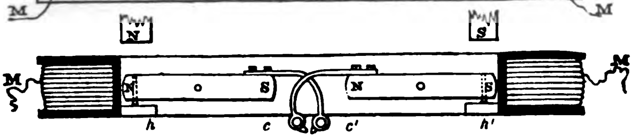
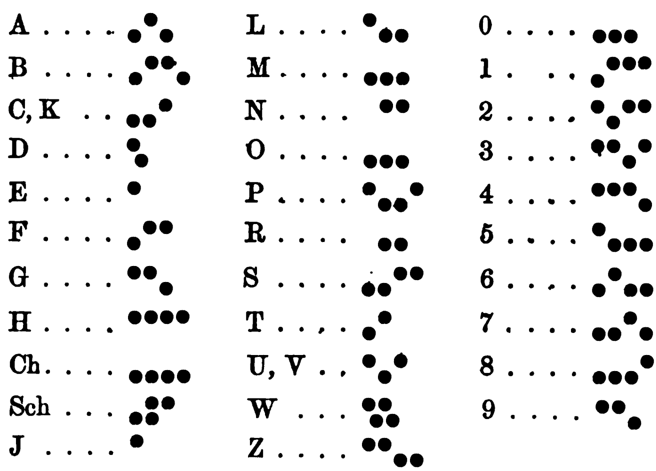


Fig. 17.

carrying on their neighbouring ends brass continuations with small ink reservoirs, *c c'*. These reservoirs were furnished with capillary tubes and filled with printer's ink, so that on coming in contact with the strip of paper travelling before them they each printed a dot. Two plates, *h h'*, prevented the needles from being deflected in the direction opposite to that in which they were to print, as the deflection by the current would otherwise have caused them to swing, and perhaps mark the paper, not only when responding to signals, but also when oscillating.

By means of the plates, therefore, a current sent through the coil deflected only one of the needles at a time, the other being held back; and on the current being changed, the reverse took place—the other needle only being deflected. Thus the signals on the paper were recorded in two lines—those to the right marking the deflections in that direction, and those on the left indicating the left hand deflections. A paper strip was kept in uniform motion by means of clockwork, which, whenever a mark was made, moved the paper onwards, leaving a blank space before the next signal. These signals were necessarily only dots, because induction currents are only of momentary duration.

Much nicety was required in obtaining magnets of exactly the right size. They could not, for example, be large, because their inertia would have been too great; nor too small, because their mechanical force would not have been great enough to have effected the printing. Two small permanent magnets in the rear of the printing needles retarded their inclination to be deflected when not under the influence of currents. The letters of the alphabet were constructed from combinations of, at most, four of the dots given in succession by the pointers of the two printing needles. They were arranged by Steinheil as follows:—



Messages were sent with this apparatus at the rate of ninety-two words in a quarter of an hour,* or over six words per minute.

The line wires were in three parts; the first included a length of 30,500 feet, erected in the air a few inches over the roofs of the houses between the Royal Academy of Munich and the Observatory at Bogenhausen. The weight of this section was about 200 lbs. The greatest span between two poles was 400 yards. The second section of the line connected the residence of Professor Steinheil with the Observatory in the Lerchenstrasse,—there and back a length of 2,000 yards; and the third section, a length of about 400 yards, connected the Academy with the workshop of the physical cabinet.

36. When experimenting on the Nuernburg and Fuerther Railway, to ascertain if the rails could not be made use of as lines for the service of a telegraph, Steinheil made the important discovery that the earth might be used as part of the circuit of an electric current. This discovery, which ranks with those of Volta and Oersted, was one of the greatest contributions ever made to the progress of the telegraph. Had the identity of the electricities been known earlier, return circuits other than the earth for voltaic currents would never have been used; for in all the earlier experiments and attempts with frictional electricity, the earth was used as the return circuit.

Steinheil took advantage of his discovery, and removed the halves of his lines, leading, in their stead, the corresponding connections of his apparatus to plates of metal buried in the earth.

A communicator of peculiar construction enabled the operator to transmit to, and receive from, either Bogenhausen or Lerchenstrasse, at pleasure. It was arranged that when the indicator was in circuit with one station, the wire of the other should be connected to the multiplier of the receiving instrument.

The receiving instrument was not used exclusively to record the messages on the paper strips; sometimes small hammers

* *Dingler's Journal*, 67, p. 370.

were substituted for the ink reservoirs, striking against bells of glass or metal of different notes. Thus Steinheil's apparatus formed also, upon occasion, an acoustic telegraph.

The history of the subject so far shows us that no single individual can claim the distinction of having been the "inventor of the electric telegraph;" but if there is one worker who deserves more credit than another for his energy, intelligence, and success in the service of his adopted science, that man is certainly Professor Steinheil.

37. The ingenious experiments with which Professor Wheatstone occupied himself, in 1834, in his researches on the velocity of the electric wave in solid conductors, seem to have first directed his attention to the subject of telegraphy. Mr. Cooke had already employed himself with the construction of telegraph lines for railway purposes before he joined Professor Wheatstone.

Their first joint invention was a telegraph with five indicators and as many line wires. Its appointments were as follows:—Five multipliers of fine insulated copper wire, with light magnet-needles, were arranged in a line across the back of a diamond-shaped dial-plate. The upper side of the plate, which served at the same time as a cover for the case containing the multipliers, was marked with twenty letters of the alphabet, C, J, Q, U, and Z being omitted, as capable of being replaced by others, at the expense, perhaps, of a little orthography, but at the saving of another line wire with its magnet-needle and multiplier. The margin contained the nine numerals and 0. Fig. 18 shows the upper side of the dial-plate, with pointers attached to the axes of the magnet-needles, broken away in the middle, to show the multipliers. Each pointer was deflected from its position of rest always under the same angle on each side, so that by observing the deflections of any two needles, and following with the eye the direction pointed out by their nearer ends, at the point of intersection of these imaginary lines would be found the letter intended to be transmitted. Thus, in telegraphing a letter of the alphabet, the deflections of two needles in contrary directions were always necessary. In Fig. 18, for example, the needles 1 and 4 are deflected, pointing to the letter V. The numerals and 0 were telegraphed by the deflections, to the right or left, of single needles.

One end of each of the multipliers was brought out on the lower half of the right-hand side, and continued to one

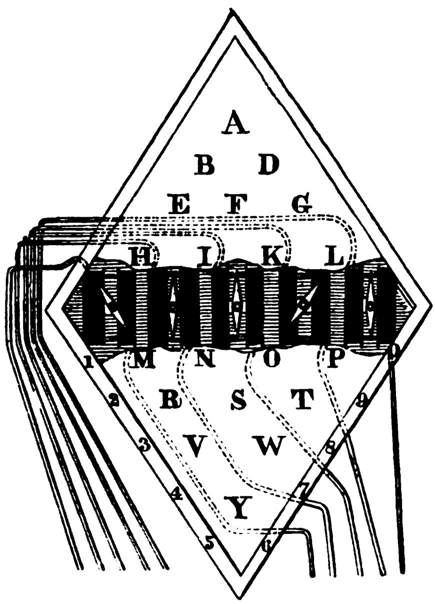


Fig. 18.

of the five-line wires; the other ends were joined together and attached to the line used for a return circuit.

The manipulator or key, Fig. 19, consisted of six metallic springs—6, 1, 2, 3, 4, 5—each of which was provided with two buttons with contacts working downwards upon two parallel metal strips, P and N, to which the poles of a voltaic battery were connected. With this arrangement, the operator, by pressing down, at the same time, the buttons of two springs, one over each of the strips P and N, could transmit a current through one line and back through another, deflecting thereby the two needles at the receiving station for signalling a letter.

As the numerals were indicated by the deflections of single needles, a sixth wire was provided for the return circuit.

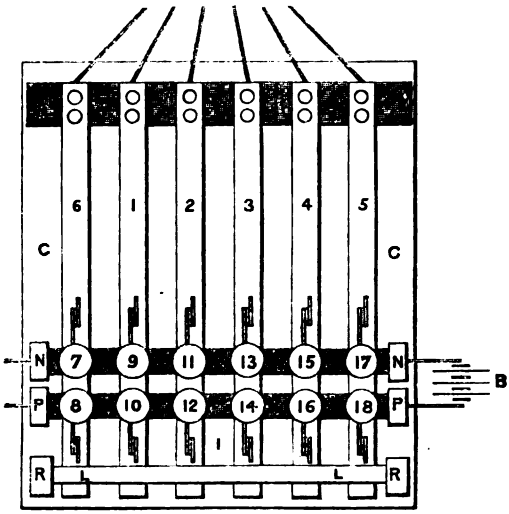


Fig. 19.

This telegraph, although extremely beautiful in detail, was inferior in a practical sense to that of Steinheil. It was put up on the London and Birmingham and Great Western railway lines, and tried fairly, but found, on account of the number of line wires, to be too expensive, and was accordingly given up.

38. The necessity of supplying the receiving station with some signalling apparatus for calling the attention of the observer to the commencement of a correspondence had been fully understood by every inventor since Reusser, who proposed to attain this by firing an electric pistol, and Sömmering, who proposed to do the same by the liberation of mechanism by accumulated gas. It was left, however, to the energy and persevering genius of Wheatstone to completely solve the problem.

The first alarm employed by him was an apparatus in which the attraction of a soft iron armature to the cores of an electro-magnet, whose coils were in connection with the line, released a wound-up mechanism.

This alarm arrangement is given in Fig. 20. The tooth-wheel *n* was arrested by the end of the lever *p*. On the other end of *p* was a soft iron armature, *v*, which, when a current passed through the coil U of the electro-magnet, was attracted, and released the wheel. The case contained a clockwork surmounted by a bell, which was struck by a hammer, moved backwards and forwards by means of an eccentric.

At the sending station were a small battery, K, and a key,

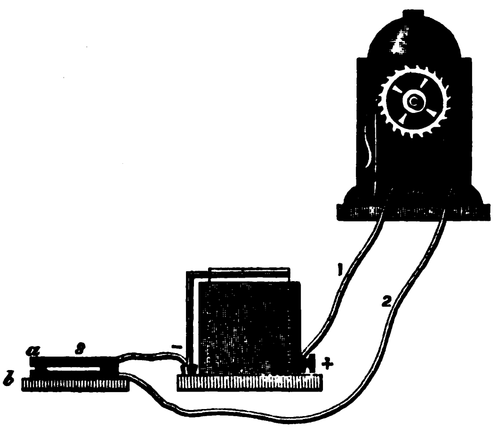


Fig. 20.

s, consisting of two metallic springs, *a b*, of which the lower one, *b*, was fixed on a block of wood, and insulated from the other by a strip of ivory. The spring *a* could be pressed against *b*; but when untouched, remained separated from it by its own elasticity.

From the positive pole of the battery, a wire, 1, went to the electro-magnet, U, of the alarm, and was turned several times round the horns of soft iron; a second wire, 2, returned to the transmitting station, where the line was connected with *b*, whilst the spring *a* was connected by a wire with the negative pole of the element.

39. On long lines of telegraph, Wheatstone found that the current became much weakened by the resistance of the wire, the coils of the apparatus, and by indifferent insulation, so that he was obliged to employ a considerably augmented battery power in order to effect the attraction of an armature, whereas, when he employed a magnetic needle, the latter was always easily deflected. This suggested to him a way to overcome the difficulty, which he succeeded in doing by closing the circuit of a local battery, by the deflection of a magnetic needle at the receiving station, by means of which the electro-magnet of the alarm described above, or an electro-magnet, whose armature formed a hammer and struck directly on a bell, was put in action. The battery at the receiving station was called the *local battery*, in contradistinction to the *line battery*, which was placed at the transmitting end. The local battery consisted of fewer elements, as its circuit was short, and the resistance of the coils of the electro-magnet not great.

It was once a popular fallacy in England and elsewhere that Messrs. Cooke and Wheatstone were the original inventors of the electric telegraph. The electric telegraph had, properly speaking, no inventor; it grew up little by little, each inventor adding his little to advance it towards perfection. Messrs. Cooke and Wheatstone were, however, the first who established a telegraph for practical purposes, comparatively on a large scale, and in which the public were more nearly concerned than in those experiments in which the ends of the wires were brought into laboratories and observatories. Therefore it was that the names of these enterprising and talented inventors came to the public ear, whilst those of Ampère and Steinheil remained comparatively unknown.

40. We read in Dr. Turnbull's book, that in the latter part of the year 1832, Mr. Morse, an American artist of some notoriety, whilst on his homeward voyage from Europe, conceived the idea of an electro-chemical telegraph; and that in

his constructions and subsequent experiments he was much indebted to the valuable aid of a fellow-passenger, Dr. Jackson, of Boston, who had witnessed in Paris numerous experiments in telegraphy, and was besides versed in both electricity and chemistry.

The first invention made by Morse was a chemical telegraph by the decomposition of acetate or carbonate of lead, or turmeric moistened in a solution of sulphate of soda on paper, by the galvanic current between platinum points.

Morse proposed to work this telegraph by means of types forming a code of the letters of the alphabet, numerals, &c., to be set up in a sort of composing stick, and passed by mechanical means under a lever carrying a contact breaker, which would rise and fall correspondingly to the forms of the types. On arriving at New York, Morse took steps to get a set of types for his proposed telegraph, but was, it is said, prevented by press of business from doing much with it until 1836. In the mean time he gave up the idea of a chemical receiving apparatus, and determined on the adoption of electro-magnetism.

41. Morse's telegraph underwent, in the few following years, many important modifications. An idea may be formed of how different the later arrangements of Morse's apparatus were from the first, from the fact that the electro-magnets of the latter weighed 158 pounds, and that two men were necessary to lift it with its stand. The bobbins of the wire coils were 3½ inches long and 18 inches diameter, and the iron core nearly 1 inch. Morse used No. 16 copper wire insulated with a coating of cotton threads, it being at that time his opinion that the coil should be made of the same sort of wire as that used for the line.

The transmitting key used by Morse in his later apparatus is shown in Fig. 21. It consisted of a lever turning on the axis, supported by uprights which were screwed into a small block of dry wood. The screw on the longer arm of the lever was pressed upon the front contact, whilst the similar screw in the shorter arm was used only to regulate the play of the key.

One pole of the battery was connected to the front contact, called the *anvil*, and the other pole to earth. The line was connected through the supports with the lever, which

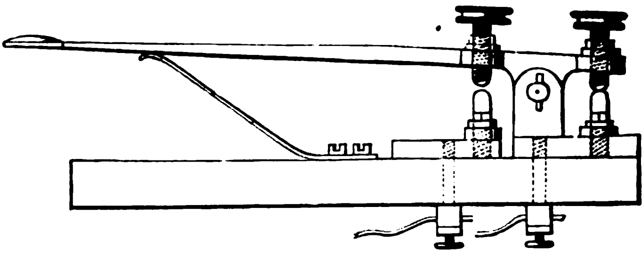


Fig. 21.

was kept on the back, or what has since been termed the *reposing contact*, when not in use, by means of a steel spring underneath the longer arm. The surfaces of the hammer and anvil of the contact were faced with platinum, in order to prevent oxidation by dampness from the atmosphere, or by being burnt by the action of the current.

42. Finding his instrument not sufficiently delicate for great distances, by reason of the line-resistance and loss of current by bad insulation, Morse had recourse to an expedient of relays or repeating circuits. The arrangements designed by him for this purpose were of a somewhat primitive form, but in principle they are the same as that known as translation, and used on all submarine lines at the present day.

43. In 1829, Edward Davy obtained a patent for an electro-magnetic chemical telegraph, in which he had ingeniously applied Wheatstone's idea of combining an electro-magnet with a clockwork, in the construction of a receiving instrument.

Davy's telegraph required at least four line wires, which, independently of its complication, would be reason enough to account for the fact that it never came into practice. It has, however, the merit of having been the first system in which the movements of a clockwork were governed by an escapement worked by an electro-magnet, and probably, in its turn, suggested many of the subsequent inventions.

With three batteries at the sending station, Davy was enabled, by reversing the currents, to deflect at pleasure the tongues or needles of six relays at the receiving station. This was done by putting in each line two relays, similar in construction to those used by Wheatstone in conjunction with his alarm, one being acted upon by positive currents and the other by negative only. Beyond the second relay coils, the three lines were connected together with the fourth line wire, which was used as a common return circuit.

The receiving apparatus consisted of a sheet of cloth or other chemically-prepared material, drawn between a metallic cylinder and a series of six platinum rings, placed equidistant on the outside of a wooden drum. Each of these rings was connected with the contact points of one of the relays, and a common local battery was inserted between all the tongues or needles of the relays and the metallic cylinder, so that when the needle of either of the relays was deflected, the current of the local battery passed through the chemically-prepared cloth to the metallic cylinder, producing a dot.

On the arrival of a current the metallic cylinder was moved forward a certain distance by means of the clockwork.

The operation of successively opening and closing the circuit at the sending station, imparted to the cylinder at the receiving station a rotatory motion resembling that of the long hand of a clock governed by the pendulum and escapement.

The cloth used for receiving the marks was impregnated with iodide of potassium and muriate of lime. Six longitudinal lines, intersected by transverse ones at similar distances, divided the whole surface of the cloth into regular squares, which facilitated reading off messages.

44. The system which we have next to notice is another invention of our ingenious countryman, Professor Wheatstone; this is his first dial instrument, patented in 1840. The apparatus in question seems to have undergone

several modifications in the course of a year or so. The principle remained, however, unaltered in all of them; it was that of sending, from the transmitting station, a series of alternate currents through the line, which, passing round the soft iron of an electro-magnet, moved an armature, and regulated the motion of an escapement similar to that of a clock.

It consisted of two parts:—

1. The transmitter, and
2. The receiving instrument.

The transmitting portion of the original apparatus consisted of a commutator, to direct the current of a battery alternately through two electro-magnets at the receiving station. The direction of the current was effected by means of a tooth-wheel, supported by a metal upright. The teeth of this wheel, to the number of fifteen, were so arranged that the teeth and the spaces in rotation represented thirty letters of the alphabet, numerals, &c. On each side of the wheel was a spring contact, only one of which made contact with the wheel at the same time; when the one pressed against a tooth the other was always opposite to a space. These springs were connected to two line wires, and a battery was inserted between the tooth-wheel and earth. From the circumference of the wheel protruded thirty spokes, and on the base of the upright was a bar, used as a stop for the hand of the operator when turning the spoke wheel, and it was wished to signal the letter opposite the spoke taken hold of.

The receiving instrument or indicator was formed by a dial having 30 divisions corresponding to the letters, numerals, &c., of the transmitter. The index which moved over the dial was driven by a clockwork, the escapement of which was fixed in the axis of a beam supporting two armatures of soft iron, over the poles of two electro-magnets, in the circuits of the two line wires. As the tooth-wheel of the transmitter was turned round, currents were alternately sent through the side contacts, through the lines, and round the cores of the escapement magnet. Whenever, therefore, the tooth-wheel of the transmitter rested at any place, a current circulated in one or other of the escapement magnets, the armature was held down on one side, and the index prevented from moving farther round the dial.

45. An improvement in the apparatus was made by dispensing with one of the line wires, as well as one of the contact springs, of the sending commutator, and one of the electro-magnets of the indicator. This was a material step in the right direction, and fulfilled the first condition of a successful telegraph—that of requiring only a single line wire.

In the improved indicator the duties of the one electro-magnet were fulfilled by a spiral spring with an adjusting screw for tightening or loosening it. This spring acted in the contrary direction to the single electro-magnet, but, of course, with inferior force. It had tension enough, however, to separate the armature from the poles of the electro-magnet, and to bring over the beam bearing the escapement, whenever the current in the electro-magnet was interrupted.

46. But the most important improvement introduced into the construction of this apparatus was in the substitution of magneto-electric currents for those of a voltaic battery.

The sending apparatus, so modified, is shown in Fig. 22. It consisted of a permanent horse-shoe magnet, or combination of magnets, fixed to the base board B, between the poles of which was placed a vertical shaft, supporting, on opposite sides, the coils *c c′* of an electro-magnet. They were so arranged that, on turning the shaft, the cores of *c c′* at the same moment approached, and left the poles of the permanent magnet. The ends of the coils of wire round the electro-magnet were connected, by means of a sliding contact underneath, with the terminal screws *e* and *f*. On the top of the shaft was a pinion D, locking into the tooth-wheel *w*. The number of teeth of the wheel *w* were in relation to those of the pinion D, so that one complete revolution of *w* would cause D to revolve half as many times as there were letters, numerals, &c., engraved on the corresponding dials of the sending and receiving instruments. It will be evident, without further explanation, that a half-revolution of the pinion and the coils of the electro-magnet would produce a current in the line in one direction, and that the continued motion in the same direction another half-revolution, would produce a current in the contrary direction.

This arrangement required a slight modification also of the receiving apparatus; but in principle it remained the same.

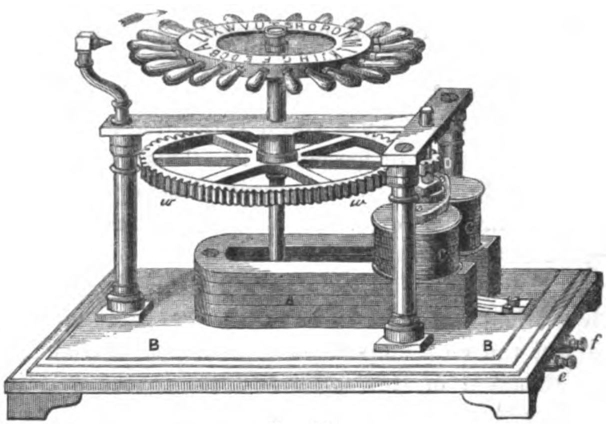


Fig. 22.

M. Froment, of Paris, has constructed some step-by-step instruments, on the system of Professor Wheatstone, in which he has succeeded in simplifying the mechanism.

V. Telegraphs now in use.

47. *Single-needle Telegraph of Wheatstone and Cooke.*—The single-needle telegraph of Messrs. Wheatstone and Cooke is a modification of the five-needle system by the same inventors, described above.

The principle of the system depends upon the construction of an alphabetical code whose basis consists in two elementary signals—the deflections of a vertical pointer to the right and to the left—as in Gauss and Weber's telegraph.

Fig. 23 represents the front view of a single-needle instrument—a mahogany case with engraved metal face, in the middle of which is a vertical pointer. In the lower part of the case is a handle, on the arbor of which, inside, a commutator is placed, so that when the electrical connections are made, the movements of the handle and pointer to right or left correspond.

On the metallic face of the instrument are engraved

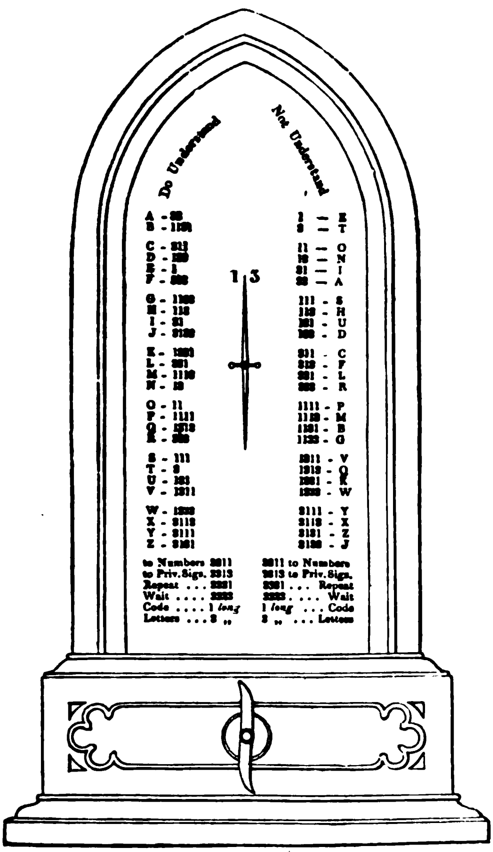


Fig. 23.

the deflections corresponding to the various letters of the alphabet. Fig. 24 represents the interior view of the same. A A is a long vertical coil of fine silk-covered wire, in the middle of which a small magnetic needle plays, having at the end of its axis the pointer seen on the outside face of the instrument.

One end of the coil is connected permanently with the terminal screw L, to which the line wire is attached at the back of the instrument, and the other end with the commutator,

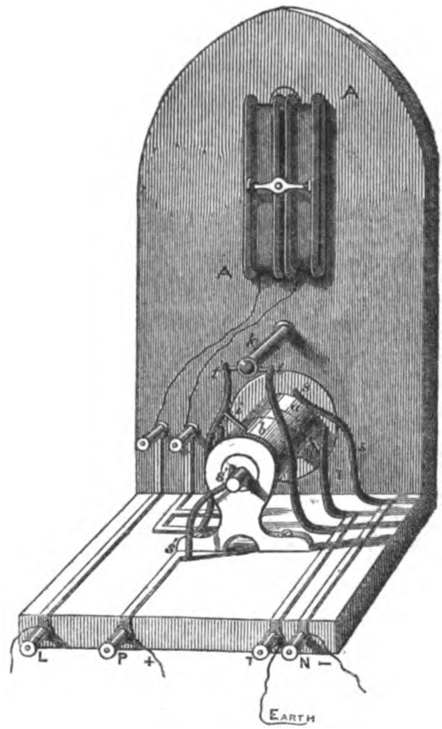


Fig. 24.

by which a battery is put between it and the earth, and its direction reversed according to the position of the handle.

The commutator is of simple construction. The arbor of the handle is divided electrically into two halves, *a* and *b*, insulated from each other by an intervening thickness of dry wood, *p*. The half *a* is connected permanently, through a spring, *s*, with the copper plate of the battery, and *b* with the zinc pole of the same, through the spring *s'*.

On the lower side of *a*, and on the upper side of *b*, are attached projecting pieces of metal, *i* and *i*, which play between the springs *t t'* and *r r'*, respectively. When the handle is vertical, the metal arms *i* and *i'* are also vertical, and the springs *t* and *t'* repose against the opposite sides of the rest *k*. On turning the handle to the right, however, the spring *t'* is lifted by the projection *i* from the rest *k*, and the projection *i'* makes contact with *r*, whilst *t* and *r'* remain unmoved. The spring *r'* is not seen in the figure. The circuit is thereupon completed from the — pole of the battery, through N, spring *s*, half *a* of the arbor, the arm *i'*, spring *r*, terminal T, earth, and from the + pole of the battery, terminal P, spring *s'*, part *b* of arbor, arm *i*, spring *t'*, multiplier, terminal L, line, opposite station apparatus, and earth.

The opposite springs are lifted and the current reversed on turning the handle the other way, The apparatus serves both as transmitter and receiver. When receiving signals, the handle remains vertical. The currents arriving by the line pass through L, coils of the indicator, spring *t'*, metal stop *k*, spring *t*, terminal T, to earth, and the needle is deflected to the right or left, according as the arriving current is positive or negative.

If signals are to be given by the apparatus, the manipulator has only to turn the handle to the right or left to effect corresponding deflections of the needle of his own instrument and of that at the station to which he is sending.

The code of signals for the letters of the alphabet, &c., is engraved on the dial, either by means of arbitrary signals, as in Fig. 23, where the right-hand deflections are shown by the numeral 3 and left-hand by the numeral 1, or by means of strokes of different lengths. In the latter case the long and short strokes indicate the number and direction of the deflections representing each letter; and shorter strokes are to be executed before the longer ones to which they are attached. The letter A, for example, is indicated by two deflections to the left; N by two deflections to the right; I, by three deflections consecutively to the right, and then one to the left; Y, by a deflection to the left, then one to the right, then one to the left, and another to the right; and so on.

This instrument is used almost exclusively on some of the railway lines in the United Kingdom and on some of those in the East. Its great simplicity, inexpensiveness, and little liability to derangement, have obtained it already a long life.

48. *Double-needle Telegraph of Wheatstone and Cooke.*—Another form of the needle telegraph, used also to some extent on some of the English lines, is the double-needle telegraph, consisting of two single-needle instruments combined in the same case. They are, however, totally independent of each other in so far as their electrical connections are concerned, each being worked with a separate line wire. The handles in front of the case are connected with two arbors inside, similar to the one shown in Fig. 24, each of which commutates the current of a battery through the galvanoscope coils surrounding the needle attached to one of the pointers.

The discs over which the pointers move are provided with ivory pegs to limit the deflections on each side of the vertical line. The discs are sometimes made circular, and may then be turned round in the dial plate, enabling the operator to shift the pegs, in order to keep the pointers midway between them when the magnet-needles are deflected by constant atmospheric currents.

The alphabetic code adapted for this instrument is as follows:—

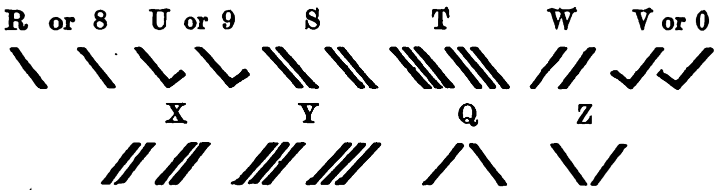
The left needle deflected alone,

+ C or 1 A B E or 3 D or 2 F G

The left needle deflected alone,

H or 4 L or 5 I K N or 7 M or 6 O P

Both needles deflected at the same time,



The same rules are observed with regard to the short and long strokes, as with the single needle instrument.

The employment of two needles in receiving the signs renders this telegraph very expeditious; the rate at which it is worked being about double that of the common Morse telegraph. The necessity of two lines, however, prevents it taking any prominent place amongst the existing systems of useful telegraphs.

49. *Principle of self-acting Make-and-break.* A considerable step in advance of then existing systems was made by Dr. Werner Siemens, of Berlin, by the invention of his first beautiful step-by-step motion telegraph.

The principle of this apparatus was that of the automatic

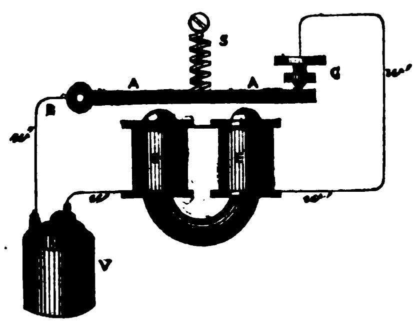


Fig. 25.

transmission of currents, or what has been called the self-acting make-and-break.

Suppose the soft iron armature A A, Fig. 25, of the electro-magnet E, is supported on an axis, B, at one end, and by the spiral spring s in the middle, by which it is pressed gently upwards against the contact-screw C at the other end, and that an electric circuit is established, as is represented in the figure, in which the positive pole of the battery V is connected by a wire, *w*, with one end of the wire-coil of the electro-magnet E, the other end of the wire-coil being connected with the contact-screw C, by a wire, *w*′, whilst a third connection-wire, *w*″, joins the axis of the armature A, with the negative pole of the battery. It is obvious that the current circulates in the coils of the electro-magnet, magnetises them, and causes the armature to be attracted to the poles, leaving the contact-screw C, and thereby interrupting the battery circuit. The instant this occurs, and the battery current ceases to circulate in the coils, the soft iron cores of the electro-magnet lose their magnetism, and have no longer the power to retain the armature which is consequently lifted up again by the spring S. On reaching its position of rest, it makes contact again with C, and re-establishes the battery circuit. This is followed by an immediate interruption; and the same play must necessarily be repeated, the armature being

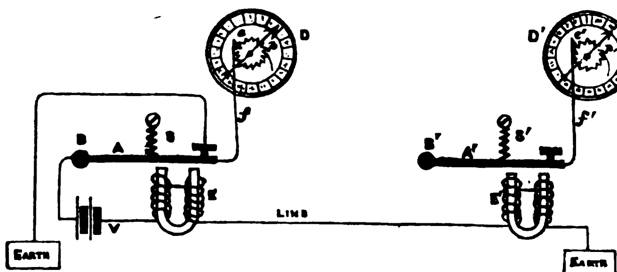


Fig. 26.

always re-attracted to the poles of the electro-magnet, breaking thereby the circuit, and being again let go, and making the circuit again, and so on *ad infinitum.*

The manner in which Dr. Siemens applied this method of interruption to the service of his telegraph system will be easily seen from the accompanying plan, Fig. 26.

If we were to take the apparatus just described and attach to the end of the armature, in any way, a continuation with an escapement, so that when the armature is moved up and down, the escapement, moved by it, works round a little scape-wheel, *e*, carrying a light pointer, *p*, around the circumference of a dial, D; it is evident that when the apparatus is connected by the wires as shown in the figure, the armature will always be moving up and down, and the pointer, therefore, always running round the dial.

If we now insert into the same circuit another electro-magnet, E′, with a similar armature, escapement, tooth-wheel, and dial, the electro-magnets being both magnetised by the same currents and demagnetised at the same time, the movements of the armatures will be synchronous; and if the pointers have been started from the same places on each dial, they will stop at the same points on the dials whenever the armature E is arrested in its upward or downward motion.

This apparatus is employed to a considerable extent on the Prussian railway lines. It has, however, not found any extensive employment in England. Apart from its somewhat complicated mechanism and costliness, it is undoubtedly the nearest approach to perfection in a telegraph apparatus of anything we have yet seen.

50. *House's Printing Telegraph.*—This telegraph, the work of Mr. House, of New York, was the subject of an application for patent in 1845. It belongs to the class of step-by-step motion telegraphs, and consists of two separate parts: the transmitter or commutator, and the receiver or printing instrument.

The transmitter is composed of a contact-wheel in every way resembling that used by Wheatstone in one of the modifications of his dial instrument, which, in turning, sends a series of currents from a battery at the transmitting station. As each make-and-break of the circuit indicates a letter, whenever a letter is to be transmitted, the contact-wheel is arrested at a certain point by which either the current is allowed to flow, or is interrupted during the continuance of the indication according as a contact-spring happens to rest upon a tooth of the wheel or opposite a space, at the moment of stopping.

For the purpose of stopping the contact-wheel at its proper place for each of the letters, House employs a key-board like a piano, with twenty-eight keys, representing twenty-six letters of the alphabet, a dash, and a dot.

The contact-wheel is of brass, four or five inches in diameter; its circumference is divided into twenty-eight equal spaces, alternately indented to the depth of a quarter of an inch, so as to expose on the surface fourteen shallow teeth. A spring of metal, insulated from the contact-wheel and shaft, is placed before the former of these, so that when it revolves, the top of the spring comes in contact with each of the teeth in succession, but has not the power to penetrate into the spaces and make contact there.

The plan adopted by Wheatstone to hold his current on or to interrupt it, during the reading of a signal, was to stop his commutator opposite an index or pointer at the letter to be indicated. House does this otherwise, with the aid of his piano keys: he puts two rows, of each fourteen pegs on the outside of a cylinder, each peg turning with the cylinder underneath one of the keys of the piano. The latter are held up by springs, and furnished with hooks or cams which, when depressed, catch hold of the pegs of the revolving cylinder and arrest its motion.

The pegs of successive letters follow each other round the circle in a spiral at distances of one twenty-eighth of the circumference, and therefore, when the cylinder is turned from one letter to another, just so many contacts and interruptions are given as will bring the pointer or wheel of the receiving apparatus round the same distance.

The receiving apparatus is rather complicated; it is started by an electro-magnet of very novel construction.

Above the movable armature, on a common shaft, is a hollow cylindrical slide-valve, in connection with a chamber of compressed air, filled by means of a pump, and supplied with a safety-valve to permit the escape of superfluous air when the pressure becomes greater than is required for working the apparatus.

The piston moved by the compressed air let into the cylinder by the slide-valve, moves horizontally, and is in connection with the lever of an anchor-escapement engaging with the teeth of the scape-wheel of the printing machine.

The scape-wheel has fourteen teeth, and requires, therefore, twenty-eight movements of the lever to complete a revolution. A steel type-wheel revolves with the same shaft as the scape-wheel, its circumference being furnished with twenty-eight equidistant projections, on which are engraved the letters of the alphabet, a dot, and a dash. The shaft also carries a little drum with letters painted on it in the same order as those on the type-wheel, by which the operator may read off the message when the type-wheel is not printing.

On the upper surface of the type-wheel, at the extreme edge, are twenty-eight teeth, against which plays a small steel arm, attached to a metal cap, turned by friction on a shaft revolving in the reverse direction. When the type-wheel is in motion, this arm plays over the teeth, but as soon as the wheel is stopped, falls in between them, which it has not time to do during the revolution. By falling in the teeth of the type-wheel, the arm allows the cap to revolve with its shaft, and by means of two pins, to release a detent, which, in its turn, permits an eccentric to revolve. A connecting-rod from the eccentric, pulls the paper strip to the type-wheel and prints the letter.

An ingenious arrangement is also made for the progression of the paper, by means of a ratchet-wheel and clicks attached to a notched drum over which the paper passes.

The line from Philadelphia to New York was the first on which this instrument was used. It found very general adoption on the American lines, after the year, 1849, and is still to be found at work. It is said to be much less liable to get out of order than would be judged, at first sight, from the complication of the receiving apparatus.

51. *Hughes' Roman-type printing Telegraph.*—The essential principle of this highly ingenious system is the synchronous movements of type-wheels at two or more stations, and of the power to press a strip of paper at each of the stations simultaneously against the types on the correspond-

ing parts of the wheels, by the action of a single electric wave or impulse.

A clockwork at each station turns, with a continuous and uniform motion, an axle, at the extremity of which the type-wheel is supported. The synchronism is attained by the aid of a vibrating spring and anchor escapement. The rotation of the type-wheel is transmitted to a vertical arbor, furnished at its lower extremity with a horizontal arm travelling over a circular disc, in which is arranged a series of contact pins, in number corresponding to the types. Each

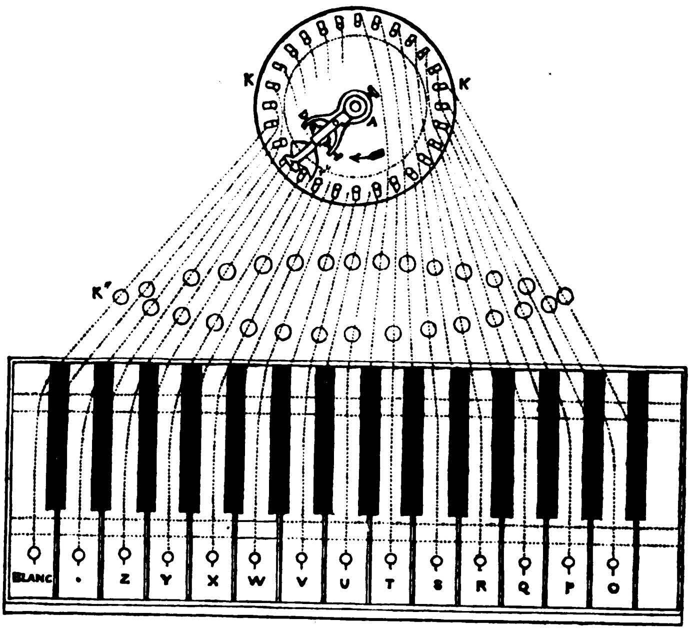


Fig. 27.

pin therefore represents a letter, and is raised when it is wished to telegraph this letter along the line. The horizontal arm, which travels round the disc with a motion uniform with that of the type-wheel, comes in contact with the pin just at the moment when the corresponding type is at the lowest point and closes an electric circuit, by which the paper is lifted up against the type-wheel, and the letter printed.

The key-board used to elevate the contact pins is shown in Fig. 27. It consists of twenty-eight keys, alternately white and black, marked with the twenty-six letters of the alphabet, a full stop, and a blank, corresponding to an empty space in the type-wheel. Below each of the keys is a movable lever, whose fulcrum is at K″, and which terminates at the bottom of one of the contact pins K K, arranged in a circle in the metal box A, in the top and bottom of which are holes for the ends to protrude—the upper holes being long, to allow of a radial motion. Each pin is held down by the pressure of a small spring, but may be elevated by pressing down the corresponding key of the piano-board.

Fig. 28 gives a vertical section of the printing instrument and key-board. The section shows a white key, hinged at K″, connected to its lever K′, a contact pin, *k*, on the right, and also to a black key, whose lever reaches to a contact pin on the left of the box A. The contact pins are provided with shoulders to limit their movements in each direction.

The horizontal arm, which travels over the circle of contact points, is attached to the bottom of the vertical arbor Q, to which motion is imparted by the bevelled wheel G_2, on the shaft G. It is made up of three principal parts—the arm *r*, jointed at *a*; the resting piece, or earth-contact, *r′*; and the shovel *r″*. The vertical shaft Q is of brass, and is divided electrically into two parts by an insulating ring of ivory, *q*. The lower part is supported by the central pedestal, which is insulated from the box A by a non-conducting ring.

The continuation of the jointed arm *r*, which is held by the portion of the shaft above the insulating ring *q*, is pressed down by a spring, which keeps a small screw in the middle of the continuation in metallic contact with the second piece *r′*, supported by the portion of the shaft below the ring. The shovel *r″* is of steel.

When a key is depressed, the corresponding contact pin is elevated, and if the arbor Q is in motion, the extremity of the arm *r* mounts upon the elevated pin, by which contact between *r* and *r'* is interrupted, and that of *r* with *k*

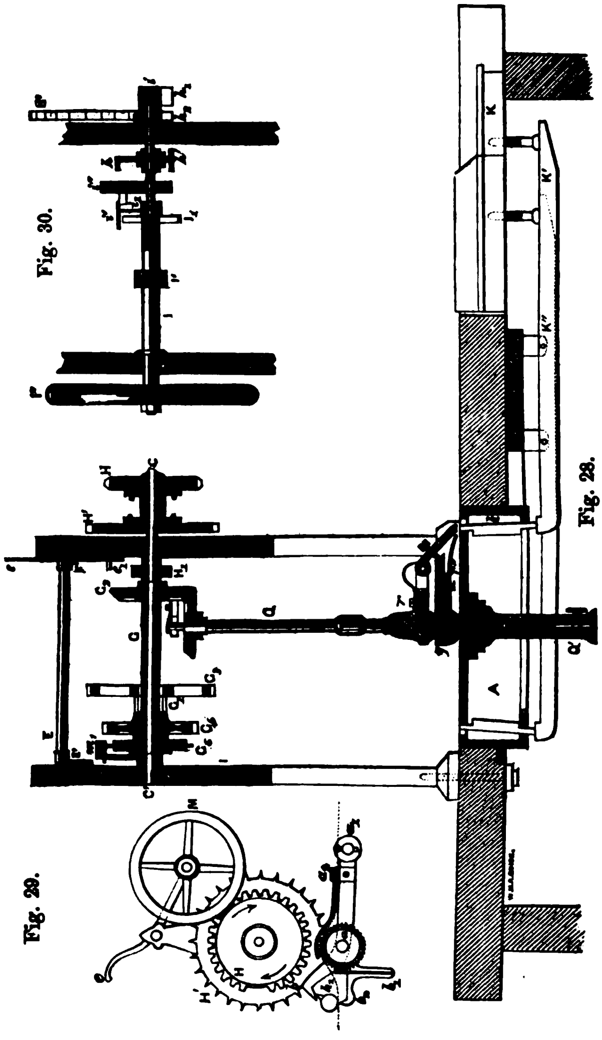


Fig. 30.

Fig. 28.

Fig. 29.

established. The arm *r* having made contact, the shovel *r''*, which immediately follows it, pushes the pin *k* in its slot outside the circumference swept over by r; so that if the latter make another revolution whilst the finger is kept down upon the key, no second contact is made, and the same letter is not repeated. The operator feels a vibration of the key as the shovel passes by the pin, and is thus made aware that the letter has been printed.

The type-wheel H contains on its circumference, in twenty-eight equal spaces, twenty-six letters of the alphabet, a dot, and a blank space; it is fixed to the extremity of the axis C C′, which is put in motion by means of the hollow axis G, enveloping it in the greater part of its length. The connection between C C′ and G is made by the mediation of a fine rachet-wheel, G_5, attached to the axis G, the click m_1 being on the axis C C′. On the latter are supported, besides the type-wheel and click, a corrector, H′, or wheel with long narrow teeth, equal in number to the types, serving to establish precision between the movements of the horizontal arm r and the type-wheel. On the same axis is a wheel, H_1, having a notch at one part of its circumference for stopping the type-wheel when the blank space is opposite the printing press, in case it should spring forward.

The hollow axis G is turned by a clockwork moved by a weight, a wheel of which engages with the pinion G_1, and supports, besides the racket G_5 and bevilled-wheel G_2 already mentioned, the escape wheel G_4 and a tooth wheel G_3, which locks into the pinion I_1 (Fig. 30) of the printing shaft I.

The printing shaft turns seven times as fast as the type-wheel, and carries a fly-wheel, I″, at one extremity, in order to overcome the inertia of a small shaft, whose duty is to lift the paper up to the type-wheel at the other extremity. This is shown partly in section in Fig. 30. The printing shaft I and its continuation i are locked together by means of a ratchet-wheel, I_1, and click, i'. At the end of the continuation shaft i is a cam, h_1, for lifting the press and the paper against the type-wheel.

The printing press is shown in Fig. 29. Underneath the type-wheel is a small cylinder a, over which the paper is led, its axis being in the middle of a bent lever, b, turning at a_1;

attached to it is a ratchet-wheel, in the teeth of which catches a click affixed to a movable piece, b_1, terminating in the rectangular arm b_2, which is forced upwards by a spring attached to the frame of the apparatus, but is stopped against the axis *i*. When *i* makes one revolution, the cam lifts the arm *b* of the lever, together with the cylinder *a* and paper strip up to the lowest tooth of the type-wheel by which the paper strip is impressed with the print of the type, kept inked by an inking roller, M. The cam being very sharp, the movements of ascent and descent are proportionally rapid, and the paper touches the type during only an infinitely short space of time. The axis continuing to turn, the cam meets the arm *b* and depresses it, causing the click to draw round the cylinder and advance the paper a certain distance.

By the side of the ratchet-wheel I′ the printing shaft

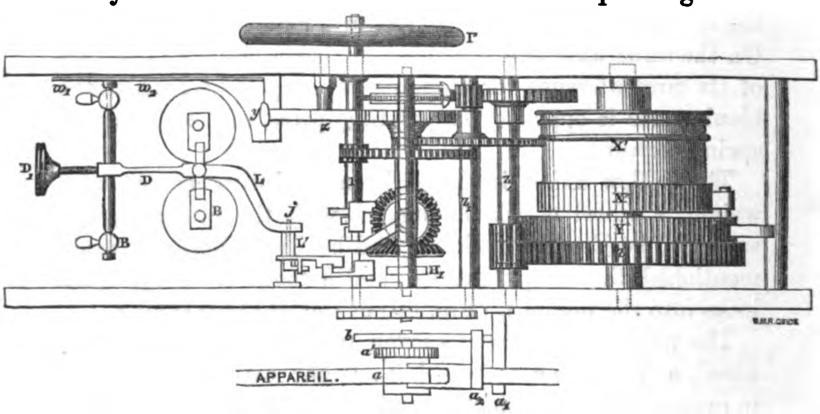


Fig. 31.

carries an escapement *h h′*, arrested by a continuation of the lever L L′, moving with the armature of the electro-magnet. The armature is of soft iron, supported at the extremity of a lever D over the poles of the electro-magnet Fig. 31. The lever turns between supports on the axis, and tends to rise by the force of a spring regulated by the adjusting screw D′.

The screw *d′* (Fig. 32) on the end of the lever L L′, turning on the axis *j*, sits over the armature; the other end of the lever engages with one of the pallets of the escapement *h h′*, and governs the motion of the axis *i*. When a current traverses the coils of the electro-magnet the armature and lever are depressed, the click is put in gear, and the pallet *h* of the escapement, released, turns with the axis *i*. At the moment when the pallet *h′* passes under the lever, it relifts

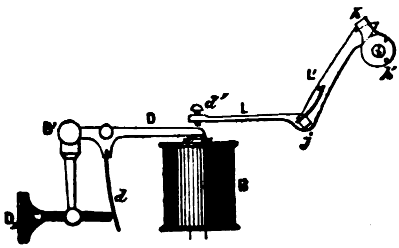


Fig. 32.

it, and depresses the screw *d′*, returning thereby the armature to the poles of the electro-magnet, and, at the same time, throwing the click out of gear.

The magnet B is of novel construction. It consists of a permanent horse-shoe magnet, with soft iron cylindrical continuations on the poles. These continuations are each encircled by a coil of wire. When no current passes through the coils, the armature is attracted to the poles by the magnetism distributed in the iron. This force is opposed by the adjusting spring, which is so regulated that, the armature being in contact, a very weak current is able to neutralise the attraction.

The printing shaft has also the duty of correcting the movements of the type-wheel, and of insuring always that, at the moment of printing a letter, the type is in its proper position. This is effected by means of a curved cam, h_2, on the axis *i*. The instant the cam *h′* lifts the arm *b* of the frame carrying the printing roller, the projection h_2 locks into the teeth of the wheel H′, and adjusts, if it be necessary, its position. If, on entering the teeth of H′, the cam has to push the wheel forwards, or, to accelerate the motion of the axis C C′, the click *m* is pushed onwards, passing over one or more of the teeth of the ratchet-wheel G_5. If, on the contrary, the cam has to retard the motion, the click pulls the ratchet-wheel backwards, for which purpose the latter is not made rigid on the axis, but is formed of a disc held between leather washers supported by two plates of metal, fixed on the hollow shaft G.

The electric circuits of the apparatus are very simple. The bottom of the vertical shaft Q is connected to earth, and the upper part to one end of the coils of the electro-magnet, the other end being to line. One pole of a battery is connected to the levers *k* of the contact pins, the other pole to earth. At two corresponding stations the plates of the batteries must always be looking the same way, because the home apparatus is intended always to work as well as that of the distant stations, and the armature of its magnet is only liberated by currents in one direction.

When a current arrives, therefore, from the line, it passes first through the coils B of the magnet, then through the vertical shaft Q, which it descends, and goes over from the screw in the jointed arm *v* to the resting piece *r*′, and from this to earth. When a current is to be transmitted, the operation consists principally in interrupting the earth circuit, and in inserting the battery into the break. This is done by the contact pins and jointed arm of *r*. A key being depressed, the arm *r* in its journey rides over the pin, and its screw is lifted up from contact with *r*′, which breaks the direct earth circuit. At the same time the contact of *r*′ with the pin *k*, which is in communication with a pole of the battery through the lever K, sends a current from the battery (K *k*, *r* Q), through the coils of the magnet into the line, &c.

Suppose two such apparatus, properly adjusted, at the extremities of a line of telegraph, the clockwork wound up, the electrical connections properly established, and the type-wheels locked. The employé who desires to transmit presses down the blank key of his instrument; this pushes up the corresponding contact-peg in the circle K, and when the chariot arrives over the pin, the extremity of the piece *r* rides over it, separating the earth contact and introducing the battery into the line circuit. The current passes through the vertical shaft, the coils of the magnet, and line wire to the other station, where it circulates in the coils of the magnet, the vertical shaft, &c., and goes to earth.

In traversing the coils of the magnets of both instruments, the current weakens the attractions of the armatures to the poles of the electro-magnets; the former are forced off by the spring, the screws *d'* are raised, and the levers L at the same time depressed. The pallets *h* of the escapements *h h'*, are thereupon released, the axes *i* put into gear with I, and the type-wheels released. During the revolution made by the axes *i*, the cylinders *a* are raised by the cams, and lift the paper up to the printing-wheels at the moment when the latter are unlocked. No letter is printed, because the blank space in the type-wheel occurs just there. The paper strips and cylinders descend again; the former advancing a step. The clicks are then disengaged from the ratchets, and the pallets *h* recaught by the levers L', which were lifted up, causing the armatures to be pushed down again to the poles of the magnets.

If a key answering to any letter be now pressed down, the current is repeated the moment the chariot passes over the raised contact pin; the printing axis is put in motion, the letter printed, and the paper pushed on as before, and so on, until the message is completed.

It sometimes happens that the apparatus do not agree when one of the stations sends its message. In this case, the employé at the receiving station advises his correspondent of it by giving him a signal; both then arrest their type-wheels, and the transmission is recommenced, beginning always with the blank.

To avoid the inconvenience of irregular working, which might arise from changes in the battery power, Professor Hughes has adopted a method of short circuiting the coils of the electro-magnet the instant after the armature is released, that the current, whatever may be its intensity, comes into play only long enough to effect the required weakening of the magnetic attraction. This is done by connecting one end of the electro-magnet coils with D, and the other end with L, in addition to the other connections, and by adjusting the screw *d′*, so that when at rest the armature, reposing on the poles, does not touch it; but as soon as the neutralisation occurs, it is lifted up by the force of the spring, and the coils short circuited by contact of D with *d′*.

The speed of transmission attained with this apparatus is very great. The chariot and type-wheel revolve about 120 times in a minute, and an expert manipulator can transmit on the average two letters during a single revolution of the shaft.

The word "telegraph," for example, is completed in six turns, as follows:—

1st turn	blank and *t*.
2nd "	*e* and *l*.
3rd "	*e*.
4th "	*g* and *r*.
5th "	*a* and *p*.
6th "	*h*.

The French word "bonté" is done in four turns:—

1st turn	blank.
2nd "	*b* and *o*.
3rd "	*n* and *t*.
4th "	*é*.

Another example is the word "dintz," more fortunate than either, being transmitted during a single revolution.

This invention was brought by Professor Hughes from America, before the submersion of the old Atlantic cable, on which he made his first important experiments on the speed attainable in working his apparatus on submarine lines. Since then important improvements have been made in the construction and mechanical execution of the apparatus, in the atelier of M. Fromont of Paris. The principles have, however, undergone no change.

The system has been adopted by the United Kingdom Telegraph Company, under an arrangement giving the Company the exclusive right to use the apparatus themselves, and grant its use to others in this country. On the company's line between Birmingham and London, on which messages and press matter are constantly passing to and fro with the aid of this apparatus, the average speed, as stated by the company, is forty messages per hour, and is believed to be capable of considerable augmentation when the employés have had more practice. The company intend introducing this system on all their lines, and have reasonable hopes of its ultimate success. In France the system is gaining daily a wider employment; in Russia and Germany the administrations of telegraph are likewise disposed to adopt it.

The following is a fac-simile of the printing:—

BY HUGHES'S TELEGRAPH INSTRUMENT.

52. *Bréguet's Electro-Magnetic Dial Instrument.*—The principle of Bréguet's apparatus is that of alternately making and breaking at the transmitting station, the circuit of a voltaic battery. At the receiving station is an electro-magnet, whose armature is correspondingly attracted and let go. The armature acts on a pallet, which interposes itself between the teeth of two scape-wheels turned by clockwork.

The apparatus consists of three parts:—

The transmitter,
The receiving instrument, and
The alarum.

The transmitter is shown in Fig. 33. It consists of a metal dial, supported by three pillars on a wooden base. The whole dial is divided into twenty-six equal sections, separated by two circles. In the inner circle are engraved twenty-five letters of the alphabet and a +, and in the outer circle, the numbers from 1 to 25, and a +. Opposite each letter, on the periphery of the dial-plate, is an indentation for dropping the handle into. Underneath the dial-plate is a disc, G, with a serpentine groove on its underside, turning on the axis of the handle H, which moves above the dial. A small peg with a friction wheel runs in the groove, and imparts a vibrating motion to the contact lever. The further end of this lever is faced with platinum on each side, and makes

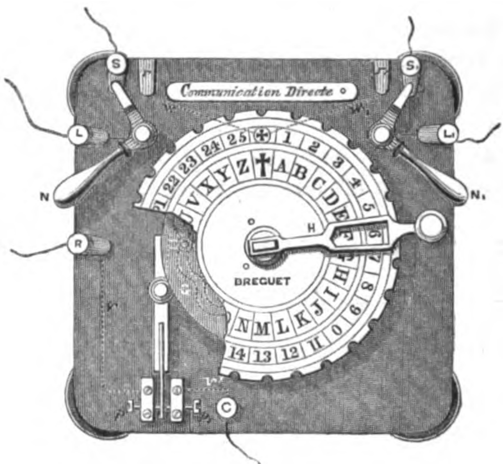


Fig. 33.

contact alternately with the screws p p', — with p, when the handle is over the even numbers, and with p' when it covers the uneven.

The terminal C is connected with the positive pole of the battery. It is also connected by a wire, v', to the contact screw p'. The terminal R, on the left, is in permanent connection by a wire, v, with the contact p, and is intended for the wire leading to the receiving instrument. The terminal L of the left line-wire communicates with the contact lever, N. The point of N touches, at pleasure, either the contact S, to which the alarm is connected, or r, which is in communication with the revolving disc, and through this and the friction wheel and l l' with battery and earth, or, lastly, it may touch the end of a metallic strip marked "*communication directe.*" On the other side of the dial is a similar lever, N', connected with the terminal L' of the line on the right. N' may be placed on S', the alarm, or on r', which, like r, is connected with *l l'*, or lastly, it may be placed on the other end of the metal strip "*communication directe.*"

Fig. 34 represents the interior of the receiving instrument seen from the back; M M is a horizontal electro-magnet, whose armature, suspended between screw points, carries on its upper side a metallic rod *q*, which is limited in its play by adjusting screws in the frame *f*. At right angles to *q*, near the top, is a peg, *q'*, working in a fork F, fixed to

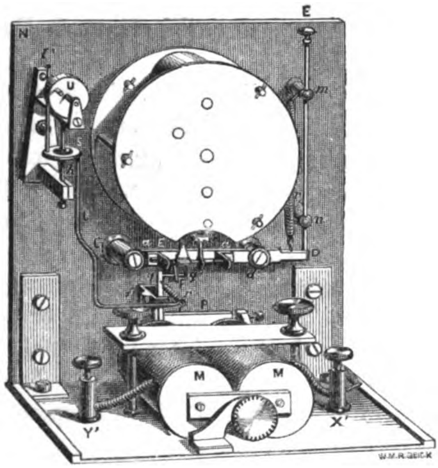


Fig. 34.

one end of the horizontal shaft *a*. At the other end a pallet, *g*, engages alternately with two parallel scape-wheels, impelled by a clockwork in the case above, and placed so that the thirteen teeth of the front and back wheels alternate when looked at from the front. When the apparatus is at rest and the armature held back by the spring, the pallet locks into the teeth of the back wheel; but on the attraction of the armature to the poles of the magnet, the pallet springs into the teeth of the front wheel, which, being half a tooth in arrear, allows the wheels and pointer to turn one twenty-sixth of the whole circle. As soon as the armature is released the pallet leaves the teeth of the front wheel, and re-enters between those of the other. The latter being half a tooth behind, the clockwork turns the wheels and pointer another one twenty-sixth. Thus every time the circuit is made or broken, the pointer advances one of the twenty-six divisions of the dial.

The spring for drawing the armature from the poles is adjusted by means of a bent lever, *t*, on the end of which it is hooked. The lever itself is fixed to the under side of a disc, *s*, turning on the vertical axis *h*. On the opposite side of the disc *s* is a long vertical pin, *t′*, which is gradually turned with the disc in a small angle by an inclined plane on the rim of the drum U.

The shaft *a*, with its pallet and fork, is supported by a frame or lever, C D, turning on the centre C on the left, and on the right held up by a spiral spring which forces it against a pin, passing through the guides M and N. On pressing upon the button E of the pin, the frame is moved downwards and releases the escapement-wheels from the control of the pallet, but carries down with it a check which prevents their unlimited run. As soon as they are free to rotate, the wheels turn round with the pointer until their further progress is arrested by the check which catches hold of a pin at the back of one of the scape-wheels, corresponding in position with the zero or + of the dial.

The alarm generally used with this instrument contains no new principle whatever. The attraction of an armature liberates a clockwork, which turns a disc with an eccentric crank. The latter in revolving moves the hammer of a bell to and fro. It is similar in construction to Wheatstone's first alarm.

Another alarm which Bréguet has supplied with some of his telegraphs is constructed on the principle of the self-acting make-and-break employed in Dr. Werner Siemens's first dial-telegraph.

The connections of the apparatus for a station will be seen by reference to Fig. 35, which shows the various pieces of the apparatus.

When neither of the stations is using the line the switches N and N′ of both the apparatus are placed on S and S′, so that a signal arriving from either side, L or L′, will be given notice of by the alarms A and A′. In this way the current from the left goes from L, past a lightning guard, *e*, through a galvanoscope, G, L, N, S, alarm A, earth, and back

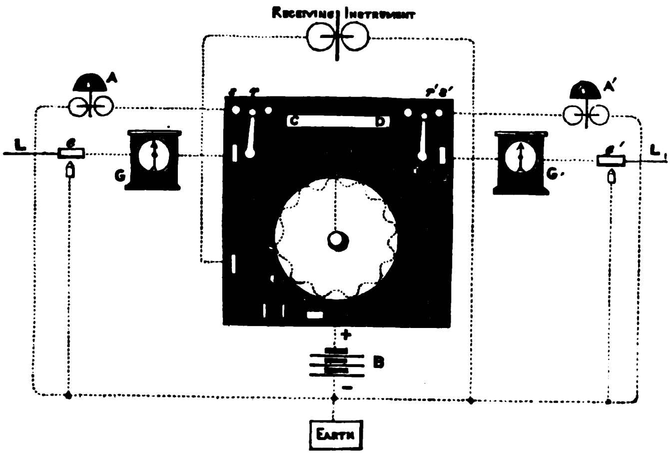


Fig. 35.

again. Arriving by L′, a current passes the lightning guard *e*′, G′, L′, N′, S′, alarm A′, earth, and so on.

When a signal is given from L, the employé turns his switch N on *r*. The current passes then from L through the galvanoscope G, the needle of which it deflects, L, N, *r*, disc, contact-lever, *p*, R, receiving instrument, earth, &c.

Bréguet has also made use of an idea used previously in the construction of telegraphs in Germany. Instead of the movable armature and stationary electro-magnets, he sometimes employs a cylindrical electro-magnet made to turn on its longer axis on screw points. The poles of the soft iron core are furnished with soft iron continuations, which hang down between the opposite poles of two permanent horseshoe magnets. When the current magnetises the soft iron core and its continuations, the coil with core and continuations are deflected to one side or to the other, attracted by one of the permanent magnets, and repelled by the other.

When the current is reversed the polarity, and therefore the deflection, is also changed.

53. *Kramer's Pointer Telegraph.**—The different telegraphs which have hitherto been mentioned are worked by sending currents of electricity from the transmitting station, either from a galvanic battery or from an induction apparatus. As soon as the signal is given, or the work done, the current is cut off, and the line becomes inactive. The reverse of this mode of operation was introduced by Kramer, in his dial-telegraph, and subsequently by Frischen, for working the Morse instruments on the lines under his charge. In both these systems the current of a galvanic battery circulates continually in the line, and attracts, when at rest, the armature of an electro-magnet at the receiving station. On breaking the line at any point the armature falls off, and remains off until the battery circuit is closed again.

With the system of currents transmitted for each signal, it is obvious that a separate battery is required for each station. This is not the case when the system of closed circuit is used; because an interruption in any point must be followed by the same effect on the armatures of all the electro-magnets in the circuit.

The exterior of Kramer's apparatus differs in appearance very little from that of Siemens and Halske's. It consists of a round dial, with thirty keys on the circumference, numbered from 0 to 29, inclusive. An inner circle is marked, in corresponding sections, with the letters of the alphabet irregularly placed, and a third circle, concentric with the others, contains a double row of numerals from 1 to 9, and some other figures and blanks.

The interior of the apparatus is shown in Fig. 36. Two circular plates of metal are connected together by means of three pillars near their periphery; through their centres passes the axis C of the pointer *z z* seen on the dial. This axis carries a scape-wheel, *r*, and a tooth-wheel, R; it is turned by the tooth-wheel H engaging with its pinion 3. On the axis of the wheel H is a pinion locking into a tooth-

* Der Elektro-magnetische Telegraph. Schellen, p. 195.

wheel attached to the barrel, on which is wound a cord passing over a pulley and carrying the weight G.

The escapement *r* is formed by a horizontal wheel, on the rim of which are sixty vertical steel pins—thirty projecting downward, and the same number upwards—arranged alternately at equal distances from each other. The prongs of a

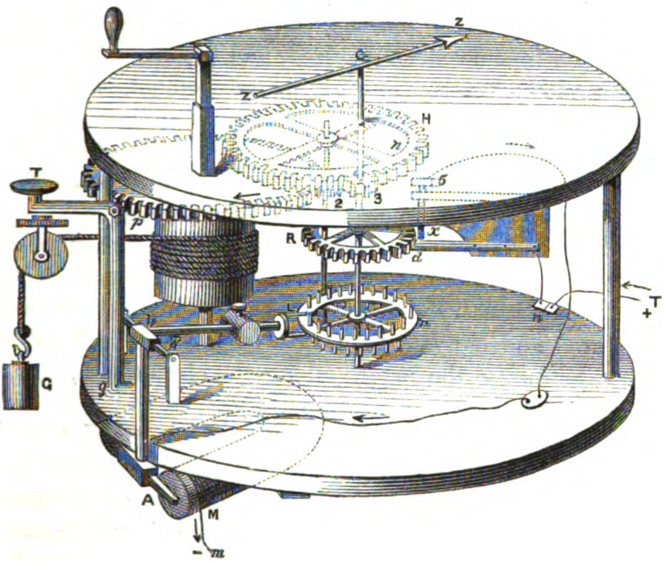


Fig. 36.

steel fork lock into the pins, and are just so far apart, that when one prong touches the rim on one side, the next pin can pass under the other prong. The fork is supported by a bell-crank lever, *h*, turning on the axis w, between upright bearings. An armature, A, of soft iron is supported by the lower arm of the lever, opposite the poles of an electro-magnet, M, which regulates the movements of the fork and scape-wheel. The poles of the magnet are covered with thin pieces of German silver soldered to them, to prevent the armature making close contact with them. The figure shows the armature attracted to the poles, which is the position of rest of the apparatus.

The wheel commutator R, the tongue *d*, and contact anvil *x*, are provided to regulate the interruptions of the currents. The wheel has on its circumference thirty teeth, which, in the course of one revolution, lift the hammer, therefore, thirty times from its contact with the anvil.

When the armature of the electro-magnet is attracted to the poles, a tooth of the wheel R lifts up the hammer from the anvil, and interrupts the circuit, the electro-magnet immediately becomes demagnetised, and the armature falling off again, depresses the fork of the escapement, and allows the scape-wheel to advance six degrees together with the wheel commutator, R. By this means, contact is re-established between *d* and *x*, the tooth which separated them passing by, and the end of the hammer *d* falling into a space.

The electrical circuit is shown in the figure by wires, and in following the motions of the scape-wheel, contact-wheel, R, &c., it is necessary to imagine a battery inserted between T′ and *m*. The current, then, goes from the + pole of the battery, following the arrows along the circuit T′, *n*, *d*, *x*, 5, coils of M, to the — pole of the battery.

In this way the pointer keeps on running round the dial as long as the maintaining power of the clockwork lasts. The motion may be arrested either by breaking the battery circuit, in which case the armature falls off, and the fork-escapement rests on the upper surface of the scape-wheel, or by arresting the pointer itself. The latter is the method employed in telegraphing; the key over the dial, corresponding to any letter, on being pressed down, interposes a peg which bars the further progress of the pointer, and, in this respect, resembles the arrangement of Siemens and Halske's pointer telegraph.

When it is wished to advance or to put back the pointer on the dial, at any station, without the assistance of the current, this is done by pressing on the button of the lever T, *p*, *q*, which presses the armature against the electro-magnet, and lifts the fork.

54. An alarm used with this telegraph is rung by the release of a soft iron armature from the poles of an electro-magnet.

At an intermediate station, during the correspondence between two end or distant stations, when the continued interruptions of the circuit would cause the alarm to sound whilst the correspondence lasts, which would become annoying to the employés, an arrangement is made for so weakening the currents in the coils of the electro-magnets by means of a shunt, that the alarm does not sound. This

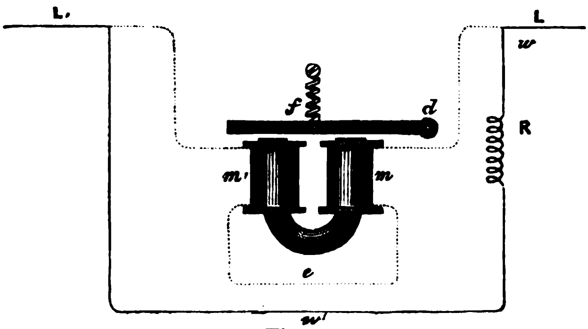


Fig. 37.

shunt is shown in Fig. 37, by a wire, *w*, *w'*, and resistance coil, R, which has about five times the resistance of the coil of the electro-magnet, allowing therefore only about five-sixths of the current to pass through the legitimate route.

This shunt circuit has another object. At the moment a current is sent through the coils of the electro-magnet *m m'*, the induced current tends to weaken the effect of the battery current. This would not be perceptible if the induced current were obliged to traverse the whole line. But in going round the shunt L, R, L', with little resistance, it exercises its full opposing force on the magnet, and prevents the armature being attracted.

The plan, Fig. 38, shows an ingenious arrangement for providing against the errors frequently arising in systems based on the principle of closed circuits, from bad insulation of the line. Should there be, as is sometimes the case, a battery at each of the end stations, and the line, in some points intermediate, in imperfect contact with the earth, it is evident that when either of the intermediate stations interrupts the circuit, the current at the stations near the ends will not be interrupted, but only weakened. Kramer, unable to realise a perfectly insulated line, and having to provide against emergencies, makes his

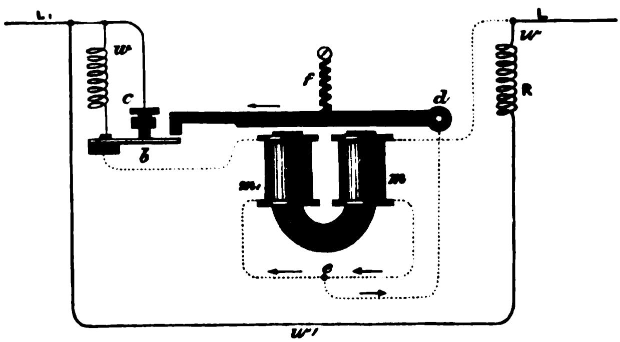


Fig. 38.

alarm work as well by a weakening as by a complete interruption of the current.

For this purpose he short-circuits one of the coils of his electro-magnets in the following manner. In front of the armature a contact screw, C, is pressed upon by a metal spring, *b*, so that when the armature is attracted towards the poles of the electro-magnet, at half-way, it comes in contact with *b*, and separates it from *c*. The axis on which the armature turns is connected by a wire with the middle *e* of the electro-magnet coils; the contact screw *c* is in connection directly, by a wire, with the line L′; and between the back of the spring *b*, and the same line-wire L′, a resistance, *w*, equal to that of the half, *m*′, of the electro-magnet coils, is inserted.

A current, arriving by the line L (disregarding the shunt R), passes from L by *m*, *e*, *m*′, *b*, *c*, to L′. Very little goes through *w*, because its resistance is very great in proportion to the resistance of *c*. The armature is thereupon attracted, and as it descends, carries down the spring *b* with it, and interrupts the short-circuit *c* L′, but makes, at the same time, contact between itself and the spring *b*, and in so doing, shunts the current from the half *m′* of the electro-magnet coils, by the circuit *e*, *d*, *b*, *m′*. The short-circuit to line *c* L′ being broken, the current must pass from *b* through *w*, whose resistance is equal to the resistance *m′*; thus the total resistance of the circuit remains unaltered. The armature is now held by only the one pole *m*, and the spring *f* is so adjusted that on the slightest decrease in the magnetism of *m*, it exerts force enough to pull back the armature.

The idea of attracting the armature a certain distance by two poles, and this done, of holding it there by one, is as novel as it is ingenious, and answers its purpose very well in this instance. The plan is, however, complicated, and the apparatus, of course, requires very nice adjustment.

55. *Magneto-electric Pointer Telegraph of Siemens and Halske.* — More generally employed than their pointer telegraph with voltaic currents, and than Kramer's, is the convenient and trustworthy instrument which Siemens and Halske some years since constructed for the Bavarian telegraph lines. The system is almost exclusively employed on the lines of the *Grande Société des Chemins de Fer Russes*, by the London, the Danzig, and the Kœnigsberg fire brigades, and on various other lines in England and elsewhere.

The apparatus consists of a battery of permanent magnets, between the poles of which a coil of insulated wire on a revolving armature of soft iron develops, on being turned on its axis, alternately positive and negative currents. These currents traverse the line one after the other, and passing through the coils of an electro-magnet at the receiving station, cause its armature to vibrate and turn an escapement-wheel and pointer.

Fig. 39 represents an external view of the complete apparatus. A A is a cylindrical case, containing the transmitter; C, a handle which, in operating with the apparatus, is turned round from letter to letter, marked on the horizontal dial-plate, stopping always against the tooth opposite the letter to be indicated; and B, the receiving instrument, supported by a bracket at the back. The latter has in front a small dial, corresponding in its arrangement with that of the transmitter, and a pointer whose motions follow

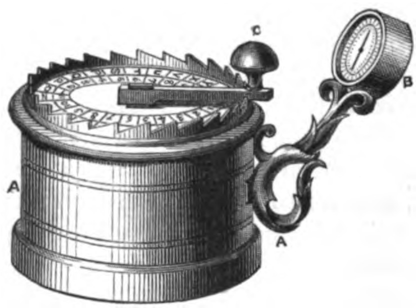


Fig. 39.

faithfully those of the handle of the instrument which is working.

Fig. 40 shows the internal mechanism of the transmitter. The metal disc J, with inclined teeth on its rim, is supported by the back *x*, and by two square pillars *y*. On the back, which consists of a stout plate of soft iron, are screwed a series of several pairs of permanent magnets, G G; those on one side with their north, and those on the other with their south poles projecting.

Between the poles of this system is a cylinder of soft iron, E, which serves as keeper of all the magnets. It is cut out longitudinally in two deep, broad grooves, on opposite sides, in which a spiral of fine well-insulated copper wire is coiled. The whole armature is supported by the brass caps F F′, in pivots above and below. Above the spiral, the pinion T locks into the tooth-wheel L, turning on an arbor A A, by means of the handle H above the disc J. The proportion between the teeth of the wheel and those of the pinion is such that one revolution of the wheel causes the pinion to revolve thirteen times, changing the magnetism along the whole length on each side of the armature, and thereby inducing in the coil, if the circuit is closed, thirteen positive and thirteen negative currents of equal magnetic effect.

When the coil is turned half round on its vertical axis, the polarity of the armature is also changed, and a magneto-electric current induced in the coil w in one direction, and

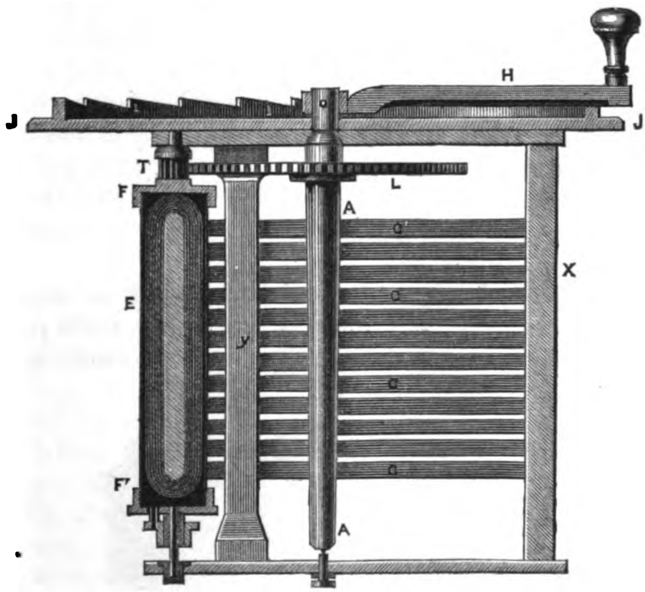


Fig. 40.

on turning it half a revolution farther round, so that it takes up its former position, a current in the opposite direction is induced.

The ends of the coil of wire, which are attached to the brass caps, are connected, one to an earth plate, the other to the coils of the electro-magnet of the indicator, and thence to the line.

In employing a series of separate magnets, arranged at a distance from each other, a greater inductive effect is produced than if only a single permanent magnet were used, or if the separate magnets were combined in the form of a battery; because the poles, acting at the same time upon the armature, produce along its whole length on each side an uniform magnetism, so that the wire coil receives, in every point, the same magneto-electric impulse.

The interior of the indicator is shown in Fig. 41. The top S S of a permanent magnet of hard steel, bent in a rectangular form, and having a space cut out of its upper end, protrudes through the side of a circular brass plate, A A, one-eighth of an inch thick. In the slit in the upper end S S of the magnet is the axis of a movable tongue of soft iron, having at its extremity the same polarity as the end S, and vibrating between the poles *n* and *s* of a polarised electro-magnet, *m m'*. By polarised is meant that the soft iron cores around which the wire is wound receive polarity from a permanent magnet.

In this case the cores of the electro-magnet are attached to a stout piece of soft iron, resting on the north pole of the angular magnet which distributes to the whole system

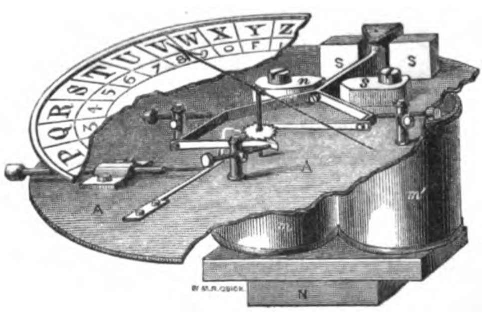


Fig. 41.

above the point of contact north polarity. The tongue or armature of soft iron is, therefore, attracted by both the poles of the electro-magnet with equal force, and if not exactly balanced in the middle between them, will rest on one side or on the other by the superior attraction of the nearer pole.

When a current is sent through the coils of the electro-magnet in the direction which increases the magnetism of the more distant pole, whilst it reverses the magnetism of the nearer, the latter forthwith repels the armature with nearly the same force with which the former pole attracts it, and the armature in consequence goes over to the former pole, and rests there, not only as long as the current lasts, but afterwards, when no current is circulating in the line. It is this which renders this indicator so sensitive for induction currents which are only of momentary duration.

At the end of the armature is a German silver fork, carrying two horizontal arms—thin steel springs with hooks which catch into the teeth of a ratchet-wheel. The ratchet-wheel has thirteen teeth, so that when the armature oscillates from right to left, or from left to right, the wheel advances half a tooth; and in order that the pointer may march over the whole dial, the armature must oscillate thirteen times in each direction. This is provided for by exactly that number of reverse currents being transmitted from the sending station, when the handle of the transmitter is turned once round the dial.

Behind the hooks are two screw stops which limit their motion and prevent the skipping of the wheel.

56. The alarm is generally a separate piece of mechanism; it was, however, sometimes in the earlier forms of this apparatus combined with the indicator by attaching a hammer to a continuation of the armature of the electro-magnet, and letting it strike on two bells placed just within its reach; but this plan has been almost entirely abandoned in favour of the alarm shown in Fig. 42. The principle is the same as that on which the indicator is constructed: a polarised electro-magnet, $m\ m'$, is supported by the upper pole of the angular bent permanent magnet M on a wooden base, *b*. From the lower pole of M springs a movable armature or tongue of soft iron which takes polarity from it, and plays between the projecting cores of the electro-magnet, which are also polarised. A continuation of the armature forms a hammer, *h*, and strikes upon the bells $b\ b'$.

A commutator is sometimes employed for directing the arriving currents, at pleasure, through the indicator or

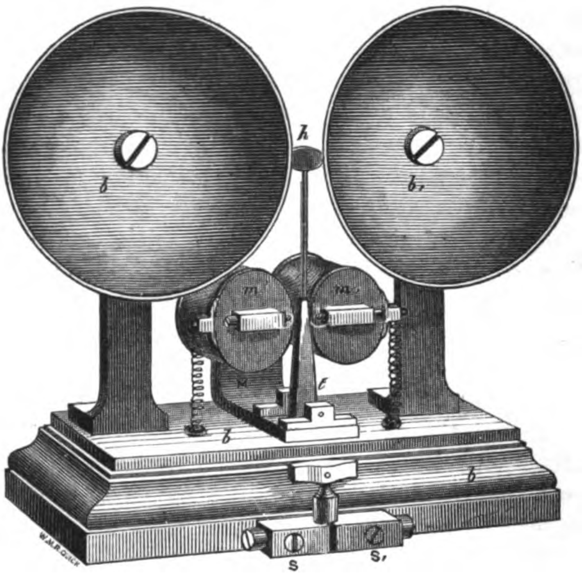


Fig. 42.

through the alarm; but, more usually, the alarm is inserted in the same circuit, and when it is not required to give notice of the arrival of a current, its coils are short-circuited by a contact peg inserted in a hole between the terminals *s s'* of the electro-magnet coils.

The plan according to which two such instruments are connected up for two stations is shown in Fig. 43, where the line L is connected at each station to an alarm, A, which can be short-circuited at *s*, if required; the other side of the alarm is connected with one side of the coils of the indicator I by a wire, *w*; thence a connection, *w'*, leads to the coil of the transmitter or inductor T, and to earth.

On turning the handle of the transmitter, the currents pass, first of all, through the indicator of the home apparatus, the pointer of which turns correspondingly with the handle;

thence over the terminals of the alarm, through the line, to the alarm of the distant station, which it rings or not, according as the contact peg is out or in, through the indicator coils, moving its pointer simultaneously and corre-

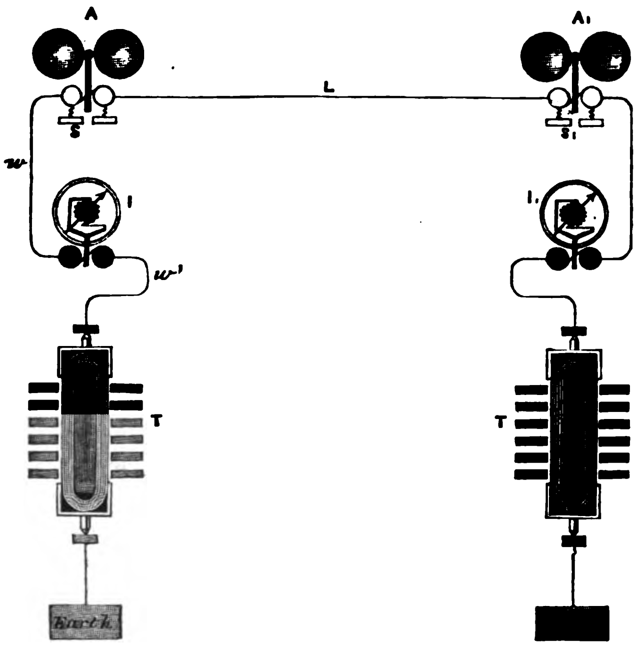


Fig. 43.

spondingly to the movements of the first indicator, and, finally, to earth—a short circuit over the coils of T being established when the handle stands at zero of the dial.

The older forms of the apparatus were a little clumsy and noisy in manipulating; but the vast improvements made lately in its construction in the London establishment of Messrs. Siemens Brothers have reduced these inconveniences to a minimum, without in the least lessening the power or trustworthiness of its indications. It is spoken very highly of by the employés, and may be looked upon as one of the best existing pointer telegraphs.

57. *Wheatstone's Universal Telegraph.*—This is another form of step-by-step telegraph, the invention of Professor Wheatstone. During the last few years it has obtained considerable employment on private lines, being found at nearly all the ends of the network which Professor Wheatstone has helped to spin over the metropolis.

It consists of two parts—the "communicator" and the "indicator."

The communicator is contained in a small square box, on the upper surface of which is a raised dial-plate, surrounded by thirty equidistant keys radiating from the same centre. Upon the dial-plate are marked the twenty-six letters of the alphabet, three points of punctuation, and an asterisk; in an inner circle are the nine numerals and a cross on each side. A hand or pointer, turning on an axis in the centre of the dial, rotates in connection with the handle in the front, and may be arrested at any letter while the handle is being turned, by depressing one of the keys or buttons.

Inside the box is a fixed permanent horse-shoe magnet, placed horizontally, carrying, on its poles, four soft iron cylindrical cores with their coils of wire, arranged at equal distances from each other in the circumference of a circle. On an axis passing through the centre of this circle, in connection with the handle, revolves a soft iron armature whose breadth is a little greater than the distance between two adjacent cores. When the armature revolves, therefore, it approaches one pole as it recedes from the one diagonally opposite, and thus induces simultaneously in the two coils currents in the same direction.

A small circular chain is placed horizontally underneath the keys, and becomes slightly bulged to the extent of its slack when a key is pressed down. As soon as another key, however, is pressed down, the chain straightens itself underneath the first key and lifts it up. The purpose of the keys is to arrest at pleasure the march of the pointer round the dial, and to short-circuit the currents at any letter. This is done by an arm, attached to the axis which carries the pointer on the dial, coming in contact with the lower part of the depressed key. Motion is imparted to the axis of the pointer and carrier arm from the handle by means of a bevilled wheel, which engages with a pinion fixed to the axis carrying the armature of the electro-magnet. The proportion is so adjusted that, for every current induced in the coils, the pointer shall advance the distance of one letter on the dial. If, therefore, the pointer and arm start freely from zero when the handle is turned and any key, as D for example, depressed, the armature is rotated, producing alternate electric waves whilst the pointer will pass over A B and C respectively. Arriving at D, the carrier-arm comes into contact with the depressed key and cuts off the passage of the subsequent currents until another key is depressed, by which the carrier-arm is released and travels on with the pointer.

The face of the indicator is divided into thirty equal spaces exactly similar to the dial of the communicator, with a double circle of letters and numerals. On an axis in its centre is a pointer like the minute hand of a watch, to which motion is given by a small escapement-wheel with fifteen teeth. Two magnetic needles, or bars, fixed to an axis, lie parallel between two small electro-magnetic coils with soft iron cores, and are so arranged that, when currents pass through the coils and magnetise the cores, the latter exercise mutual attractions and repulsions on the poles or extremities of the magnet-needles, imparting a backward and forward motion to their axis. The scape-wheel is carried by a short vertical arm fixed to the end of this axis, and is rotated by working to and fro against stops or pins.

The electrical connections of the apparatus are simple. The coils of the communicators and indicators of all the apparatus are connected up in a common circuit. When the coils of one of the communicators are turned round by means of the handle, if the pointer is free to move round the dial, a current traverses the line at every letter which the pointer passes over, moving the hands of the indicators correspondingly; but as soon as the carrier-arm attached to the axis of the pointer is arrested by coming in contact with a depressed key, the currents which follow are short-circuited. The hands of the indicators therefore stand still upon the same place on the dials until the key is raised and the short circuit removed.

In the front of the indicator a contact lever is moved between stops marked A and T. When the lever is placed on A the arriving currents ring the alarm, the telegraph being thrown out of circuit; when it is placed on T, the alarm is out of circuit and the indicator works.

The working of this instrument, as well as the neatness with which the whole is constructed, cannot be too highly spoken of. The great advantage which it possesses over the other step-by-step telegraphs, in which the coils or armatures are stopped and started at every letter, is that its currents are uniform, whereas in the other systems, at starting and stopping, the operator cannot avoid moving his handle slower than when driving it midway between two letters, which very frequently gives rise to "skipping" of the pointer.

58. *Simple Morse Circuit.*—In its simplest form the Morse telegraph consists of a transmitting key and a recording instrument, with intervening line wire, battery, and earth connection. The purpose of the key is to close the circuit of the battery conveniently for the formation of arbitrary signals. The signals representing the letters, &c., consist of combinations of two elementary marks, a dot and a dash. The former is given by the momentary closing of the circuit, and the latter by closing it for a longer time, by means of the key. The signs are received at the distant station by the corresponding attractions of the armature of an electro-magnet, which marks them on a strip of paper in its vicinity. The plan by which these arrangements are made at two stations is represented in Fig. 44. At each of the stations, B is a battery of voltaic pairs, connected between the point 1, underneath the metallic lever K, and the earth. When the lever K is not being manipulated, it is held by a spring upon the metal point 2, between which and the earth are inserted

the coils of the electro-magnet M, whose armature is employed to mark the paper and record the signals given from the distant station. On pressing down the key K, for example, the contact between the lever and the point 2 is interrupted and that at 1 established, the current of the battery B goes from C through the contact point 1 and front

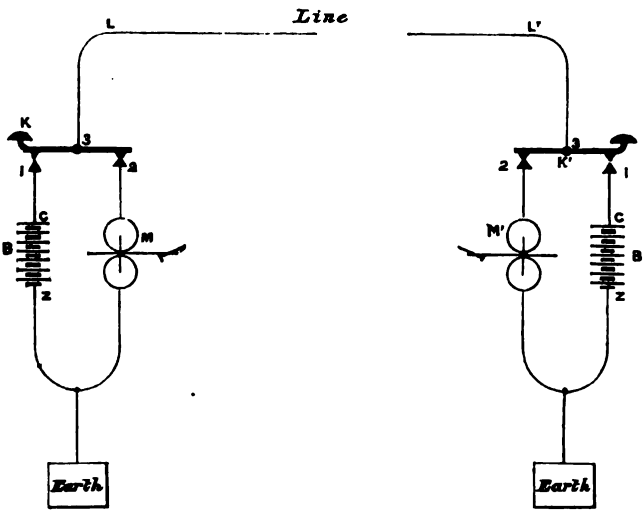


Fig. 44.

part of the lever to 3, where it enters the line L. Arriving by L′ the current passes over K′, from the middle 3, to the back contact point 2, and from this, the key being at rest, it traverses the coils of the electro-magnet M′, and then goes through the earth back again to the battery B.

59. In construction, the Morse instruments are very various, nearly every maker having peculiar arrangements of his own. The earlier apparatus in America and England were homespun, and of little mechanical merit as specimens of art, nor did they advance very considerably beyond this until within the last few years. In the hands of the French and Germans mechanicians, however, the instrument reached a high degree of completeness, and has secured for

itself in every country where the telegraph is to be found an employment exceeding that of any other system. The adoption of the Morse instrument by the French Administration of Telegraphs in 1857, gave an impetus to inventors, and many real improvements were the result.

60. *Embossing Instrument with movable Magnet.*—This is a construction of the Morse by Messrs. Siemens and Halske, of Berlin, once extensively used on the Russian, Danish, and some of the German lines, but at present replaced to a great extent by newer constructions. The movement of the writing-lever is effected by the attraction of the opposite poles of two electro-magnets rendered active by the same currents.

Fig. 45 gives a perspective view of the instrument. *m m'* are two straight electro-magnets. The core of *m'* is furnished with a facing of soft iron, *r*, on each of its poles; the core of *m* is supported between two screw-points, and is furnished at each end with a continuation, *p*, ending in a facing opposite to and of the same size as *r*. Between the two continuations *p p*, is a frame carrying the printing lever. *a b* and *a' b'* are the ends of the coils of the electro-magnets connected electrically with the terminals A and B.

When a current traverses the coils it polarises their cores in reverse directions, that is to say, when the end and continuation *p* of the core in front are south-polar, the corresponding end of the other core, with its continuation *r*, will be rendered north-polar—the reverse polarities being, of course, at the further end—and the faces of *p* and *r* on each side, having opposite magnetism, will attract each other.

The attraction of these four poles in the same sense renders the instrument extremely delicate, and the force with which the poles tend to approach each other being very great, the instrument is well adapted for recording signals by scoring the style into the paper strip.

When the current ceases the printing-lever is brought back by means of the spring *f*. W W' are the rollers between which a paper strip is drawn. The style, carried at one end of the beam, enters a groove in the middle of the roller W, when the other end of the beam is depressed. The play of the beam, which turns on the axis c, is limited by the adjusting screws *u* and *z*. The style is carried on the end of a screw which enables the operator to regulate its position in the groove so as to indent the paper more or less legibly.

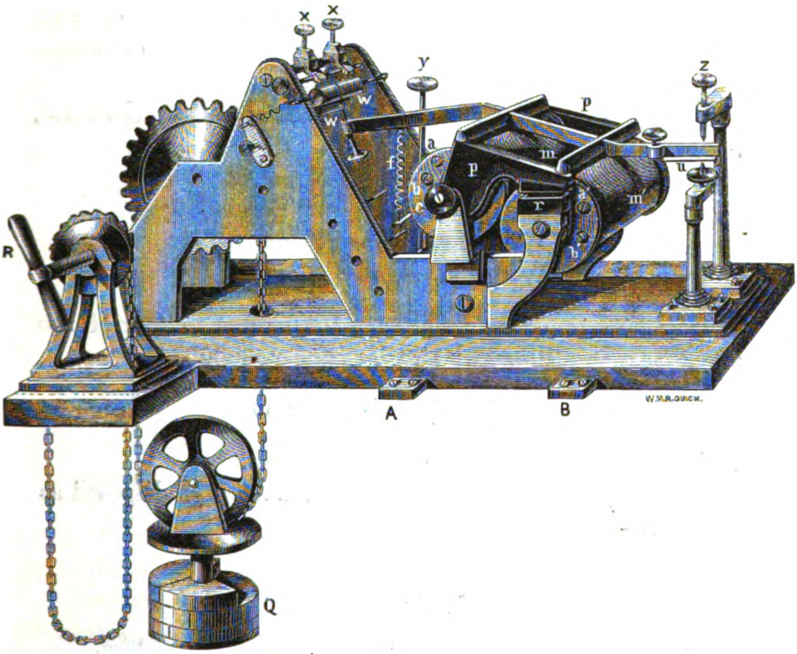


Fig. 45.

When the current passes through the coils of the electro-magnets, the armatures are attracted to each other and the style forced into the paper strip underneath the groove, where it is held while the current lasts, and as the paper during this time continues to be drawn through, a long or short score is produced, according to the time which the transmitting key is held down.

61. *The Morse Code.*—The elementary signs of the Morse telegraph are two, a dot and a dash, produced by the record-

ing instrument according to the time which the key at the transmitting station is held down.

The general adoption of this system on the Continent some years back occasioned the establishment of certain rules for the settlement of the letters, numerals, &c., which have been subsequently almost universally adopted.

The formation of so many letters, &c., out of two elementary signs required the greatest number of variations with the given number of elements.

The number of variations, with repetitions of two elements, are:—

With single signs	2	$= 2$
With two signs	2^2	$= 4$
With three signs	2^3	$= 8$
With four signs	2^4	$= 16$

Therefore, by using variations of from one to four of the two elementary signs, we have at our command

$$2 + 4 + 8 + 16 = 30$$

variations for the formation of an alphabet.

These variations, with some others, have been disposed as follows:—

I. Alphabet.

Letter.	Sign.	Letter.	Sign.
A . . .	· —	J . . .	· — — —
Ä . . .	· — · —	K . . .	— · —
B . . .	— · · ·	L . . .	· — · ·
C . . .	— · — ·	M . . .	— —
D . . .	— · ·	N . . .	— ·
E . . .	·	O . . .	— — —
É . . .	· · — · ·	Ö . . .	— — — ·
F . . .	· · — ·	P . . .	· — — ·
G . . .	— — ·	Q . . .	— — · —
H . . .	· · · ·	R . . .	· — ·
I . . .	· ·	S . . .	· · ·

Letter.	Sign.	Letter.	Sign.
T . . .	▬	X . . .	▬ ■ ■ ▬
U . . .	■ ■ ▬	Y . . .	▬ ■ ▬ ▬
Ü . . .	■ ■ ▬ ▬	Z . . .	▬ ▬ ■ ■
V . . .	■ ■ ■ ▬	Ch . . .	▬ ▬ ▬ ▬
W . . .	■ ▬ ▬		

II. Numerals.

Numeral.	Sign.	Numeral.	Sign.
1 . .	■ ▬ ▬ ▬ ▬	6 . .	▬ ■ ■ ■ ■
2 . .	■ ■ ▬ ▬ ▬	7 . .	▬ ▬ ■ ■ ■
3 . .	■ ■ ■ ▬ ▬	8 . .	▬ ▬ ▬ ■ ■
4 . .	■ ■ ■ ■ ▬	9 . .	▬ ▬ ▬ ▬ ■
5 . .	■ ■ ■ ■ ■	0 . .	▬ ▬ ▬ ▬ ▬

III. Punctuation, &c.

	Sign.
Full stop	■ ■ ■ ■ ■
Colon	▬ ▬ ▬ ■ ■ ■
Semicolon	▬ ■ ▬ ■ ▬ ■
Comma	■ ▬ ■ ▬ ■ ▬
Interrogation	■ ■ ▬ ▬ ■ ■
Exclamation	▬ ▬ ■ ■ ▬ ▬
Hyphen	▬ ■ ■ ■ ■ ▬
Apostrophe	■ ▬ ▬ ▬ ▬ ■
Fraction line*	▬ ▬ ▬ ▬ ▬
†Inverted commas	■ ▬ ■ ■ ▬ ■
†Parenthesis	▬ ■ ▬ ▬ ■ ▬
†Italics or underlined . . .	■ ■ ▬ ▬ ■ ▬

IV. Official Signals.

	Sign.
Public message	■ ■ ■
Official (Telegraph) message	■ ▬

* To be placed between the numerator and denominator of a vulgar fraction.

† To be placed before and after the words to which they refer.

Private message	▪ ▬ ▬ ▪
Call	▬ ▪ ▬ ▪ ▬ ▪ ▬
Understood	▪ ▪ ▪ ▬ ▪
Interruption	▪ ▪ ▪ ▪ ▪ ▪ ▪ ▪ ▪
Conclusion	▪ ▬ ▪ ▬ ▪ ▬ ▪
Wait	▪ ▬ ▪ ▪ ▪
Receipt	▪ ▬ ▪ ▪ ▬ ▪ ▪ ▬ ▪

The length of a dot being taken as a unit, the length of a dash = 3 dots.

The space between the signs composing a letter = 1 dot.
" " " letters = 3 dots.
" " " words = 6 dots.

The formation of the numerals is ingenious; they are each represented by five of the two elements, and so that, disregarding the dashes which stand on the right hand, and giving a value of unit to a dot and two to the dashes on the left, the value of the numeral represented is expressed.

The signs of punctuation, official signals, &c., are either higher variations or arbitrarily chosen letters of the alphabet whose single appearance is a sufficient indication that they are not to be construed as forming parts of words.

62. *Morse's Transmitting Plate.*—Soon after Morse's invention of the transmitting key his attention was directed to the fact that some people find great difficulty in manipulating the arbitrary combinations with uniformity in the length of the marks and spaces. He, therefore, constructed an arrangement for facilitating the transmission. On a metal plate, B B, Fig. 46, are soldered series of raised rectangular pieces of metal, whose lengths and distances apart correspond with the arrangement of the Morse alphabet. Between these pieces, strips of ivory of equal thickness are inlaid, making the whole surface, A A, level. These metal pieces are shown black in the figure and the ivory white. From a binding screw, C, attached to the plate B B, and therefore in electrical connection with each of the metallic rectangles, a wire, *m*, is led to the receiving instrument and a battery, the further

pole of the latter being to earth. The line wire *w* ends in a spiral of insulated wire fastened to a style, G, with blunt platinum point and insulated handle.

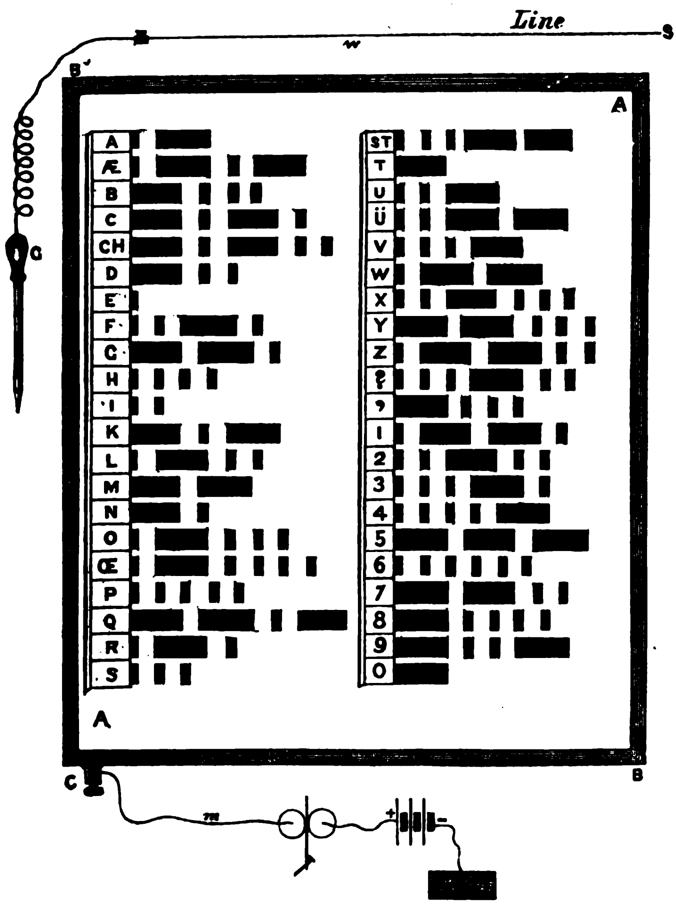


Fig. 46.

This apparatus is intended to replace the key. In order to transmit a message with it the operator takes the insulated handle in his hand and scores the point with an uniform speed over the signs of the letters, one after the other, which he wishes to telegraph. In doing so the circuit is closed as soon as the point of the style touches any of the metal pieces, and is broken again when it moves over the ivory.

The arrangement has never enjoyed an extensive employment, and is now, perhaps, entirely out of use. The reason of this is probably to be found in the fact that the imperfect appreciation of time which prevents some acquiring uniformity in manipulating the key renders them as unable to move the style with an equal velocity over the plate, time being a factor of velocity.

63. *Morse Apparatus with Relay.*—When the line connecting two stations is long, it is impossible sometimes, even with very great battery power, to move the armature of the electro-magnet with force enough to impress the paper legibly. It was on this account that Morse employed a relay in working his recording apparatus. The principle of the relay has already been explained in conjunction with Wheatstone's alarm. The form of relay used with the Morse instrument differs, however, from that invented by Wheatstone. Instead of the magnetic needle and mercury cups, the local circuit is closed by the contact of the armature of an electro-magnet, with a metal anvil, both being inserted in the local circuit. A common form, known as the American relay, from its general employment on the American lines, is shown in Fig. 47. The electro-magnet M M is fixed horizontally on a board, having before its poles the soft iron armature *a*, supported by a tongue turning on the axis *b*. The armature is held back by a spiral-spring *f*, stretched between the tongue and an adjusting screw, *g*. The coils M M of the electro-magnet terminate in the binding-screws L′ L″, to which are brought respectively the line and earth wires. The local battery and Morse apparatus are inserted between the terminals L′ L″. The former of these is in permanent connection with the axis *b* by a wire, *x*, and the latter with the body of the bracket *k i*, which carries two screws, *h d*, with a platinum point, and *c*, whose point is insulated with agate.

When at rest the tongue leans against the agate point, and the local circuit is open; but when a current circulates in the line and coils of the electro-magnet the armature is attracted towards the poles, and the tongue strikes against

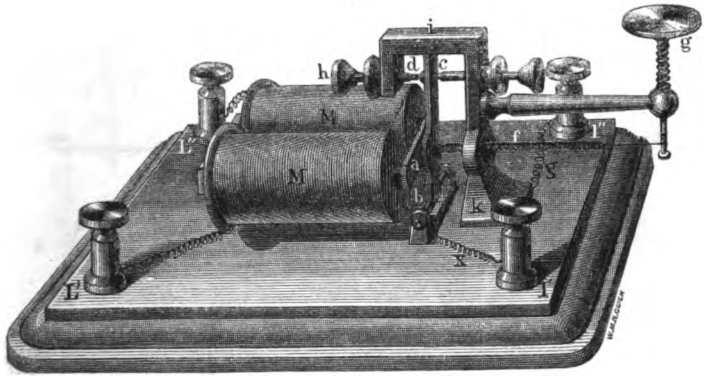


Fig. 47.

the point of the contact-screw *h d*, and closes the local circuit, the current of which passes from l' (*x*, *b*, *d*, *i*, *k*, *g*) to l''.

64. *Simple Morse Embosser for two Stations with Relay.*—Fig 48. represents a plan of connection of a Morse embosser with relays and local batteries for two stations. G is the line galvanoscope connected, on the one side, with the line, on the other, with the lever of the key K. Its purpose is to show the presence of current in the line, and to give a rough idea of its strength. The front or working contact 1 of the key is connected with the pole C of the line-battery B, and the other pole Z with the earth-plate. The back, or reposing contact, of the key is connected with one end of the electro-magnet coils of the relay R, the other end being in communication with the earth-plate. Lastly, between the contact-point 2 of the relay and its tongue or armature are inserted the coils of the Morse M and the local battery L B.

When in repose the levers of both keys are on the contacts 2, and the line, therefore, at both ends to earth through the coils of the relays. On pressing down either of the keys the current passes direct from the z-pole of the battery to the earth-plate and earth, and from the c-pole through the line galvanoscope, line, key of opposite station, and relay, to earth. The deflection of the relay-tongue, from contact 1

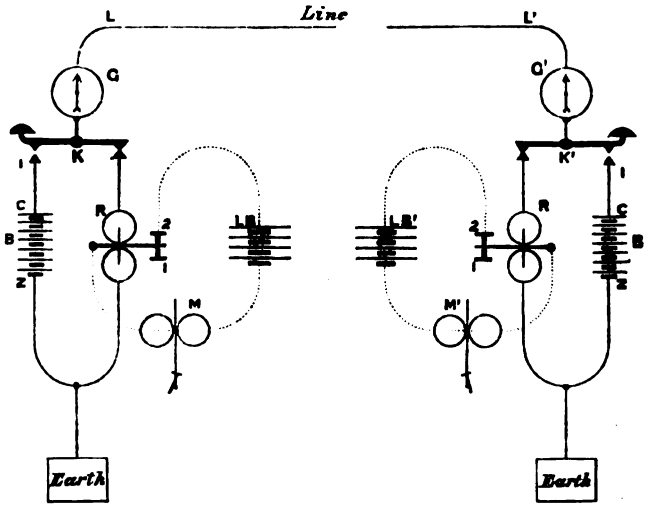


Fig. 48.

to contact 2, closes the local circuit, and the armature of the receiving instrument works in conformity with the motions of the key at the sending station.

Another method of connecting up the same instrument for two stations is shown in Fig. 49. In this method the lever of the key is in permanent contact with earth. The c-pole of the battery is connected with the front contact of the key, and the z-pole with the point of junction between the galvanoscope and relay, the latter being inserted between the galvanoscope and back contact of K. The local circuit is arranged as before.

A current arriving by the line while the key is at rest passes through the galvanoscope, coils of relay, back contact and lever of key to earth. When the key is pressed down on the contact 1, the c-pole of the battery is put to earth through the lever of the key, and the circuit being thus completed, the current from the z-pole passes through the galvanoscope into the line.

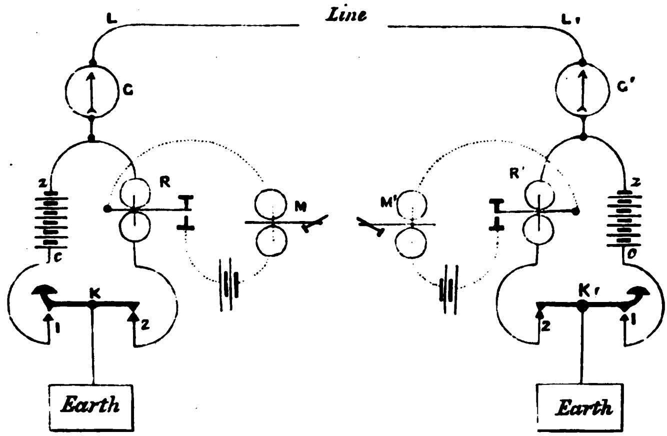


Fig. 49.

In the former method (Fig. 48) the operation of the key consists in shifting the line from relay to battery. In the other method, the battery and relay have the same fixed contacts 1 and 2 of the key; but the earth and line change places, the line taking the place of the earth in the former, and the earth being shifted by the key from relay to battery.

This is by no means so good as the former method, because it necessitates a good insulation of the battery, without which a current, depending on the magnitude of the fault, will not only pass always through the line, but also through the coils of the home-relay; and any accidental contact of the battery with earth will give a signal at the relays of both stations, whilst, with the former method, a similar accident would be entirely without effect further than weakening the currents sent on to the line, notice of which is amply given by the galvanoscope.

65. *Intermediate-station Commutators.*—Where intermediate stations occur, which are supplied each with only one Morse

instrument, it becomes necessary to employ a commutator or current director to put the apparatus at pleasure in the circuit of the up or down line in order the meet the requirements of the service. At such a station the apparatus must be so arranged as to be able to assume either of these three positions :—

(1.) When the intermediate station is entirely cut out of circuit, and the end or distant stations on opposite sides correspond directly through the line.

(2.) When two end or distant stations on opposite sides correspond with each other, and the intermediate station receives the despatch, at the same time.

(3.) When the intermediate station wishes to communicate with a station up or down the line whilst it has notice of currents arriving from the other side.

To avoid the inconvenience of altering continually the connections to suit these various positions of the apparatus, commutators are employed. Various forms of these instruments are given by Siemens, Nottebohm, Borggreve, and others.

66. One of the completest is that of Nottebohm. It consists of six bars of metal screwed on to a wooden base, cut out in seven holes to receive contact pegs between them, so as to bring them in metallic contact with each other.

Fig. 50 gives the commutator in half-size, and Fig. 51 the contact peg in full-size. $\underset{\cdot}{L}$ and $\underset{\cdot\cdot}{L}$ are the terminal screws to receive the line wires coming from the galvanoscopes. R_0 and R_u the ends of the electro-magnet coils of the relay. T is connected with the back contact, 2, of the key, and E with earth. Between the front contact of the key and the bar R_0 the line-battery is inserted. The beam of the key is also to earth, according to the second plan mentioned above (Fig. 49) for arranging the Morse system.

In the first position, when the intermediate station is to be cut out of circuit to let two other stations correspond direct, the contact peg is put into the hole 3. The current coming from the left-hand side passes over G', $\underset{\cdot}{L}$, 3, $\underset{\cdot\cdot}{L}$, G_2, and so on, to the other line. The employé can see, by the deflections of the needles of his two galvanoscopes, G_1 and G_2, when the stations are corresponding, and when both have done, at a given signal, he re-arranges his commutator for regular work. This signal is given by both stations simul-

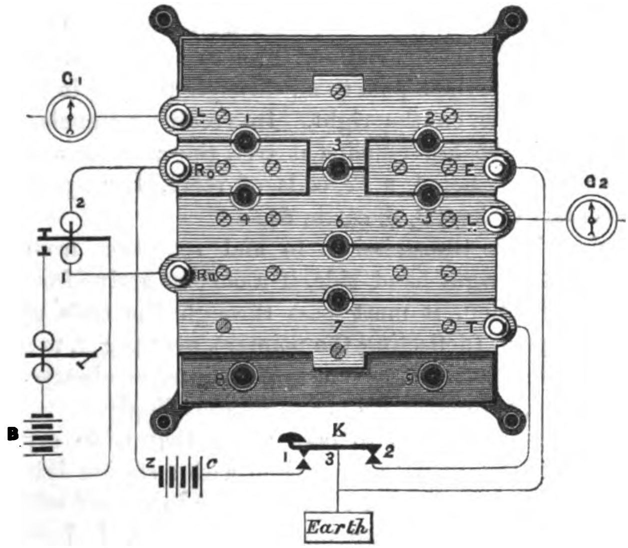


Fig. 50.

taneously, and consists in pressing down their keys for the space of one minute, by which the needles of the galvanoscopes are deflected steadily in one direction for that length of time.

In the second position, by which the intermediate station participates in the messages transmitted by the distant stations, and which are, for the most part, official instructions, time, or information for the employés, contact pegs are put into holes 1 and 6. A current then arriving from the same side will traverse G_1, L, 1, R_0, 2 (coils of relay), 1, R_u, 6, L, G_2, to the other line. The relay then performs its functions of closing the local circuit and setting the recording instrument in motion.

Fig. 51.

Position No. 3 is attained by two different arrangements of the contact pegs, according as the one or the other of the lines is to be used. When the apparatus at the intermediate station is to correspond with a station on the right, whilst the line on the left remains in circuit with the board, holes 2, 4, and 7 are provided with pegs. If the intermediate station now works the key, currents circulate from the C-pole of the battery through 1, lever of key, 3, earth; and from the Z-pole to R_0, through the peg in hole 4, L, G_2, to the line on the right. In receiving signals from the same side the key remains at rest, the currents arriving pass over G_2, L, peg 4, R_0, 2, coils of relay, 1, R_u, peg 7, T, back contact of key, 2, 3, earth, &c.

During both transmission to and reception from the station on the right-hand side, if a current arrive from the opposite direction, it must pass through the coils of the galvanoscope G_1 (deflecting the pointer), over peg 2, to earth. The deflection of the galvanoscope pointer is observed by the employé, who takes his measures accordingly.

When the reverse is to take place, that is to say, the intermediate station is to correspond with a station lying to the left, whilst that on the right remains in circuit with the galvanoscope, the pegs are inserted in holes, 1, 7, and 5. The signals given by the key take the following road: Z, of battery, R_0, peg 1, L, G_1, to line on the left, apparatus at the opposite station, and earth, and from the C-pole of the battery to 1, lever of key, 3, earth. Arriving currents from the same direction come over G_1, L, peg 1, R_0, 2, coils of relay, 1, R_u, peg 7, T, key, 2, 3, earth.

Those arriving from the other side deflect the pointer of G_2, and to pass to earth by G_2, L, peg 5, earth.

In both cases the employés have to pay attention to the galvanoscope, as in cases of emergency it is sometimes necessary to postpone the transmission or reception of a message on one line until the more pressing one from the other side has been disposed of.

67. *Siemens and Halske's Intermediate Station Commutator.*—The commutator represented in perspective in Fig. 52 is much simpler in construction than that of Nottebohm, and answers all the requirements of an intermediate station

where a single apparatus only is used. The apparatus is put in circuit between the screws 1 and 2, to which the lines L_1

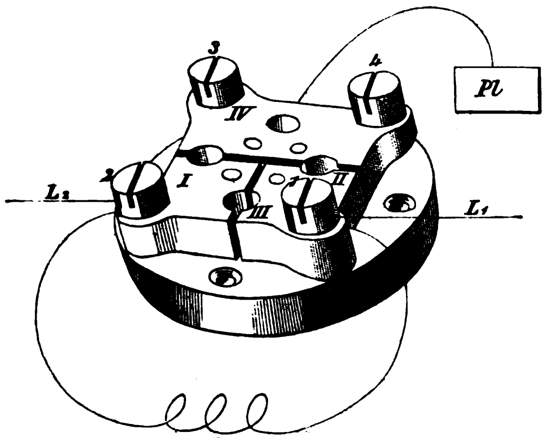


Fig. 52.

and L_2 are respectively connected, while the earth-plate is brought to one of the screws, 3 or 4.

When the contact-cone is out, the current passes through the apparatus in the circuit

$$L_2, 2, A, 1, L_1,$$

that is to say, the intermediate station receives the signals in common with a distant station.

When the contact-cone is in hole III the apparatus is short-circuited, and the current passes through

$$L_2, 2, \text{contact-cone in III}, 1, L_1.$$

When the contact-cone is in hole I the apparatus is used as terminal of the line L_1, and the currents from L_1 take their way through L_1, 1, A, 2, I, earth, &c. Those from L_2 through I to earth. If the contact-cone is put in II the instrument receives from and transmits to the line L_2 on the other side, in the same way. In both positions the currents arriving by the line which is not being corresponded with pass through the galvanoscope inserted in the line circuit and give notice to the operator.

68. *Borggreve's Commutator for Intermediate Stations.*—The many inconveniences arising from delay in the reception and transmission of messages, combined with the possibility of mistakes in stoppering the holes of Nottebohm's commutator for the different positions of the apparatus, has shown the necessity of furnishing intermediate stations with two apparatus. This enables them to correspond with the stations on both sides at the same time.

M. Borggreve, Inspector of Telegraphs in the Prussian service, has arranged a commutator for the use of intermediate stations with two apparatus, in which, as in that of Siemens and Halske, only one stopper is required. It is composed of five brass slabs screwed on an insulating base of vulcanite.

The way in which the commutator is connected with the two Morse-apparatus, as well as its form and appointments, is shown in the plan, Fig. 53.

The line wires L^1 and L^2 are connected to the upper screws, while the lower screws on the same bars are connected with the levers of the transmitting keys K^1, K^2. To the binding-screw of the middle bar is attached the earth-wire, and to the screws of two intermediate bars, the cross-commutators C^1 and C^2, whose opposite points go to the back contacts of the keys. R^1 and R^2 are the relays of the two Morse-apparatus M^1 and M^2. The two local circuits are supplied with a common local battery, B, and the two line circuits with a common line battery, L B. When the contact plug is inserted in hole 1 of the commutator U the apparatus are both short-circuited, and currents pass through L^1, G^1, stopper 1 of commutator, G^2, L^2, &c. The employé sees by the deflections or otherwise of his galvanoscope-needle when the direct correspondence of the end or distant stations is concluded, usually by an agreed signal.

If the stopper is in hole 2, apparatus 1 can correspond with the line L^1, and apparatus 2 with the line L^2, independently of each other. The currents arriving by L^1 go through G^1, U, K^1, C^1, and coils of R^1, C^1, U, 2, earth, &c. The cross-commutators are put between the back contacts of the keys and bars of the commutator U, in order to enable the operator to invert the coils of the relays, in case the residuary

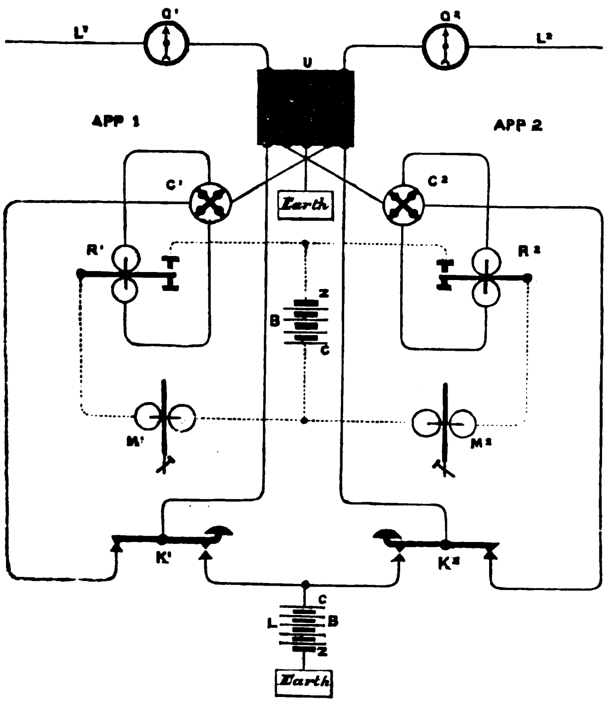


Fig. 53.

magnetism in the soft iron cores, from continued currents in one direction, should interfere with their delicacy.

The currents transmitted from the station towards L^1, by pressing down the key K^1, take the direction from L B, copper pole C, front contact and lever of key, first bar of commutator U, G^1, and L^1. The operations with apparatus 2 and L_2 are similar.

When the contact peg is put in one of the holes, 3 or 4, the apparatus on the opposite side to that in which the peg put in, is ready for participating in any messages that may be passing through the line in either direction. Suppose the peg to be inserted in the hole 3. The currents coming from the direction L_1, go then from L_1 through G^1, peg 3 of the commutator C^2, coils of relay on the right, back contact of K^2, lever K^2, commutator U, G^2, L^2, &c. The relay R^2 will be set in action and work the Morse M^2, which will print all the signals passing from the line L^1 into the line L^2.

69. *Commutator for Stations with three or four lines from different directions.*—Where more than two lines from different directions meet at a station, it is required to employ a commutator by which, whilst one or two lines are being corresponded with, the remainder can be connected up, two and two, for circular correspondence.

When three lines meet at a station a commutator, arranged by Borggreve, is usually employed, by which any two of the lines may be connected together in circuit with a galvanoscope, or complete recording apparatus, while the third line is open for telegraphic communication from the same station as terminal.

When four lines meet, it is necessary to arrange the commutator so that, upon occasion, they may be connected up two and two with intervening receiving apparatus, by which the corresponding stations are in direct communication, and the intermediate stations able, at the same time, to participate in the information transmitted.

Fig 54, *a*, gives a plan of connections of Borggreve's commutator for three lines, by which the following combinations are possible:—

1. L^I circular with L^{II}, L^{III} with apparatus.
2. L^I „ „ L^{III}, L^{II} „ „
3. L^{II} „ „ L^{III}, L^I „ „

In using this commutator three of the holes are always stoppered at the same time. Fig. 54, *b*, gives the position of the stoppers in the holes answering to the positions 1, 2, and 3, above.

In the first position the circular current traverses L^I, 1, circular apparatus, 2, commutator, 3, L^{II}, &c., and the currents received or transmitted by the intermediate station, L^{III}, commutator, 4, back-contact of key, relay, 5, earth, &c.

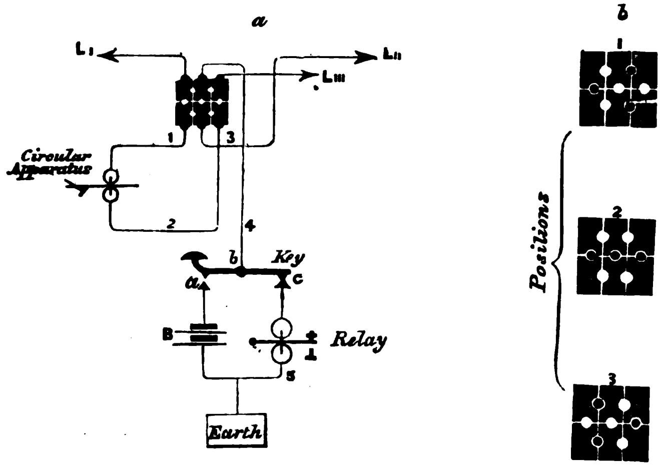


Fig. 54.

In the second position, the circular-current goes through L^{I}, 1, circular apparatus, 2, commutator, L^{III}, &c., and the station currents through L^{II}, 3, commutator, 4, back-contact of key, relay, 5, earth, &c. In the third position, circular currents go over L^{II}, 3, commutator, 1, circular apparatus, 2, commutator, L^{III}, &c., and station-currents over L^{I}, commutator, 4, back-contact of key, relay, 5, earth, &c.

The plan of connections for a station with four lines combines both Borggreve's commutators; and the combinations in which the operator can arrange the lines are as follows:—

1. L_{I} with L_{II}, and L_{III} with L_{IV}
2. L_{I} „ L_{III} „ L_{II} „ L_{IV}
3. L_{II} „ L_{III} „ L_{I} „ L_{IV}

In each combination the positions of the lines with regard to the apparatus may be:—

(1.) Direct, the station not receiving the message.

(2.) Circular, the station participating in the despatches.

(3.) Corresponding, the station transmitting and receiving by the lines.

70. *Battery commutator.*—When the insulation of the line varies, or by any other reason—as, for instance, when an end station has to transmit to a near station with little line resistance in the circuit—it becomes necessary to alter the strength of the current, a battery commutator is inserted, by which one-third, two-thirds, or the whole of the elements, may be brought into service by simply changing the place of a contact peg. Such an apparatus consists of four slabs, as in Fig. 55. The copper pole of the battery is connected to the screw of the bar, B, and connections from elements one-third and two-thirds of their number from the copper pole, are brought to the screws of the bars C and D respectively; the zinc pole being connected in the usual way with earth. The place of the stopper in *b*, *c*, or *d* determines the battery power used.

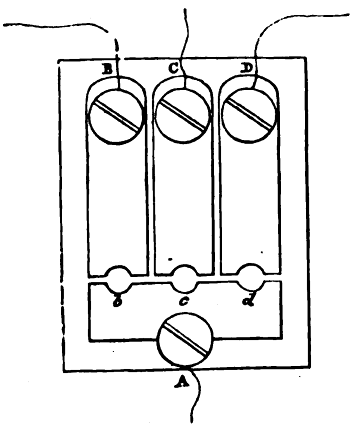


Fig. 55.

When more than one line is worked with a single battery, a bar-commutator (Fig. 56) is used. Three brass bars, 1, 2, and 3, are screwed on a slab of dry wood or vulcanite, and, above them, at right angles, three others, I, II, III. The bars are insulated from each other when the holes are open, but when a contact cone is inserted in one of them, the corresponding cross-bars are electrically connected. If the front contacts of the keys are connected to the three bars I, II, III, and three parts of the battery, as above, to the bars 1, 2, 3, the operator is able to work the lines with either of the battery powers which may be necessary.

71. *Translation or re-transmission of Morse-signals.*—On long telegraph circuits, where the wires are insulated by

the ordinary means of suspension, a considerable decrease in the intensity of the currents which leave the transmitting station, occurs before they reach their destination; and this waste it is impossible to prevent. If no other causes were

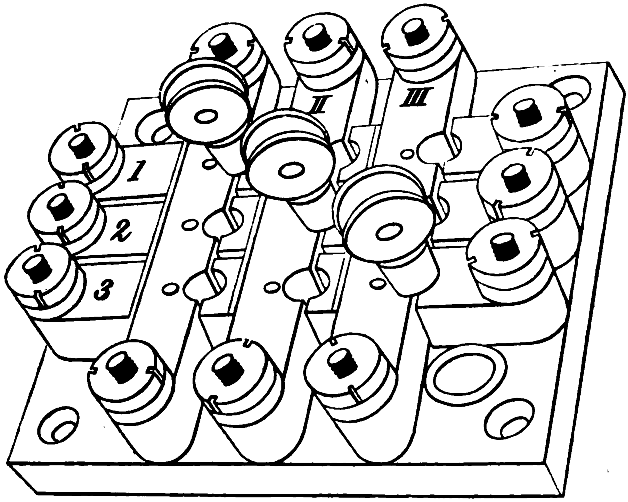


Fig. 56.

present, the resistance of the wire, combined with the fact that no absolute insulation, even under the most favourable conditions, exists, would alone put a limit to the length of line on which it would be possible to work direct. But this limit is, in practice, very considerably contracted, as the methods of insulatiom employed are always liable to temporary derangements by dampness of the atmosphere, dirt, and other causes, which account for the innumerable little shunts that a current finds all along the line, and by which it tries its utmost to get back, without going to the end of the line.

Imagine a long line between two distant stations, A and E, with three intermediate stations, B, C, and D, also far apart. If A wanted to send a message to E, the line being too long and the leakage of the current too great, it would have to send the message first to B ; B would receive it and forward it to C ; C, in like manner, to D ; and, lastly, D to E.

This method was adopted once, and not only took away much valuable time, but was found to be a prolific source of mistakes, which crept into the unfortunate despatches so transmitted.

The arrangement introduced by Morse, described before, to remedy these inconveniences, remained for some years in abeyance. At length a modification of his plan was adopted. It consisted in making the printing lever of the instrument at station B perform the functions of a transmitting key for the line between B and C, and, by the motions imparted to it by the currents arriving from A, of sending the currents of another battery on to C. At C the instrument does the same, and so on, until the despatch finally reaches E, in the same signals, and practically at the same instant as the despatch left the hand of the operator at A. The manipulation at the intermediate stations is therefore performed by the apparatus without the least interference on the part of the employés.

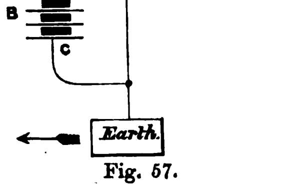


Fig. 57.

Fig. 57 is a plan showing the manner in which the printing-beam of the Morse apparatus is arranged to perform this duty. L^1, L^2 are the up and down lines. A current arriving by L^1 passes through the coils *m m′* of the electro-magnet to earth, and back to the transmitting station. The beam *b* of the recording apparatus is deflected from its position of rest on the contact screw 1, and makes contact with the screw 2. A circuit is thus closed :—Earth, C (battery), Z, 2, *b*, L^2, line to the next station on the side of L^2, recording apparatus, and earth. Through this circuit the current of the battery C Z passes as long as the current from L^1 attracts the armature, and keeps the beam *b* against the contact 2.

It is evident, therefore, that the currents arriving by L^1 and transmitted along L^2, exactly correspond with each other, and that, with regard to the battery C Z, and the line L^2, the beam *b* of the apparatus in the figure replaces a common transmitting key.

Each station corresponding with two lines, however, is almost invariably provided with two instruments, so that correspondence in both directions may be carried on at the same time.

When this is the case, the two instruments are connected up, as is shown in the plan Fig. 58, in which the necessary

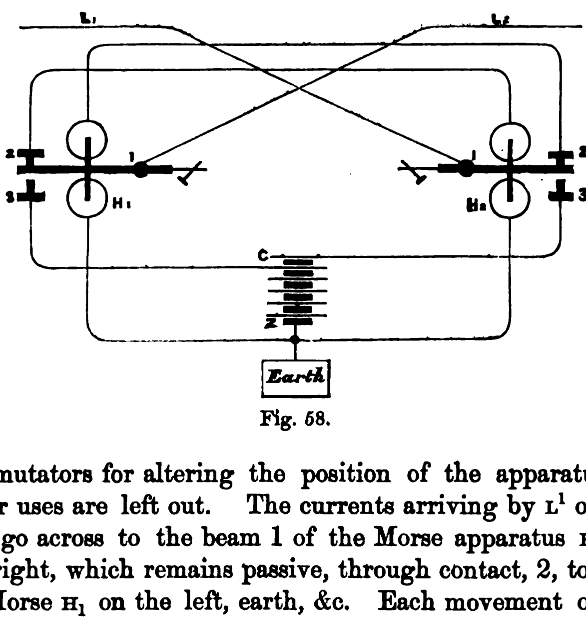


Fig. 58.

commutators for altering the position of the apparatus for other uses are left out. The currents arriving by L^1 on the left, go across to the beam 1 of the Morse apparatus H_2, on the right, which remains passive, through contact, 2, to coils of Morse H_1 on the left, earth, &c. Each movement of the beam of the latter closes the circuit of the line-battery, C Z, with the line L^2, through C, 3 (beam of Morse H_1), 1, L^2, opposite station apparatus, earth, back to Z of battery.

72. *Varley's Translating Apparatus.*—A highly ingenious arrangement has been invented by Mr. C. Varley, formerly engineer to the Electric and International Telegraph Company, and is used on the company's lines.

A theoretical plan of the system, arranged for a translating station, with two Morse apparatus, is shown in Fig. 59, in which the letters and other indications of the various pieces on the board correspond, those on the right being distinguished by dashes. G is a galvanoscope, provided with two separate coils of wire of different lengths, the purpose of which is, that the outgoing currents, having their full strength, may pass through the shorter coil; and the arriving

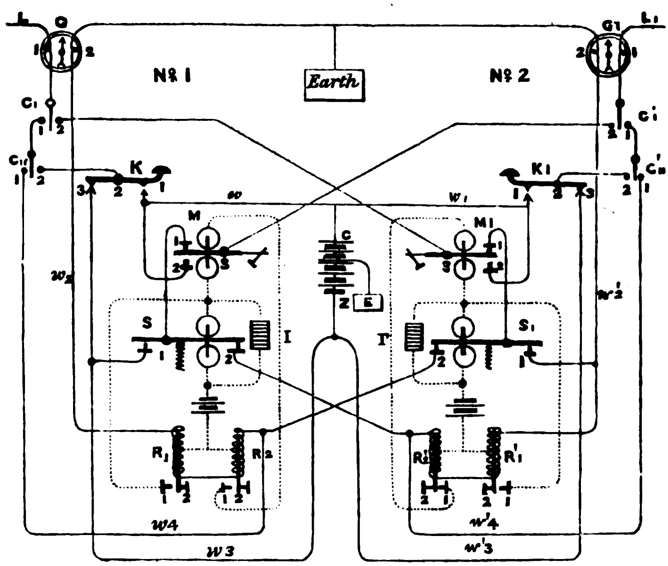


Fig. 59.

currents, which are comparatively weak, through the longer. A single galvanoscope is thus used for showing the strengths of both the currents. The shorter coil, or that intended for showing the transmitted currents, may be short-circuited by means of a contact-peg inserted in a hole between two terminals.

K is a transmitting key of ordinary construction.

M is a Morse embossing-apparatus precisely similar to those ordinarily used in Morse circuits.

R_1 and R_2 are two polarised relays of the construction invented by Mr. Varley, each consisting of a soft iron bar turning horizontally on points within the two coils of a cylindrical electro-magnet. Each end of the bar plays between the poles of a permanent horse-shoe magnet. The contacts 1 and 2 limit its motion; 1 being a platinum-point forming, with the soft iron bar, part of the local circuit; and 2, an insulated rest.

One of the relays, R_2, is used for closing the circuit of the Morse-instrument, and that of a key or spacing-apparatus; and the other, R_1, for closing the circuit of the spacing-apparatus alone.

The spacing-apparatus, S, performs the functions of a key; it consists of a metal beam, with an armature of soft iron at one end, held in close proximity to the poles of an electro-magnet. The beam is supplied with two contact points, one at each end, which strike upon two upright anvils, and is held by a spiral spring upon the reposing contact 2, until the armature is attracted by the electro-magnet, when it is deflected and makes contact with the other anvil, 1.

An important adjunct to this apparatus is a series of induction plates, I, connected across the terminals of the coils of S. It is composed of several similar plates of lead or carbon, made up in the form of a battery, and charged with dilute sulphuric acid. By itself a system of this kind gives no current, but it becomes polarised by the current of a battery being sent through it; and on removing the battery and replacing it by a conductor, a current passes through the latter in the reverse direction to the battery current, decreasing in strength until the polarisation is neutralised. Its purpose, in this instance, is to prevent for a moment the armature of the spacing-apparatus being released from the poles of its electro-magnet, when the circuit of the local battery is interrupted by the relay on the cessation of the positive current in the line. The polarisation current magnetises the cores before the armature is released, and retains the beam on the contact 1 until the opposite current in the line deflects the bar of the relay R, which closes the local circuit, including the electro-magnet of the spacing-apparatus.

C_I and C_{II} are two switches for altering the position of the apparatus to suit the requirements of the service. The former—the line switch—is for directing the line, on one side, for translation, and on the other, for ordinary reception from, and transmission of signals to the station on the side of the switch; the latter, or key switch, is for arranging the board for sending or receiving.

When the apparatus is connected up for translation, which is done by simply turning over the arms of the switches C_I and C_{II} to their contacts, 2, a positive current arriving by the line L on the left-hand side, has to pass through the longer coil 1 of the galvanoscope, G, of apparatus No. 1; by C_I to the point 2, and from this direct by the leading wire, across to apparatus No. 2, where it passes passively over the printing beam 3 of the Morse instrument, M_1, by the contact screw 1, to the beam of the spacing-apparatus, over which it also passes passively to the reposing contact 2; from this, back again to apparatus No. 1, where it traverses in succession the coils of the two relays, and, finally, by wire w_2, passes through the shorter coil 2 of the galvanoscope, and goes to earth at the plate marked "earth."

The coils of the relays R_1 and R_2 being connected up so that the current circulates in reverse directions in them, the positive current, which we are considering, can only deflect the armature of R_2, which closes that side of the local circuit containing both Morse and spacing-apparatus, the beams of both which will be depressed.

The beam of the Morse, M, being connected by means of the line-switch C'_I, through G_1, with the down line L^1; and the contact-point 2 on which the beam of the Morse strikes, being connected by wire, w, with the copper pole of the battery C, E, a positive current passes from C, E (w, 2 M, 3, C'_I, 2, G'_1) to L_1.

During this time, the armature of the spacing-apparatus, although drawn down, has sent no current into the line, because its circuit is interrupted by the depression of the printing-beam of M from the contact screw 1. When the line current in L stops, the tongue of the relay R_2 falls back on the insulated rest 1, the local circuit is interrupted, and the beam 3 of M returns to the reposing contact 1. The beam of the spacing-apparatus S is, however, not released at the same moment, because the current of the polarisation battery I has quickly reversed the magnetism of the coils of S, before the armature had time to get away. And a negative current immediately following the positive one, by the line L, deflects now the bar of the other relay, R_1, which closes that part of the local circuit containing the spacing-apparatus only. The beam of S is therefore retained during the continuance of this current, and a negative current passes into the down-line from E Z (w_3, contact 1 and beam of S, contact 1 and beam 3 of M, to c'_I, 2 G_1, 1) to L_1.

On the interruption of this negative line-current in L, the polarisation battery performs its functions again.

When the translation is from the down to the up-line, the connections remain precisely the same; the Morse spacing-apparatus, and relays, however, are in action on the other side, whilst those on the left become passive.

Signals are given to the line L by turning the switch C_I on 1, and C_{II} on 2. The positive current given by pressing down the key, then goes in the circuit E, C, w, 1, and 2 (of key) C_{II} 2, C_I 1, G 1, L; the negative, when the key rests on the reposing contact 3, passes in the direction E, Z, w_3, 3 and 2 (of key) C_{II} 2, C_I 1, G 1, L, &c.

To receive from the same side, C_I is put on contact 1, and C_{II} on 1. The arriving current from L goes through G 1, C_I 1, C_{II} 1, w_4, coils of both relays, w_2, G_2, and earth. When the arriving current is positive, it deflects the bar of relay R_2, and closes the local circuit of the Morse and spacing apparatus; when negative, in deflects the bar of R_1, and closes the local circuit of the spacing apparatus only.

73. *Static Induction in Submarine and Subterranean Lines.* —It has already been explained that the outside of a Leyden jar becomes charged by induction when the interior coating is charged by contact with some source of static electricity;

and the similarity in the behaviour of galvanic and frictional electricities has also been spoken of.

When Siemens and Halske were engaged in the construction of their subterranean line between Berlin and Frankfort-on-the-Maine, and Kramer his between the Prussian capital and Cologne, in 1848, they were both astonished to observe a phenomenon resulting from the two facts alluded to above.

Dub says: "Whilst Kramer was able to speak with the greatest ease on an overland line from Berlin to Magdeburg, he found it absolutely impossible to do the same on a subterranean line. With the greatest trouble and slowness, according to his own account, it was scarcely possible for him to accomplish a satisfactory correspondence between Potsdam and Magdeburg. Siemens and Halske found the same difficulty with their instruments, particularly on the line between Erfurt and Halle, which set all their efforts at defiance. An exchange of the apparatus was also without result. Bad insulation was, at first, supposed to be the cause of the disturbances; but it soon appeared that the better the insulation, the greater became the difficulty. Kramer says that he has often left his bureau and destroyed the insulation of his line at a thousand paces distance, in order to be able to forward a despatch with greater ease."

Dr. Werner Siemens, writing about the same date, in a paper* presented to the Academy of Sciences in Paris, says that when the extremity, B, of a covered wire was insulated, and the other end, A, made to communicate with a battery of which the opposite pole was to earth, the instant of contact being established, a current of short duration was observed in those parts of the wire not too remote from the battery, in the same direction in which the current traversed the line, when the end B was brought into contact with the earth. When the wire was perfectly well insulated, he did not observe, after the first instant, the least trace of current. On replacing, suddenly, the battery (by means of a key), by a

* Mémoire sur la Télégraphic Électrique, 1850.

short-circuit to earth, however, he observed a momentary current, the intensity of which was equal to the current first observed, but in the reverse direction. And, lastly, when the connection at A with battery and earth was interrupted, and the end B suddenly put to earth, a current was observed at B, of almost the same intensity as the two preceding currents, and in the same direction as the current due to the battery.

Both Kramer and Siemens came at once to the conclusion that these phenomena were attributable to static electricity. They compared the subterranean cable to a Leyden jar of very great surface, the interior coating being formed by the metal conductor, the dielectric by the gutta-percha or other insulator, and the outer coating by the metallic covering, or by the dampness occasioned by contact with the earth; and this view was subsequently confirmed by the experiments of Faraday and Wheatstone.

74. *Siemens and Halske's Submarine Key.* — Several arrangements have been hit upon for rendering the return currents harmless in the practice of subterranean and submarine telegraphy. They consist, for the most part, of constructions by which the line is put to earth, for an instant, before bringing the relay in circuit, and by which the signals and pauses are given by reversed currents instead of by the occasional contacts of the same pole of a battery as in overland lines.

That of Siemens and Halske is shown in plan in Fig. 60.

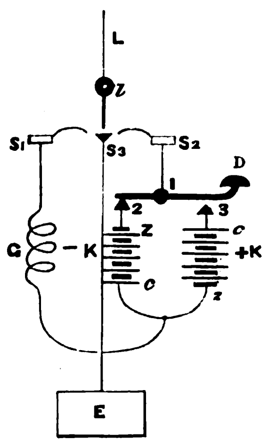


Fig. 60.

With the ordinary key, when the current of the battery is sent through the submarine line L, by pressing down the lever K on the front-contact 1 (Fig. 48), and the key then let go till it makes contact with the rest at the back, the return current or discharge passes from the line, over the key, and through the relay R to earth.

In order to avoid the derangement incidental to the discharge currents passing through the relay, the plan Fig. 60 is generally adopted.

When the line L is brought, by means of the switch *l*, into contact with the point S_1, the relay G is in circuit for receiving despatches. When *l* is in contact with the point S_2, the key D is put into circuit for forwarding despatches, and the relay cut off from the line and prevented receiving the discharge currents.

If, in this position, the key D is pressed down on the front-contact 3, a positive current is sent from the main battery +K; but whilst the key rests upon contact 2, a negative current is sent from the counteracting battery — K into the line. The discharge currents are thus made use of

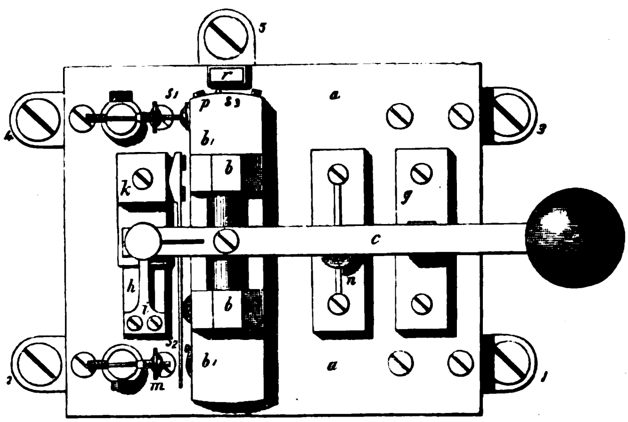


Fig. 61.

in signalling. Lastly, in order to prevent the final discharge passing through the relay when communication is re-established with S_1, a contact is made by L with S_3 and earth in passing by, so as to discharge the line.

The mechanical construction of the key is shown in the plan Fig. 61. The bearings *b*, *b*, in which the lever *c* works, are cast on a base, b_1, movable horizontally on an axis in the board *a*, in permanent contact with the terminal 1 and the line wire, and also with the spring *i*. When the key is at rest, a spiral spring underneath the board keeps it in contact with the point s_1. This point is in constant communication with the terminal 4, which leads to relay and earth. The conditions under these circumstances are, therefore, precisely the same as when the line is brought into communication with s_1, by means of the switch *l*, in Fig. 60.

While in this position it is impossible to press down the knob *d*, the lever *c* resting upon a small elevated bed on the bar *g*.

To forward signals the lever must be turned to the left, by which the contact at s_1 is broken; that is to say, the relay is cut out of circuit, and the little insulating buttons *o*, *o*, press the spring s_2, which is fixed at the side of the bar *k*, against the contact-point *m*, permanently connected to terminal 2, which is in connection with the counteracting battery — K. If the key is pressed down now, the back contact is broken and the front one *n* established, by which the circuit of the counteracting battery — K is interrupted, and the main battery + K brought into play. Consequently the same takes place as in Fig. 60, when the line L is connected, by means of the arm *l*, with the contact-point S_2, and the key D pressed down.

In order completely to discharge the line after finishing the transmission of a despatch, a metal point, *p*, projecting from one end of the base *b* of the bearings of the lever, rubs against a contact-point, S_3, connected with the terminal 5 and earth, when the former returns to its position of rest at S_1.

75. *De Sauty's Submarine Key.*—A submarine key has been invented by Mr. C. V. Sauty, with which the operator in manipulating presses down a button in the middle of the knob, and thus removes the line connection from the relay to the battery-commutator.

Fig. 62 represents a plan of this key. The lever is of vulcanite, supported on a pin, *a a*, in the bearings *b b*, on the base *c c*. On each side of the lever at its fulcrum is a plate of brass, *p* and *p′*, insulated from the pin *a* and from the bearings. At each end of the plate *p*, underneath, is a platinum contact-point which presses upon one of the contact-anvils *c′* and *s″*; the underside of the plate *p′* carries a spring at whose ends are similar contacts, which press alternately upon the anvils z' and c''. The board is furnished with five terminals for the reception of the outside wires. L is the line terminal, R that to which the one side of the relay is brought, the other side being to earth; E the earth terminal, and between C and Z is inserted the line battery, only one

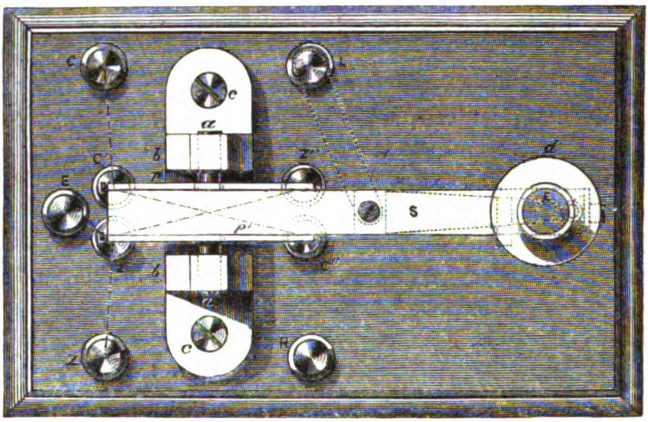


Fig. 62.

battery being required for reversals with this key. In the fore part of the key, underneath the lever, is a spring, or strip of brass, S, in permanent contact with L; when the key is at rest this spring makes contact with a platinum point, which is in permanent contact with the terminal R (relay); a second point, underneath the spring, is in permanent connection with the plate *p* of the commutator arrangement just described. When working the key the operator presses the button E down into the knob *d*, and establishes contact between S and *p*. Half-way between the upper and lower contacts of S the spring meets with a small strip of metal in connection with the earth, by which means, after working the key, the line is discharged. The strip S is fastened to a block, from which a pin presses upon a spring underneath, reaching from the line terminal L, and keeping at the same time the metallic strip S in connection with the line, and holding the lever back upon the reposing contacts c', z'.

The anvils c' and c'' are in permanent connection with the terminal C of the battery, and z' and z'' with the terminal Z. The spring S being down whilst the lever rests on c' and z', therefore the current from Z goes through z', spring, plate p', spiral of wire, to E, and thence to earth; the current from the C-pole goes from C, through c', plate p, the connection wire, from this to the contact with the spring S, terminal L, line, opposite station apparatus, to earth, &c. The finger being still kept upon the button, when the lever is pressed down the contacts c' and z' are broken, and c'' and z'' made with the plates p and p'. The current from z' now goes through z', z'', plate p, connecting-wire, to E, spring S, L, line, &c.; whilst the current from C goes through c', c'', plate p', spiral, E, earth, &c. Thus by keeping the button pressed down and manipulating the key, reversed currents are sent into the line.

76. *Varley's Switch for Submarine Work.*—This arrangement, used on the Electric and International Company's submarine line between England and Amsterdam, is for sending a reverse current into the line when a usual signal has been given by the key, and at the same time for keeping the relay out of circuit so long as to insure it against the injurious effects of the return currents.

This is done by means of an extra relay, or electro-magnetic switch.

When the key is depressed at the transmitting station, a positive current passes directly into the line, and a second circuit is closed, which includes the electro-magnetic switch, the attraction of whose armature breaks the relay circuit, but completes the circuit by which a reverse current is sent into the line as soon as the key is let go again.

The key used in this arrangement is shown in Fig. 63. The customary working and reposing contacts are represented by a and d; c is the bearing of, and in contact with, the lever. A third contact is brought on in front at a', which is touched by the spring F, attached to the terminal b, when the spring is pressed down. F is, of course, pressed down by an insulated arm so as not to be in metallic contact with the key. The circuit of the switch is made between *a′* and *b*.

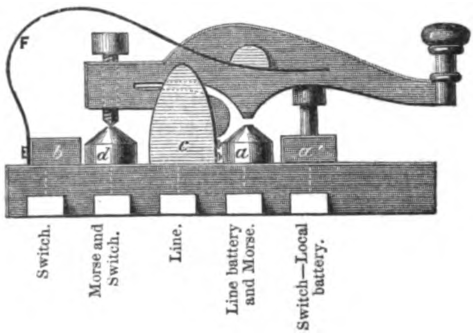


Fig. 63.

The switch is shown in Fig. 64. It consists of a bent metal beam, *e e*, supported by the uprights *e′*, and makes contact at one end with the screw *u*, at the other by means of a spring, *f*, with the screw *w*. The beam is held in its

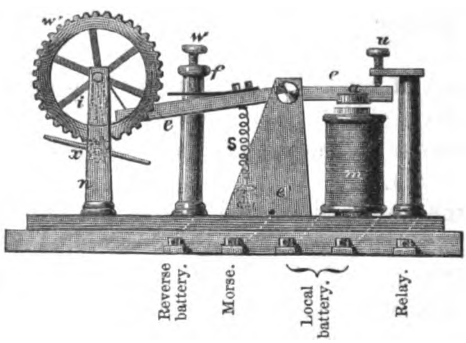


Fig 64.

position of rest by the spiral spring s, and is deflected by the attraction of a soft iron armature, *a*, to the poles of the electro-magnet *m*. On the upright *n* is a tooth-wheel, *w′*, engaging with a pinion. On the axis of the latter is a fly, and round that of the former passes a cord with a weight at one end, the other end being attached to the extremity of the beam. By this means the extremity of the beam may be raised very quickly, allowing the weight to drop and the cord to run over the axis; but it cannot be lowered without first turning the wheel, pinion, and fly, and raising the weight, an operation occupying about half-a-second.

The purpose of this is that the armature may be attracted suddenly to the poles of the electro-magnet when a signal is given, but that on being released the beam shall take some time to return to its position of rest, and that during the greater part of this time the spring *f* shall remain in contact with the screw *w* in connection with the reverse battery.

A plan of the station arrangements at London on the line working to Amsterdam is shown in Fig. 65.

When transmitting or receiving, contact-pegs are put into the holes 1 and 2 of the commutator C. On giving a signal by pressing down the key, contacts between *a* and *c* by the beam, and between *a′* and *b* by the spring moved by the lever before mentioned, are established. By means of the former, the circuit of the *copper battery* is closed (*c*, *a*, *e*, III, commutator 1, II, G, line), and by means of the latter that of the switch (*b*, coils of switch, Z, switch battery, C, *a*, spring of key). The beam of the switch is in permanent connection with the reposing contact *d* of the key, and by oscillating puts on one side the relay, on the other the zinc-pole, of the battery into circuit.

When the switch is at rest the relay is in circuit with the reposing contact of the key, (line, G, II, comm. 1, III, key, *e*, *d*, IV, switch-beam, *u*, V, coils of relay, earth); but as the return currents would take this way when the key is lifted up, the contact *u* is interrupted by the attraction of the armature. At the same time the contact *w* with *f* is made, and this advances Z of the zinc-battery (Z, switch, *w*, *f*, IV, *d*) to the back contact of the key, so that the moment the key is let go the circuit of the *zinc-battery* may be completed (key, *d*, *c*, III, comm. 1, II, G) with the line.

If this takes place at London the positive currents will arrive at Amsterdam by cable, commutator, key, switch, coils of relay, earth. The tongue of the relay at the Amsterdam station will be deflected against the contact-point and close the local circuit, working the recording instrument. The negative current will take the same road as the positive, and throw

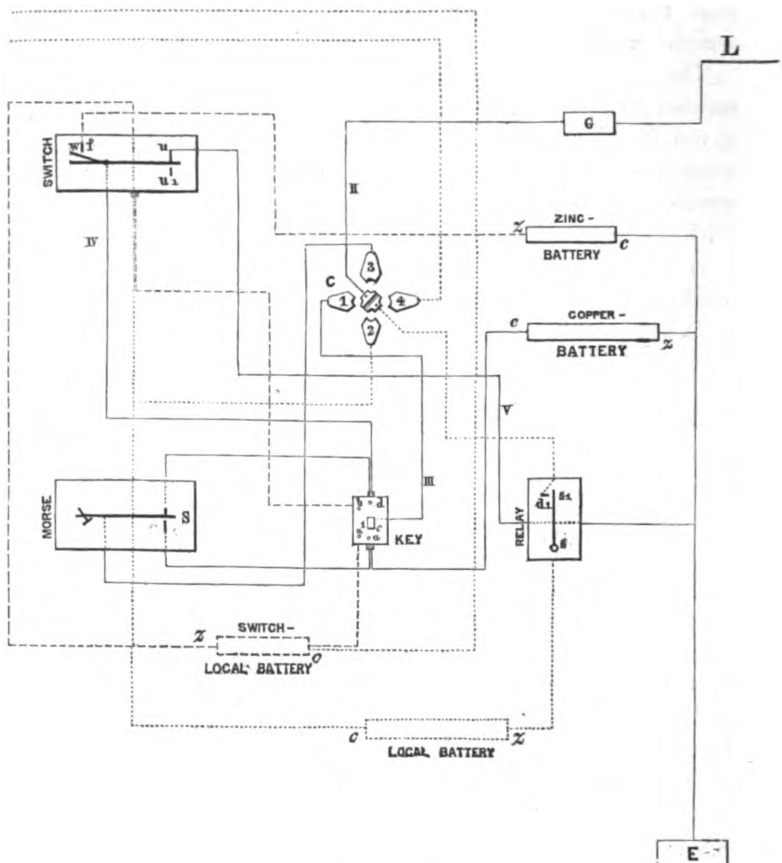


Fig. 65.

back the tongue of the relay against its insulated contact, thereby breaking the local circuit.

77. *Thomas John's Telegraph.**—The great force necessary to press the style against the paper strip in order to leave visible marks, and the consequent employment of a relay with local battery, were obviated by the invention of an Austrian telegraph engineer, Mr. John, as early as 1854.

* Brix. Journal, vi. p. 5.

In his apparatus the marks were made upon the paper strip by means of a small circular disc of metal kept revolving in a dish of coloured fluid, and pressed gently against the paper, when the armature of the electro-magnet was attracted. Beyond this, all the rest of the Morse arrangements of clockwork, &c., remained unaltered. The object of the invention was solely to diminish the force necessary for marking the paper, so that the electro-magnets might be able to work the beam when inserted directly in the line. And in this the method has signally succeeded, as the almost universal adoption of modifications of it has proved.

The apparatus, as constructed by the inventor, was by no means a piece of elaborate workmanship, nor were his

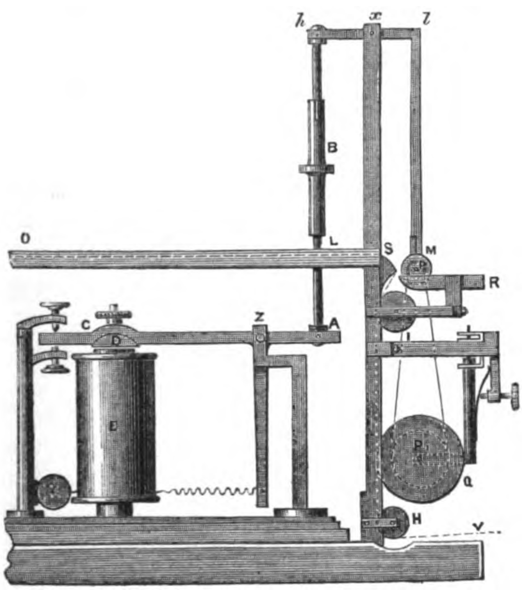


Fig. 66.

arrangements of levers and paper-guides quite so commodious as were desirable, but the happy fate of the Morse system is, probably, in no slight degree indebted to this idea.

In Fig. 66 the clockwork is left out. E is the electro-magnet, whose armature, D, is affixed to one end of the beam A C, and plays between adjusting screws. The beam is supported at z, and has on its shorter arm, A, a connecting rod, B, hinging at *h* on the horizontal arm of the bent lever *h l* M, which turns on an axis at X. At M the lever carries the printing-disc, the lower segment of which is immersed in a dish of indian-ink, R. On the axis of this printing disc is a small pulley, P, with a cord passing over, and receiving motion from the pulley P′ below. P′ is attached to a drum, Q, which revolves with it. The paper strip, shown in the figure by dotted lines, is led to the apparatus from V underneath a guide-drum, H, at the back of the drum Q, which it rubs against and turns round (thereby imparting a rotary motion to P, P′, and to the printing disc), behind the drum I, over a metal edge, S, and across the stage L O, where the message is read off. The purpose of the metal edge S is to present a sharp corner of the paper to the printing disc in order that it may receive well-defined marks.

When the electro-magnet is in action the armature D is attracted, the connecting-rod lifted up, and the inking disc, which needs not be at a greater distance than half a millimeter, pressed gently against the paper on the part which is travelling at the moment over the edge S. During this time the motion of the paper keeps the printing disc revolving in the ink, which causes a freshly inked surface to be always presented.

78. *The Direct Working Ink-Recorder of Beaudoin and Digney.**—The difficulties in the way of the arrangement proposed by M. John were well considered by Digney, who modified it accordingly, with the view of rendering it simpler in its construction and surer in its effects.

Instead of making the printing disc approach the paper strip, Digney lifts the paper up to the disc, which he keeps rotating on a fixed axis, moved by the same mechanism which draws the paper through. Over the top of the disc he places a roller of felt or cloth, moistened with oil colour,

* "Revue des Applications de l'Électricité en 1857—8," par Du Moncel, p. 169.

which turns by the friction of the printing disc, and keeps the periphery of the latter always freshly inked. The paper strip passes underneath the disc, over a knife-edge, forming the continuation of a beam, carrying, at its other end, the armature of the electro-magnet. When the latter is attracted, therefore, the knife-edge presses the paper against the revolving disc. John's idea is thus reversed, but the principle remains the same.

Fig. 67 represents an elevation of the apparatus, the clock-

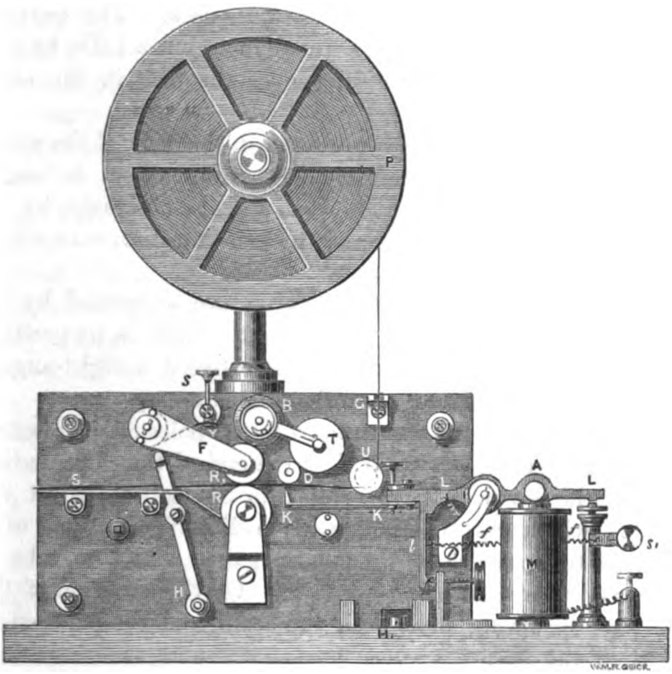


Fig. 67.

work being in the interior. The parts directly turned by the clockwork are the roller R, and the printing disc D. The paper strip is drawn from the drum P through the slit G, under the guide-pulley U, between the printing disc D, and knife-edge K, between the rollers R and R_1, and across the horizontal stage S. The jockey-roller R_1 turning freely within the frame F, and pressed down by the spring Y, holds the paper strip tight upon the roller R, so that, as the latter turns round, a progressive motion is imparted to it. The jockey R_1 can be lifted up from the paper by turning the lever H to the left. The force with which it presses upon the paper on the roller R is regulated by means of the adjusting screw *s*, against which the end of the spring Y abuts. T is the feeding roller of felt, kept moist with fresh oil-colour, and turning freely on its axis in a frame supported on a regulating-screw on the axis B. The purpose of the screw is to move the roller in or out a little to prevent its surface always riding over the disc in the same line.

The axis B consists of a pin fixed in the side of the apparatus, from which the frame containing T can be easily removed. T rests, when at work, a little obliquely, by its own weight only, on the top of the printing disc, with which it revolves.

M is the electro-magnet, A its armature, supported by the beam L L, turning on its axis I, and is held in its position of rest by the spring *f*, stretched between a right-angled arm, *l*, of the beam and the adjusting screw, S_1.

When the armature is attracted to the poles of the electro-magnet, the knife-edge, forming the end of the continuation K K of the beam, is raised, and lifts the paper against the disc D, which revolves in a reverse direction to that of R and to the passage of the paper, against which it rubs so long as the armature is kept down. On the cessation of the current the spring pulls back the beam, and the paper-strip falls off the disc.

This instrument is worked without relay and local battery, and has become a great favourite with the *employés;* the deciphering of inked letters being infinitely less fatiguing than that of embossed. The renewal of ink, when the apparatus is in full work, is not required more than once a day

Thus the principal difficulties in the way of the Morse apparatus are removed. The Digney instrument has been found by the French Administration of Telegraphs to work so well, that they have adopted it for use on the Government lines in France and the colonies. This success is in a great measure due to the nice discrimination between the sizes of the movable and fixed portions of the apparatus having reduced the *vis inertia* of levers, armatures, &c., to a minimum, whilst amply sufficient strength is insured to effect the complete marking of the paper.

M. Guillemin, in 1862, made a series of interesting experiments with this apparatus to determine the maximum number of elementary signals, and, consequently, how many words it was capable of recording in a given time. The transmitting apparatus he employed consisted of four wheels of twenty-five centimètres diameter on a common axis: one of them made dots, the second dashes, whilst the two others served to discharge the line after every elementary signal. The words *France* and *Paris*, which in the Morse alphabet represent a mean of the French words, were repeated on a line of 750 kilomètres, in fine weather, thirty times per minute, and in wet weather he easily attained the rate of forty words. On a line of 450 kilomètres, passing by Le Havre, the reception was augmented to seventy-five words per minute—six times that which the *employés* are able to attain with the hand.

79. *Direct Working Ink-Writers of Siemens and Halske.*—An important modification of Digney's instrument is made by Siemens and Halske, who substitute a small inverted bottle containing ink, and secured by a felt stopper, for the inking roller of felt, described in the preceding paragraph.

This arrangement is represented in Fig. 68. B B is a small inverted glass bottle containing the printing fluid; its neck is cemented into a brass ring, *c*, fitting into a collar, D. At the back of the collar is a horizontal hollow axis, E, supported by a pin fixed in the side of the apparatus, on which the whole thing turns, and from which it may be removed in the same way as Digney's felt roller. A stopper of thick felt, *f f*, is put into the mouth of the bottle to allow the colouring fluid to come through very gradually. The bottle presses, by its own weight, upon the printing disc, which is in connection with the clockwork, and performs the same functions as the corresponding member of Digney's instrument—printing on the upper side of the paper strip *p p*, which is lifted by the knife-edge, K.

Both this method and that of Digney are not entirely

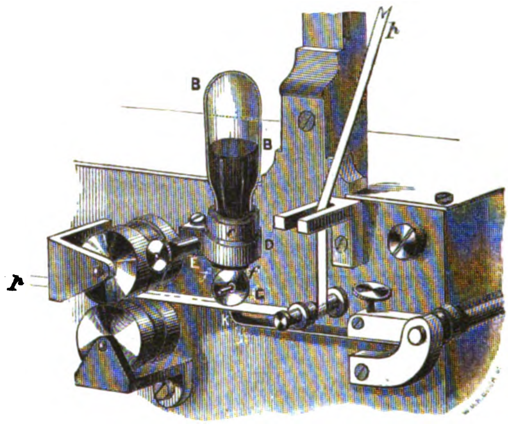


Fig. 68.

without objection, however, on account of the printing disc and paper being underneath the reservoir of ink, from which, when the apparatus stands inactive some time, the colouring fluid frequently runs down and makes a blot on the paper; besides this, they are both liable to the objection that the surface of the felt quickly dries up in warm weather.

To remedy these defects, Siemens and Halske have made a second and still more valuable improvement in the inking process. It consists in again reversing the order of things, in making the printing disc revolve with its lower half immersed in a dish of colouring fluid, and in lifting the disc up against the paper, which runs above it, instead of pressing the paper against the disc. This is the perfection of the mechanical arrangements which M. John was able, only in an incomplete way, to carry out.

This modification is shown in Fig. 69. A is a glass phial cemented into a brass neck, *a*, supported between screw-points at *n*, and by the point of the levelling screw, *b*. The forepart of the brass neck *a* is cut out in a curve, and forms a gutter, in which the lower part of the printing disc *c* dips. At *d*, a round hole in the upper part of the neck, usually covered up by a metal cap, facilitates the filling of the phial. The index *e* is intended to guide the operator

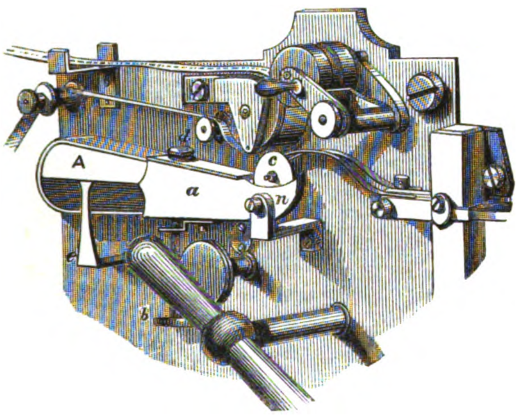


Fig. 69.

in adjusting the *niveau* of the printing fluid in the phial, so at to cover the requisite segment of the disc *c*.

80. *Arrangement of a Board with the Direct-working Ink-writer.*—The direct-working ink-writers of Messrs. Siemens and Halske are mounted on mahogany boards with the transmitting keys, galvanoscopes, terminals, and connections.

The accompanying plan, Fig. 70, gives the arrangement of two boards fitted up with all the apparatus, and properly connected together, as they are used at intermediate stations for translation, terminal work, &c.

On each of the boards are mounted an ink-writer, H, a simple transmitting key, D, a line galvanoscope, B, and twelve terminals for the internal and external connections.

The five terminals on the right-hand side are filed out, so as to admit a contact peg between their ends and a common

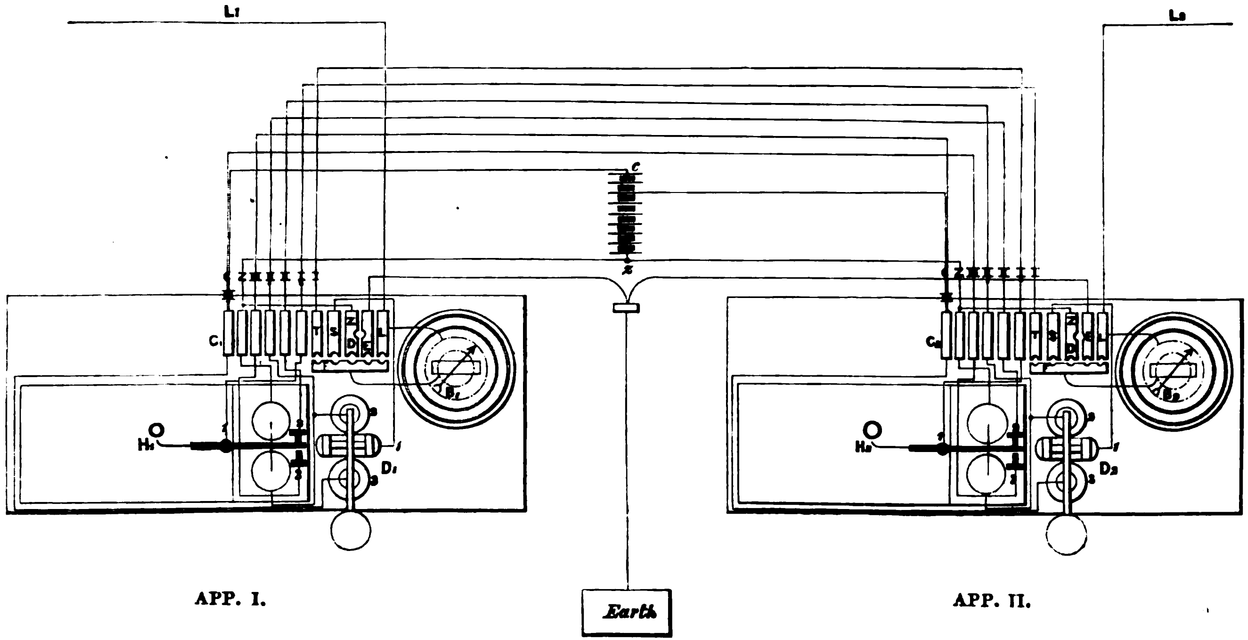


Fig. 70.

terminal bar, F, connected to one side of the galvanoscope. By supplying one or more of these holes with contact pegs, the apparatus may be arranged in different positions.

When the two apparatus, I. and II., are to work as terminals to the two lines L_1 and L_2 respectively, contact pegs are inserted in the holes S, and between $\overset{Z}{D}$ and E, of each of the boards. The circuit is then complete for receiving from L_1, through L, B_1, F, S, 1 and 2 of D_1, coils of H_1, $\overset{Z}{D}$, E, earth; and for transmitting, when the key is pressed down, through Earth, E, $\overset{Z}{D}$, Z, Battery, C, $\overset{C}{\underset{\cdot}{III}}$, and 3 and 1 of D_1, S, F, B_1, L, L_1, &c.

For translation between L_1 and L_2, contact pegs are put in the holes between T and F, and between $\overset{Z}{D}$ and E, of each of the apparatus. The currents from L_1 then pass through L, B_1, F, T, I, to App. II., $\underset{\cdot}{I}$, 1 and 2 of H_2, II, back to App. I., $\underset{\cdot}{II}$, Coils of H_1, $\overset{Z}{D}$, E, Earth, &c. The beam of H_1 is deflected, and closes the circuit, including Earth, E, $\overset{Z}{D}$, Z, Battery, C, to App. II., $\overset{C}{\underset{\cdot}{III}}$, back to App. I., III, 3 and 1 of H_1, $\underset{\cdot}{I}$, to App. II., T, F, B_2, L, L_2, &c.

Both apparatus are intermediate when a contact peg is inserted in the hole between S and F of each of the boards. In this case both apparatus are moved by the same currents, and record simultaneously.

Either of the apparatus may be used alone as intermediate or circular apparatus, when its contact peg is between S and F, while the other apparatus has a peg in the hole between D and F.

Both apparatus are out of circuit when the pegs of both are put in the holes $\overset{Z}{D}$, F. The through-circuit, L_1, L, B_1, F, $\overset{Z}{D}$, Z, to App. II., Z, $\overset{Z}{D}$, F, B_2, L, L_2, is then established.

The insertion of pegs in the holes between L and F of the boards short-circuits the galvanoscopes, and between F and L and F and E, at the same time, puts the lines directly to earth—a position always advisable during a thunderstorm.

When the ink-writer is used with a relay, the arrangements of the board undergo some modification. This consists in the addition to each board of a relay, G (Fig. 71), and of two terminals, C Z, for the poles of a common local battery.

The internal connections of the board with regard to the terminals are the same, with the exception that the coils of the

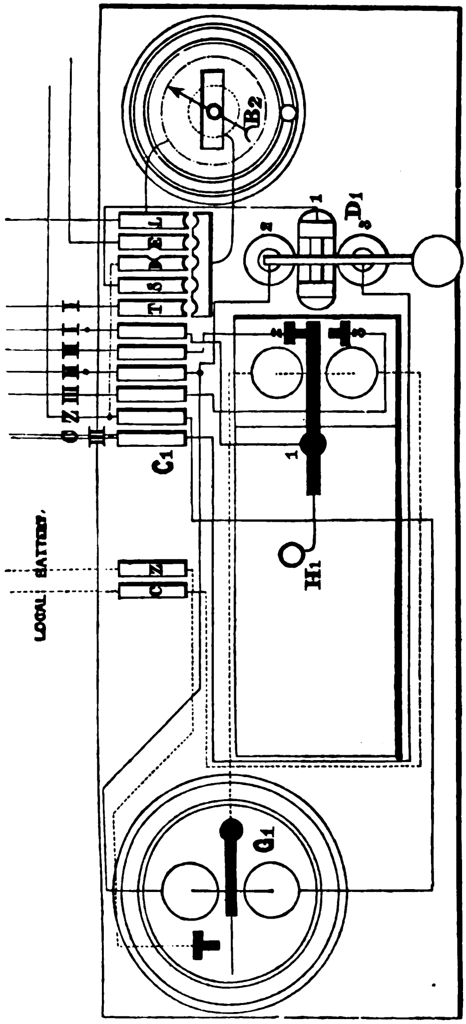


Fig. 71.

relays are substituted for those of the ink-writer between II. and Z, and that the local circuit, shown in dotted lines, is added.

81. *Morse Telegraph worked by Induction Currents.*—In numerous instances has magneto-electricity been pressed into the service of the telegraph, but always in conjunction with the step-by-step or needle systems. For the Morse it was considered useless, as the currents developed, being only of momentary duration, are only capable of themselves of giving successions of dots, whereas the Morse alphabet requires also an elementary signal of longer duration. This difficulty was removed by the ingenious invention of Siemens and Halske, in the construction of a relay, the tongue or armature of which would remain of itself on either contact, when once deflected, until a current different from the one last sent through removed it to the other side. If, therefore, when the tongue was in a state of rest on the insulated contact, a momentary current of magneto-electricity were sent in the right direction through the coils of the relay, the armature would move to the local contact, and would remain there, closing the local circuit, notwithstanding the current which deflected it had long since vanished, until a current in the opposite direction brought it back to the reposing contact. In this way either lines or dots could be produced at pleasure by regulating the interval between the succeeding currents.

This principle is the same as that used at a later date in the indicator of the magneto-electric telegraph of the same inventors, which has already been described.

The solution of this problem has placed at the command of the telegraphist a source of electricity of much greater intensity for working the Morse instruments through great distances, than the voltaic current, and which he is able to produce at a considerably less expense.

The complete apparatus consists of:—

A transmitting key,
An induction apparatus,
A polarised relay, and
A Morse recording instrument worked by a local battery.

The induction apparatus sometimes used consists of an iron core—a bundle of soft iron wires—surrounded by convolutions of thick copper wire, forming the primary, and by a long fine wire outside this, forming the secondary coil. The primary coil is put in circuit with the key and with a battery of large surface and little internal resistance. The secondary coil is connected at one end with the earth, at the other with the line. It is sometimes divided into two parts, which may be connected parallel or in series, according to the resistance of the line.

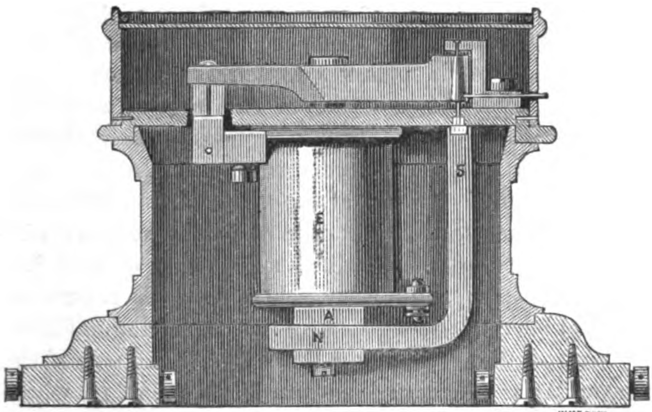
82. The polarised relay differs in its construction from all the others. There is no spring employed to pull back the armature after it is let go by the poles of the electro-magnet.

Fig. 72 is a sectional view in the direction of the armature, and Fig. 73 a top view of the relay. The perpendicular electro-magnet E is composed of two cores of soft iron united below, in the ordinary manner, by a cross-bar, A, also of soft-iron. The coils of wire terminate at the screws 1 and 2. The north end N of an angular bent permanent magnet, N S, is screwed on to the cross-bar A, to which it communicates north polarity beyond the point of contact, and also to both the cores and poles of the electro-magnet E. The soft iron tongue C is supported on an axis in a slit in the south end S of the permanent magnet, and thus receives south polarity. This tongue is so placed that it may oscillate between the north poles N and N′ of the electro-magnet. Its play is limited by the contacts D and D′. D is used as a contact for closing the local circuit, in which are included the printing instrument and the local battery, when the tongue C strikes against it. D′ is furnished with an agate point, and while the tongue rests against it, the local circuit is open. A and B are the terminal screws of this circuit.

Whilst it is situated equidistant from both the north polarised ends, N and N′, of the electro-magnet, the south polarised tongue C is attracted towards each of them with equal force.

When, at the sending station, the key is pressed down, the current of the local battery circulates in the primary wire of the induction coil. A momentary induced positive current passes through the line and relay, which has the effect of

Fig. 72.



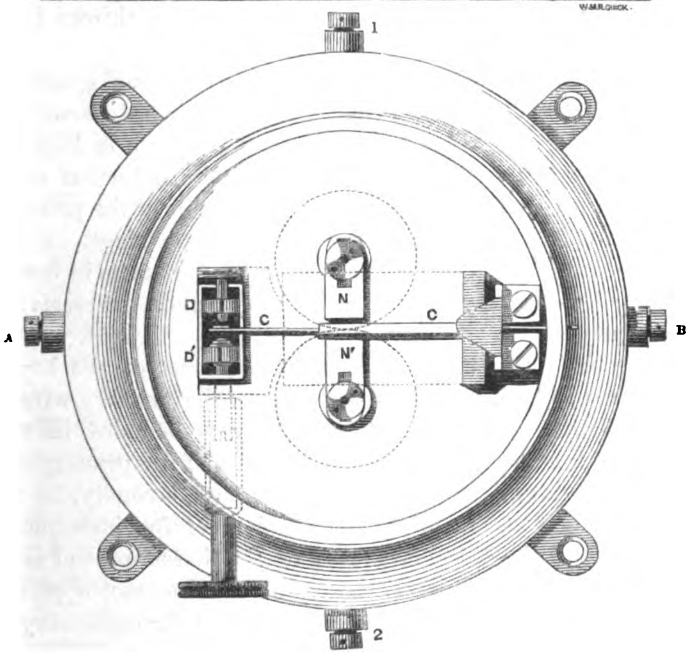


Fig. 73.

magnetising the pole N of the electro-magnet north, and the pole N′ south; but as both poles were previously north by the influence of the permanent magnet N S, the effect of the current is to strengthen the north magnetism of N, and at the same time to weaken only that of N′. The tongue C is, therefore, attracted to the pole N with double force, and remains on that side after the cessation of the current, attracted by the pole N, whose distance from C is then less than that of N′. The platinum contact of C remains against D, and closes the local circuit until the key at the transmitting station is let go, and the cessation of the current in the primary wire of the induction apparatus induces a negative current in the secondary coil, line, and relay, which has the reverse effect of the last current, strengthening the north magnetism of N′, and correspondingly weaking that of N. The pole N′ thereupon attracts C against the insulated point D′, where it rests until another positive current passes and throws it off again.

The Morse recording instrument is of the usual construction of Digney, or Siemens and Halske, described above.

83. A plan of this admirable system is shown in Fig. 74, arranged for two stations. C and C′ are the induction coils, of which *e e* are the soft iron cores; the limits of the primary and secondary coils are shown by concentric rings. K is a transmitting key, which closes two working contacts in front; R the polarised relay; B the local battery; and I the receiving instrument.

At each of the stations the middle contact of the key is connected to line, and also to one end of the primary wire of the induction apparatus. The battery is included in two circuits: first, between the remaining end of the primary coil and the second contact *b* of the key; and, secondly, in the ordinary local circuit of the relay and recording instrument. One end of the secondary wire of the induction-coil is to earth, the other connected with the first contact *a* of the key, the back or reposing contact *c* leading through relay to earth.

The key differs slightly from that used in the ordinary Morse circuits, having, as we have seen, two working contacts. The lever is furnished with a spring, which presses upon the contact *a*, by which, when the key is lifted up, the contact with *a* is interrupted an appreciable time after that with *b*.

This is necessary, because if they were both interrupted at the same instant it is evident that no induction current could arise in the secondary coil, its circuit being broken.

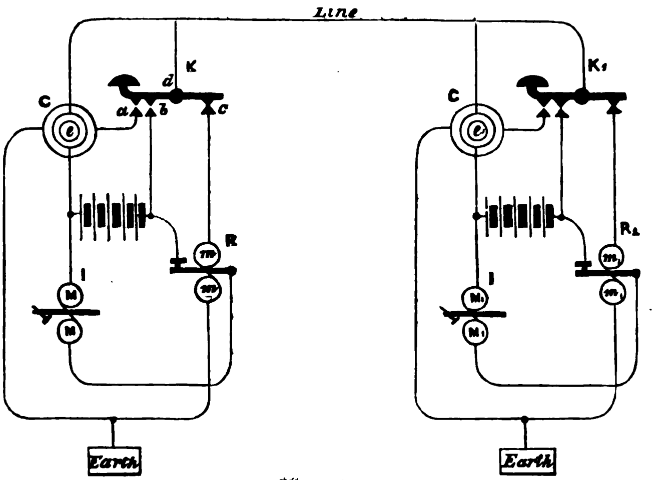


Fig. 74.

By the contact *a* continuing an instant longer than *b*, however, the induction current which follows the interruption at *b* has time to pass over *a* and through the line.

The Morse telegraph has been worked by this system of induction currents to a considerable extent on the lines in Russia, Bavaria, and Hanover. Sibeller says that messages have been sent direct, without translation, by this method, on a line of 200 German miles, equal to nearly one thousand English.

Compared with the methods of working the Morse telegraph by voltaic electricity, that of induction currents offers many advantages; the line batteries are opened, and spaces between the signals are given by reversed circuits, which work always cleaner than those given by making and breaking the same current.

The polarised relay above described is also profitably employed on lines worked only with galvanic currents, with which it is found to be far more delicate than the relays with springs. It is, however, necessary to give the armature C (Fig. 73) a bias on the side D′, which is done by advancing the soft iron continuation of the pole N′ of the electro-magnet a little nearer to the armature than N, by which, when no current passes, the tongue is held against the insulated contact, and the distances may be so finely adjusted that a very weak current suffices to move it.

84. *The Magneto-Induction Key.*—Instead of the Morse key, induction coil, and local battery, Siemens and Halske use also an instrument arranged in the form of a key, by

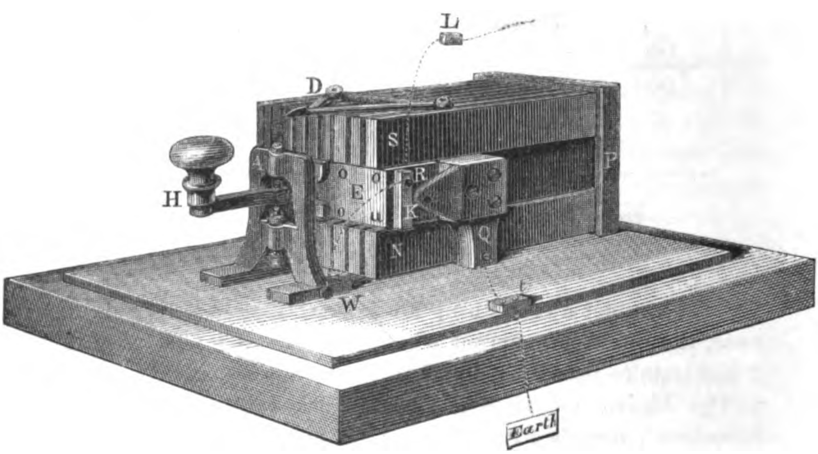


Fig. 75.

which a coil of wire, wound on a soft iron armature, is oscillated between the poles of a permanent magnet, and develops alternate currents for working the polarised relay.

The magneto-induction key is shown in Fig. 75, in perspective. S and N are two rows of permanent bar-magnets; the upper ones with their north ends, and the lower ones with their south ends in contact with a stout plate, P, of soft iron in the same way as in the transmitter of the magneto-electric pointer telegraph of the same inventors. Between the poles of this system, and oscillated in an angle of a few degrees by means of a handle, H, in the frame between two screw points, is the soft iron armature, as long as the magnet system is wide, cut in deep longitudinal grooves, on opposite sides, as is shown by the sectional sketch Fig. 67. In these grooves the coil C of fine insulated wire is wound. The play of the handle is limited by two adjusting screws in the frame A. When at rest, the handle is held against the upper screw by a spiral spring, S, stretched between the handle and front of the triangular piece D on the top.

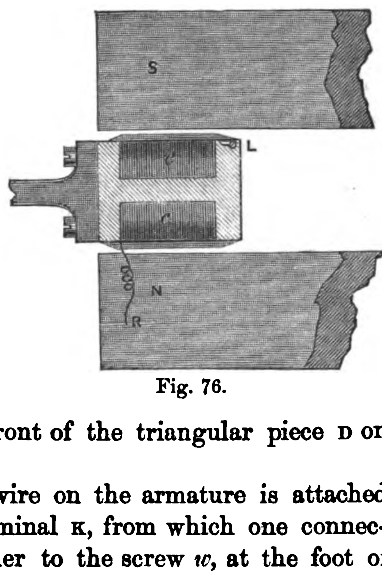


Fig. 76.

One end of the coil of wire on the armature is attached to the screw *k*, on the terminal K, from which one connection goes to line and another to the screw *w*, at the foot of the frame A. The other end of the coil is connected with the metal frame supporting the armature, and through the axis *f*, to the upright support Q, from which a leading wire goes to terminal *t* and earth.

When a current arrives while the instrument is in circuit with the line, it goes from L over R, W, upper adjusting screw in A, through handle H, axis *f*, Q, *t*, earth, without traversing the coil. This is the purpose of the connection between R and W.

When the handle is pressed down, the polarity of the armature is reversed, and a positive magneto-electric current induced in the coil, which circulates also in the line wire, and deflects the tongue of the polarised relay at the receiving station, from the insulated point, and closes the local circuit so long as the key is held down, and no negative current induced by letting the key go back to its position of rest.

85. *Siemens and Halske's Polarised Ink Recorder.*—A novel and very useful invention, where the attention of the employé is not invariably to be relied on, or he is occupied with other duties besides his instrument, was introduced by Messrs. Siemens and Halske, in the construction of their polarised ink recorder, in making the clockwork which is used to unwind the paper strip, self-starting. That is to say, as soon as a current arrives, and so long as it lasts, the clockwork is allowed to run and to draw the paper strip over the knife edge of the printing lever underneath the printing disc; but when the signals stop, the clockwork is arrested also.

In principle the electro-magnet is the same as that of the polarised relay described above. A strong angular permanent steel magnet polarises the two cores of an electro-magnet, which partake both of north polarity; while between their ends, the printing beam of soft iron, moving on an axis in the other end of the permanent magnet, has the opposite polarity.

The clockwork does not in any material point differ from that of the ordinary instruments. A hollow drum is turned by means of a mainspring in its interior, which also puts in motion the entire train of wheels, as well as the printing and driving rollers. A fly regulates the motion of the whole.

The self-starting apparatus is arranged as follows:—Close to the electro-magnet of the printing lever is a smaller electro-magnet, A B, Fig. 77, called the releasing magnet, the coils of which are in the same circuit as those of the larger one. When a current passes, therefore, through, both their armatures are attracted at the same instant. The armature C of the releasing magnet is carried by the releasing beam, turning on the axis H. At the other end of the releasing beam is a friction spring, O E, which, when the armature is in its position of rest, presses upon the ivory break-wheel F by means of a weight. The last wheel of the system is carried upon the axis on which the drum F and a fly are fixed. The clockwork is therefore stopped when the armature is at rest, or when no current passes. When, however, the armature is attracted, the friction-spring E is raised from F, and the clockwork starts; a boot, T, hanging from the beam and resting on the rim of the revolving drum M, is lifted up, and continues to dance upon the rim by the friction of the drum in revolving. After the current ceases the armature is released, and the boot, descending on the drum, is carried off by the rotation, not allowing the spring E to stop the clockwork until after the last current has ceased for some seconds. The starting of the clockwork may be effected at pleasure by the operator, by raising the friction-spring E, and it may be stopped by pressing it against the ivory break-wheel.

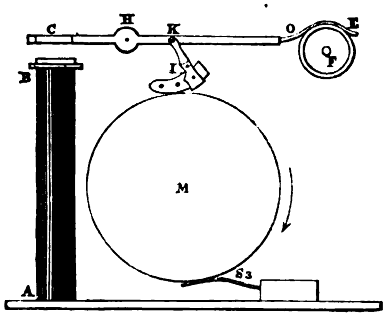


Fig. 77.

86. *The Polarised Ink Recorder used as a Submarine Key.* —*Translation.*—The manner in which the ordinary Morse apparatus is connected up for translation has already been explained. It is performed with the polarised apparatus as follows:—

When the tongue of the relay G_1, Fig. 78, of the receiving apparatus is deflected against the local contact, the local battery is put into circuit, and the printing instrument draws the beam H_1 from the screw 2 to the screw 3, the former being connected with the counteracting battery $-$ K, and the latter with the line battery + K. When the printing beam is connected by S_2 and l with the line L_2, supposing the printing lever H_1 to be resting against the contact 2, a negative current enters the line L_2 in the following way: $-$ K, earth, opposite station apparatus, L_2, l, S_2, H_1, 2, $-$ K. But when the printing lever H_1 is attached to the contact 3, a positive current enters the line L_2 as follows: + K, 3, H_1, S_2, l, L_2, opposite station apparatus, earth + K.

It is therefore evident that the printing instrument will translate any signals it may receive to the next station. As there is no communication between the line and the

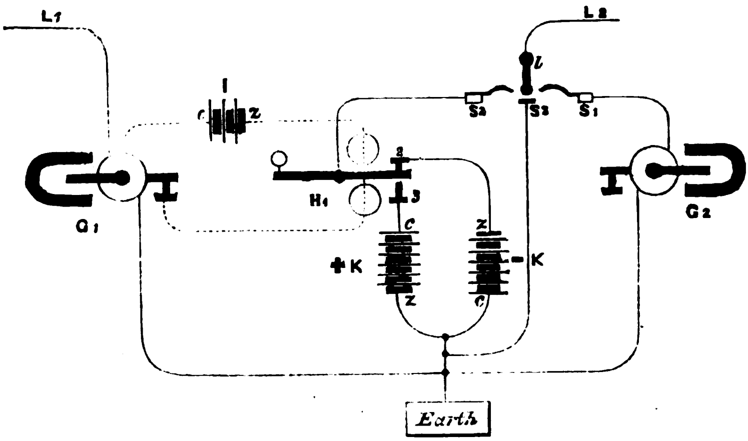


Fig. 78.

point S_1, the discharge current does not pass through the relay. Suppose now the relay G_2 placed in circuit for reception of signals, by transferring the switch from S_2 to S_1, the arm l, in going over, rubs against the earth contact S_3, and consequently the line will be discharged before being connected with the relay.

At the back of the apparatus, the axis supporting the releasing lever carries also a commutating beam, which, when at rest, makes contact with S_1, in connection with the relay; but when the armature of the small electro-magnet is attracted, the commutating lever makes contact at the point S_2, in communication with the printing lever. The discharge of the line is effected by means of the boot T, Fig. 77. This boot is insulated at the toe and heel, but not in the middle of the sole, so that either in a state of repose or when dancing, no electrical connection exits between the boot, that is to say, the lever C H O, and the drum M. As soon, however, as the current ceases, and the boot is pushed sideways, the conductor, let into the middle of the sole, comes into contact with an insulated platinum ring on the edge of the drum, and communicates through the spring S_3 with earth. The course of the current is shown in Fig. 79. In repose it would be as follows: L_2, l, S^1, G_2, earth, opposite station instrument, L_2.

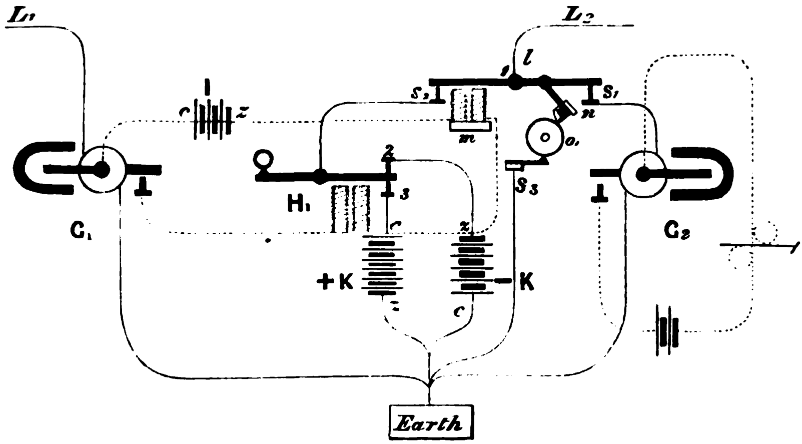


Fig. 79.

In this position the relay is in circuit. If, however, the printing lever H_1 be attracted (through the agency of an inward current through L_1) the releasing magnet m will at the same instant attract the lever l to the contact S_2, and thus break the relay circuit at S_1. The course of the current will then be as follows: + K, 3, printing lever, S_2, l, L_2, opposite station instrument, earth, + K; and as soon as the printing lever makes contact at 2, as follows: – K, earth, opposite station instrument, L_2, l, S_2, printing beam, H_1, 2, – K.

Lastly, if the conducting sole of the boot be in contact with the platinum ring o_1 of the drum, the following will be the manner of discharging the line: L_2, l, n, o_1, S_3, earth.

The Translating Spring.—In translating, the introduction of the main and counteracting batteries into the line is effected by means of the printing beam, in order that when intermediate stations connect up for translation, the signals may be passed through the whole with no interference on the part of the employés. When the printing beam is drawn from the upper contact 2, to the lower one B, by the galvanic current, a certain interval is necessary, and this interval could be subtracted from the time the armature is actually held down, and consequently from the lengths of signals on the paper. The printing beam would therefore actually be attracted for a shorter space of time than the key is held down at the sending station. The diminution would be repeated at each following station, so that, in fine, if there were several stations translating, the primary signals would have to be transmitted very slowly, in order that they might be legibly received at the terminal instrument. This is remedied, in an ingenious way, by Siemens and Halske's translating spring, which is situate under the printing beam, and immediately above the contact point 3. As soon as the beam commences its downward motion, following the attraction of the armature, the spring touches the contact point 3; and when the beam leaves the point, the spring still presses upon it for a time, and only separates from it at the last moment, so that the manipulator need not give any special attention to the length of his signals in working the key, as they will be transmitted exactly as he sends them, provided the line be properly discharged.

87. *Complete Submarine Board.*—For use on submarine lines, Siemens and Halske have had the polarised ink recorder, polarised relay, submarine key, and other apparatus, set up on slate slabs, the connections of a permanent character between the various parts being made underneath the board. The binding screws of the local circuit are marked with italic, and those of the line circuit in Arabic numerals and letters.

Fig. 80 gives a theoretical plan of the connections of two slabs at an intermediate or translating station, and Fig. 81 the arrangement of the various parts of the apparatus in one of the slabs. B B (Fig. 81) are the galvanoscopes, C the translation commutator, D the submarine key, F the current commutator, G the relay, H the printing instrument, and M the circuit breaker. Behind the galvanoscopes B B are fourteen terminal screws, to which the wires leading from the apparatus

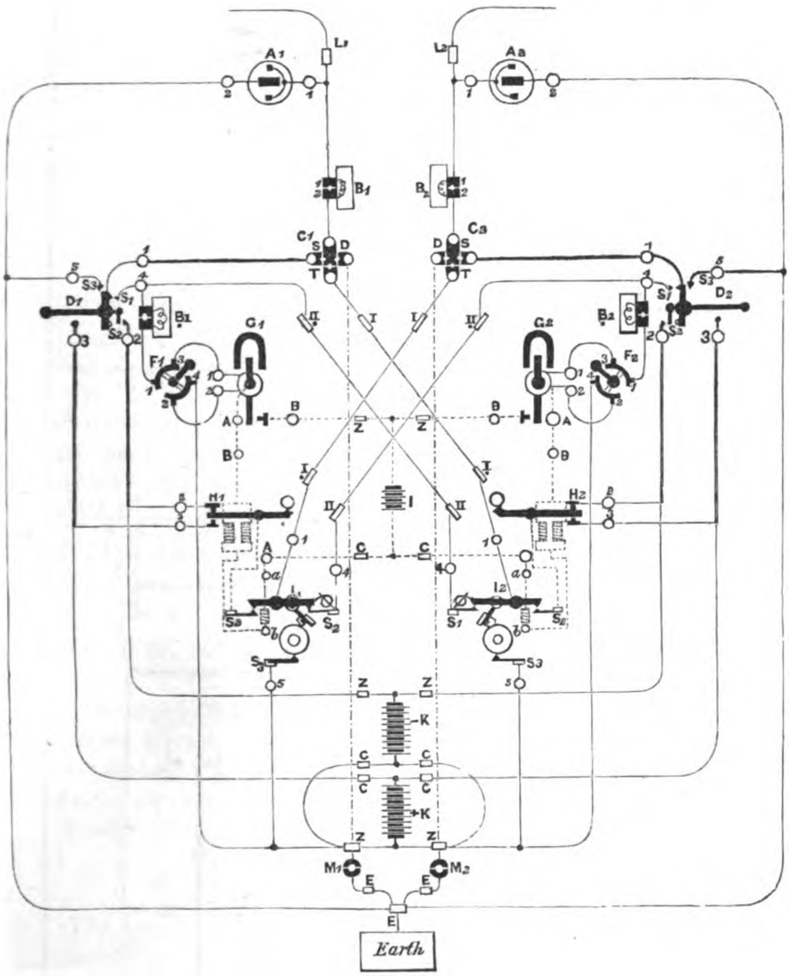


Fig. 80.

are brought, their arrangement being as follows: L is the line wire, E the earth wire, C copper pole, and Z zinc-pole of battery. The local circuit, indicated by dotted lines, shows the terminals between which the local battery is connected.

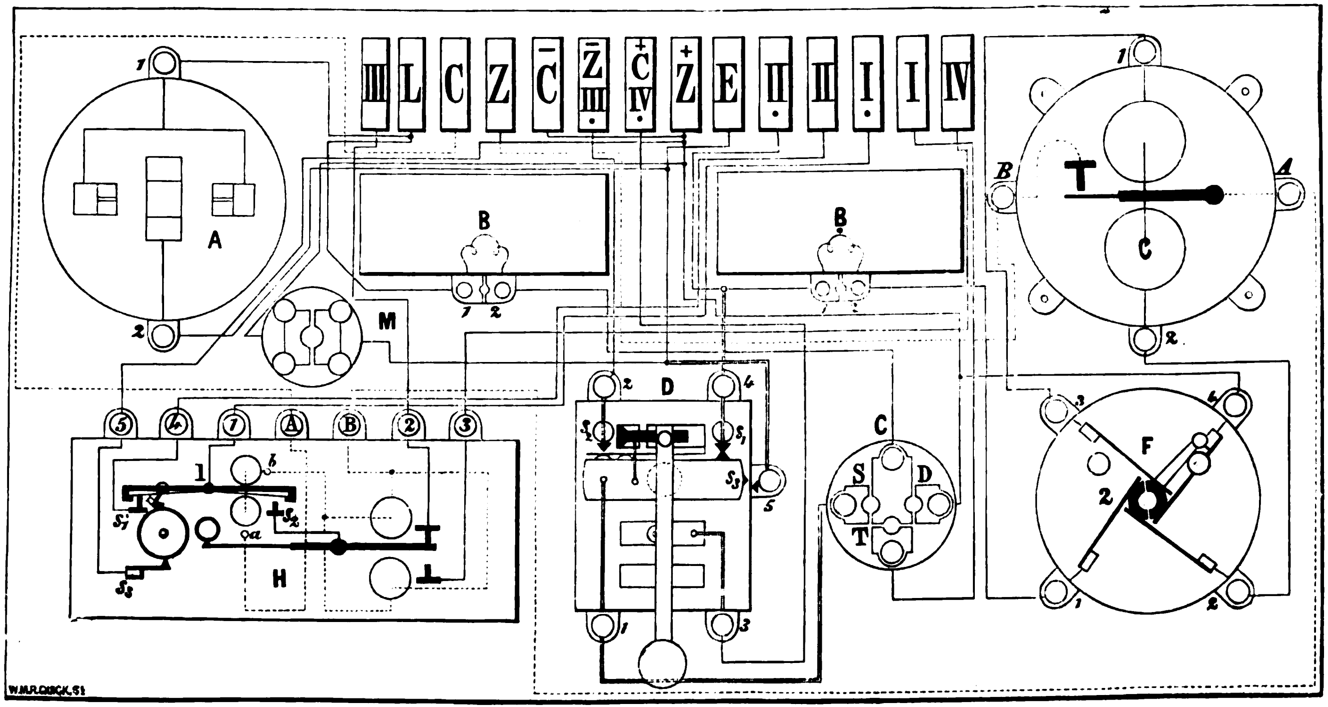


Fig. 81.

The remaining terminals, I, I, II, II, &c., are for the connections between the two slabs.

The following are the different positions of the commutators, &c., for different uses of the apparatus :—

1. The Apparatus as Terminal Station.

Position I.

Both translation commutators are stoppered at *S*. Both current commutators are at 1. Contact cones in both the circuit-breakers.

A) Apparatus I. (left) receives signals.

The current coming from L_1 passes through the screw, L_1, the galvanoscope (1, B_1, 2), the translating commutator, C_1, contact cone in *S*, key (1, D_1, 4), galvanoscope B_1 current commutator (1, F_1, 3), relay (1, G_1, 2), current commutator (2, F_1, 4), screw *Z*, circuit-breaker, M_1, screw *E*, and earth, and through the earth back to the battery of the sending station.

The tongue of the relay, G_1, is attracted against the metal contact point, and the local circuit closed as follows :—

> Local Battery (*Z*, I, *C*), the screw, *A*, of the printing instrument, *a*, through the releasing magnet, *b*, at the same time through both coils of printing magnet, *B*, to the relay, *A*, tongue, metal contact, *B*, and back to the *Z* of the local battery.

Thereupon both the magnets of the instrument are made to attract; the releasing magnet sets the clockwork in motion, and the printing lever of the other magnet is held down until an opposite current coming from L_1 repels the tongue of the relay from the metal contact.

B) The Apparatus I. is made to transmit signals.

The key D_1 is drawn sideways, so that the spring s_2 is pressed against the contact, 2. The counteracting battery, —K, is then in circuit as follows :—

> (*Z*, —K, *C*) *Z*, M_1, *E*, earth, opposite station apparatus, L_1, lightning guard A, Apparatus I. (1, B_1, 2), (C_1, *S*), (1, D_1, s_2, 2), back to the battery, —K.

A negative current, therefore, passes through the line and the relay of the opposite station, the tongue of which is consequently pressed firmly against the stone.

2. APPARATUS I. AND II. TRANSLATE.

POSITION II.

Both translation commutators in *T.*

Both current commutators at 1, and both circuit breakers stoppered. The self-releasing clockwork is in action in both instruments. In this case a positive current from the opposite station would take the following direction:—

> L_1 (1, B_1, 2) (C_1, *T*) I, I, (1, $_2$, s_1, 4) II, II, 4, B_1 (1, F_1, 3) (1, G_1, 2) (2, F_1, 4) *Z*, M_1, *E*, *Pl.*, and through the earth to the opposite station battery.

The relay G_1 completes the local circuit, and therefore both magnets of the printing instrument, H_1, become active; the releasing magnet allowing the clockwork to run, and the printing magnet working the beam. When, in so doing, the printing lever touches the contact, 3, the battery +K is put in circuit with the line, L_2, and when it touches the contact, 2, the counteracting battery —K will be similarly put in circuit with the same line.

3. APPARATUS I. INTERMEDIATE BETWEEN BOTH LINES.

POSITION III.

a) For receiving legible signals from L_1 the commutators of Apparatus *I.* must be respectively in *S* and 1.

In Apparatus *II.* the translating commutator is in *D*, and communication with the earth cut off at M_1 and M_2.

b) For receiving signals from L_2, on Apparatus *I.*, the commutators are in *S* and 2; in Apparatus *II.*, translating commutator in *D*, communication with the earth being cut off at M_1 and M_2.

When the commutator of the Apparatus *II.* is stoppered in *D*, the latter instrument is entirely out of circuit, by the connection (C_2, *D*) *Z;* while a current coming from *L*, will pass through L_1, B_1 (C_1),*s*, 1, s_2, 4 of *D*, 1 and 3 of F_1, *Z*, *Z*, *D* of C_2, and so on to L_2.

88. *The Sounder.*—In America the method of reading by sound has almost entirely superseded that of recording. The apparatus used is called a sounder. In consists simply of an electro-magnet erected on a wooden base board, with an

armature attached to one end of a lever, at the other end of which is a spiral spring for drawing back the armature when the current ceases, the oscillation of the lever being limited by anvils. When a current circulates round the cores the magnetism induced attracts the armature, by which the end of the lever strikes on the top of the lower anvil, and produces a sharp noise; on the cessation of the current, the armature is let go, and the lever drawn back by the tension of the spring strikes with a less intense noise on the upper anvil. Adjusting screws attached to the spring enable the operator to regulate the sounds of the beats on the two anvils. With this exception the whole arrangements of the Morse system, of relays, keys, &c., remain the same.

Prescott says: "It was soon discovered after the introduction of the Morse system of telegraphs that words could be read by the click of the magnet; but paper was used upon which the arbitrary alphabet of dots and lines was indented by the instrument for all matters of business up to 1852, and by many lines even later; but at the present time there is scarcely an office of any importance in the United States where the paper is used to receive the record."

The same author says that since the abolition of the paper upon the Morse lines errors rarely occur; that the ear of the employé is found to be a much more reliable organ than the eye; not one error being made in reading by sound, while at least ten were made formerly in reading from the paper.

The system has, nevertheless, the disadvantage that it leaves no record for the justification of the operator. In France the messages are invariably recorded by the Digney instrument, but it is not unfrequent that the employés read the message by ear before looking at the paper.

In addition to the methods already mentioned of recording messages by the Morse on paper strips by the decomposition of salts, by scoring or embossing, and by inking, it has likewise been attempted to attain the same object by burning holes in, and by scorching the paper.

Horne, for example, suggested the employment of a bent piece of platinum wire kept at a white heat by the passage of a voltaic current, in place of the inking apparatus or style. Messrs. Farmer and Batchelder of Boston constructed a recording telegraph in which they only scorched the paper. A platinum point was connected by a lever with the armature of an electro-magnet, and brought into contact with tissue paper by opening and closing the circuit. The platinum point was kept red hot by a spirit lamp underneath.

90. *Morse Apparatus worked by Closed Circuit.*—The method adopted by Kramer, and also by Morse in an early telegraph of his, of working by interruptions of a current instead of by occasional currents, has been taken up by Frischen, and used by him on the Hanoverian railway lines for working the Morse instruments.

" A great advantage of this arrangement," says Frischen,* "is that, on lines with several intermediate stations, only the terminal station requires to be provided with a line battery, whilst a local battery is necessary at each intermediate station. By this the cost of batteries is considerably reduced; besides which, the relays, by reason of the uniform current, do not require often to be adjusted; and the employé is enabled to place confidence in the call signal without continually having the apparatus under his eye. The last point is of particular importance when the employé entrusted with the care of the apparatus has other business to attend to, which is often the case on railway lines.

In arranging a Morse line for closed circuit between two stations the line current must traverse the galvanometer, relays, and keys in such a way as to hold the tongues of the relays on their reposing or insulated contacts, and the galvanometer needles permanently deflected. When a signal is given by interrupting the circuit, the force of the adjusting spring of the ordinary relay, or the superior attraction of the nearer pole of the polarised relay, must be sufficient to overcome any residuary magnetism which may be in the cores of the electro-magnet, and by pulling it against

* Brix. Journal, v. p. 214.

the working contact, close the local battery and work the Morse.

Fig. 82 shows the connections of the apparatus for two stations with the Morse recorder. R and R′ are the polarised relays, the coils of which are connected with line and with the levers of the keys T and T′ respectively. To the back

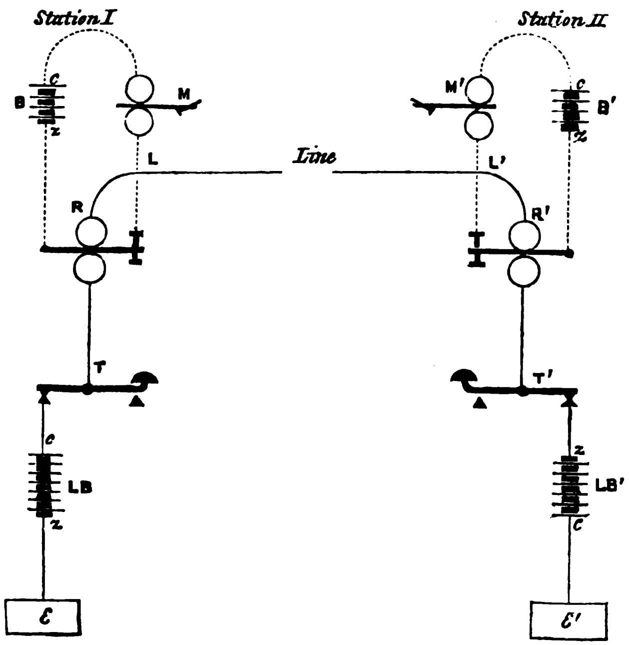


Fig. 82.

contacts of the keys are brought the opposite poles of the two line batteries; L B having the zinc and L′ B′ the copper pole to earth. The front contacts of the keys are used only as stops or anvils without electrical connections. Between the working contacts of the relays and their armatures, the local batteries B B′ and the Morse apparatus M M′ are inserted. Whilst the keys repose on the back contacts, as shown in the figure, the currents of the two line batteries circulate, in the same direction, through the line and coils of the relays: that of L B goes from Z to *E* (earth), *E'* of Station II., C, battery L B' (whose current adds itself to that of L B), C, back contact of T', lever, coils of R', line, coils of R, over the lever T, and back to C of L B.

The armatures of R and R' are therefore continually attracted to the insulated contacts, and the local circuits are open. When one of the keys is pressed down upon its front contact and the circuit interrupted, the armatures of both the relays are simultaneously released, falling upon their working contacts, closing the local circuits, and putting the Morse machines, M and M', in motion.

Frischen, who has more than any one else given his attention to the application of closed circuit methods for railway and other lines, had constructed plans of connections for station apparatus, for translation between two lines worked by closed circuit, and also for translation between a line with closed circuit and another worked with intermittent currents.

Fig. 83 represents a plan of connections for translation with closed circuits. R_1 and R_2 are the relays of the two apparatus at the intermediate station; K S T two switches, which, when the arms are in the middle between T and S, establish contact between 1 and K; when the arm of a switch rests on T, contact is made between it and T, and that between K and 1 interrupted by means of a cam of ivory on the arm, which lifts it up; and, lastly, when the arm rests on S, contact is established between them, whilst that between K and 1 is also made. M and M' are the two Morses of the usual construction, but with an additional contact at the end of the lever which makes and breaks contact between T of the switch and the line battery. K and K' are the manipulating keys, B the local battery common to both local circuits, and L B the line battery of the station.

For station work, the handles of the switches on both sides are placed on S; and the circuits of these and the corresponding terminal stations are established through the line, coils of the relay, arms and contact S (of switches), 1 and 2 of keys, L B, earth, &c. The tongues of the relays are therefore held on the insulated contacts. On breaking the line circuit at any point, the local circuits are closed, and the current of B goes through the coils of the printing instruments, which are set in action.

For translation, the arms of the switches are shifted to

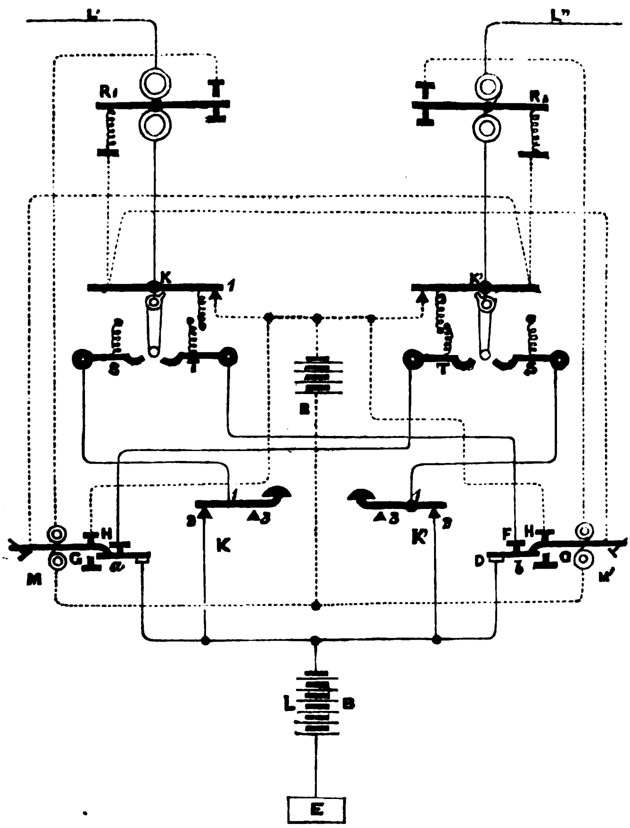


Fig. 83.

the spring terminals T; the circulating current then takes its way through L', R', K and T (of switch), over to the other side, beam of Morse M', D, line battery L B, earth, &c. The current of L B goes also to the Morse on the other side, switch T, K', relay R_2, and line L_2.

When the line L′ is interrupted anywhere, the temporary magnetism disappears from the cores of the relay bobbins the armature falls off against its reposing contact, and the left side of the local circuit with Morse M is closed. The depression of the printing beam separates the contact spring from the screw point, by which the line L″ is also interrupted; and armature of the relay R_2 falls against its reposing current.

On the deflection of the beam G of Morse M, the contact with H having been broken, the local circuit is interrupted; and, notwithstanding the action of the relay R′, the Morse M′ does not move.

Thus, in translating, both relays are in motion, but only one Morse apparatus—that on the side from which the message comes.

Sometimes another method of translation is adopted, by which the messages arriving at an intermediate station by a line with continuous current, are translated into a line worked by intermittent currents, and *vice versâ*. This is often found useful in shunting despatches between lines already arranged with different systems.

Fig. 84 gives a plan of connections for this operation, in which the single parts of the apparatus on the right-hand side are the same as in Fig. 83. Those on the left-hand side are supplied with the additional contacts of the switch and Morse. The line battery is divided in halves.

It is supposed that Line I. on the left, L, is worked by continuous, and Line II. on the right, by intermittent currents.

For station work, the continuous current circulating in Line I. (R, switch, 2, S, K 1, 2, L B, &c.) and Earth is interrupted. The armature of R then goes from the insulated to the working contact, and closes the local circuit by which the Morse M is moved. On the other side, the currents arriving go from Line II. (switch 2, S, K′, 1, 2, R′ E) to earth, and close the other local circuit setting M′ in motion. To transmit a message from either side, the arm 2 of each of the switches rests on S, and the keys K and K′ are simply manipulated.

In translation, the arms of the switches rest on the terminals T. The continuous current circulates in Line I., R, 2, T of switch, over to the right hand, F, D, L B, Earth, &c.

An interruption in this circuit caused the relay to work,

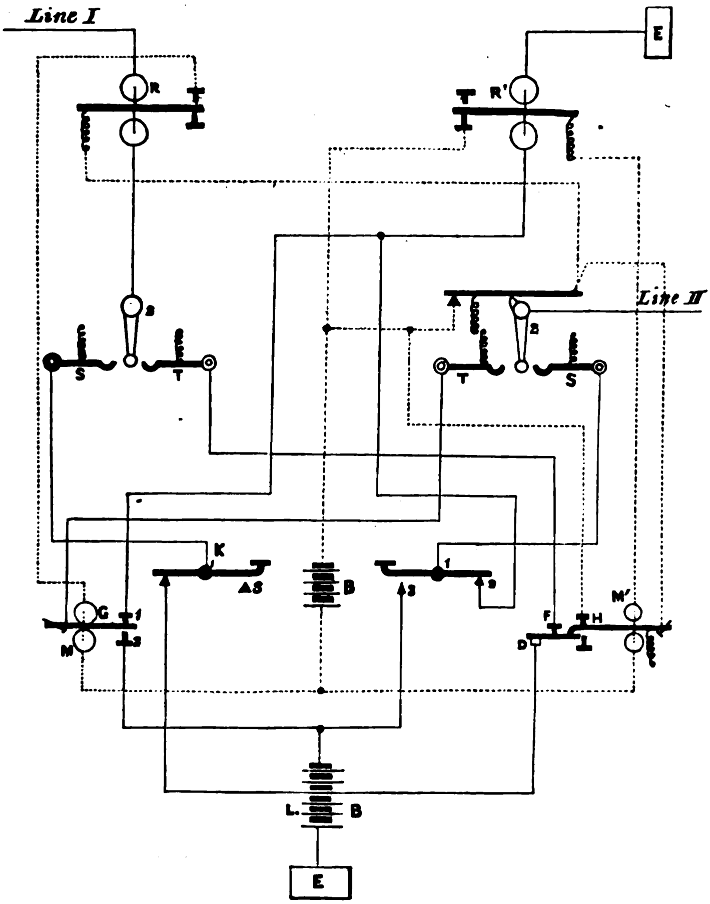


Fig. 84.

and therefore the Morse M, which directs a current, corresponding to each interruption of Line I., in the circuit E, L B, M, 2, G, to T of switch, 2, to Line II.

A current from Line II. passes through 2 and T of switch to Morse M, G, 1, coils of relay, R', to earth. The Morse M', thereby put in motion, interrupts the current of Line I. between the screw P, and spring D; and, by the separation of the beam of M′ from the upper contact H, divides the local circuit of M, which, therefore, in spite of the movement of its relay, remains passive.

91. *Methods of Telegraphing in Opposite Directions at the same time in a Single Wire.*—This feat was for a long time considered to be an impossible one. Judging from the plans employed for ordinary circuits, it was urged that on sending currents of equal intensity in opposite directions from the ends of a single wire, they would eliminate each other, and no indications could be observed at the relay or other receiving apparatus.

92. The problem was first solved in the year 1853 by Dr. Gintl,* an Austrian telegraph director, a plan of whose

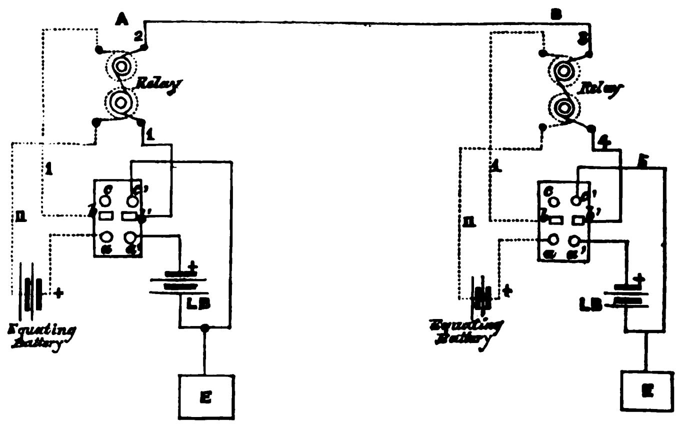


Fig. 85.

arrangement is shown in Fig. 85. The conditions which it was necessary to observe were, that the relay or other receiving instrument at each of the stations should remain always in circuit with the line, and that the currents transmitted from either station should nevertheless not affect the relay of that station.

These two conditions are fulfilled by Gintl's plan by the

* Schellen, p. 310.

employment of a relay with coils wound with two separate wires, in one of which the current of his line battery circulate, and in the other that of an equating battery. These coils, wound in opposite directions on the cores, have equal and opposite magnetic effects on the relay when connected up in their proper circuits; so that, on pressing down the key, although the whole of the current of the line battery passes through the relay, the latter remains perfectly unaffected. For convenience of closing the circuit of these two batteries at the same moment, Gintl employs a double key, *a b c*, and *d' b' c'*, consisting of two separate levers insulated from each other, being connected together by an insulating cross-piece, and having in front a common knob.

In the circuit of one series of the coils of the relay (usually the outer and thicker) are inserted, by means of the leading wires I and II, the equating battery, and the front and middle contacts, *a* and *b*, of the right side of the key. The front contact of the other side of the key is connected to the positive pole by the line battery, the negative pole being to earth; the middle contact, or lever, is connected with remaining coils of the relay, and thence, on the other side, to the line wire; and the back contact of the key to earth.

On pressing down the knob of the key, the current of the line battery, L B, goes from the + pole over the lever *a' b'*, leading wire, terminal 1 of relay, the interior coils, terminal 2, through the line to B, where it passes from 3 through the interior coils of the relay, 4, key *b' c'*, 5, E, earth, and, at station A, E to the — pole of the battery.

The current of the equating battery, at station A, goes, at the same time, through its circuit: +, key, *a*, *b*, I, the outer coils of the relay, II, &c., neutralising the effect of the line battery upon the relay.

Suppose now that, while the key of station A is depressed, that of station B is also pressed down, the line current from station B will pass from + of the battery through *a'*, *b'*, of the key, 4, coils of relay, 3, B to station A, where it will enter the coils of the relay at 2, and go from 1 over the key, *b'*, *a'*, through L B to earth, &c. Thus the equilibrium, previously established by the equating battery, is destroyed; and the relay of A will give a signal corresponding to the length of time which B keeps down his key. During also the whole time that A keeps down his key, the relay of B will be affected, whether the key at station B be pressed down or not, because, as we have seen, the effect of his own current on his relay is neutralised by his equating battery. If, therefore, both stations work their apparatus at the same instant, signals will be given properly by the respective relays.

There is only one position in which a perfect reception of the signals transmitted from one station is not attained by the other. It is when, during the manipulation at either of the stations, the lever of the key is removed from the back contacts, *c c′*, until it touches the front contacts, *a a′*, or *vice versâ*. In these cases the line circuit is interrupted for an instant at *b*, and the signal which should be given by the relay of the same station is disturbed.

This is, however, a small evil compared to the great difficulty in retaining the compensation of the line and equating batteries for any length of time. The plan adopted by Gintl, of using a thicker and shorter coil on his relay for the equating circuit, occasioned the equating battery to expend itself quicker than the line battery, which encounters considerably more resistance; and this continued diminution of the intensity of the compensating current, whilst the line battery kept nearly constant, caused a corresponding effect on the home relay, which gave the operator often some of his own signals back again, if he does not continually see to the strength of the currents.

93. This system was first used on the line from Prague to Vienna, but difficulties soon induced Gintl to forego the attempt to work Morse instruments by this method, and to adopt instead a chemical telegraph, by which he obtained much better results.*

The plan of this modification is shown in Fig. 86, in which *a b* is the line wire from one station to the other, con-

* "Dub's Auwendung, &c.," p. 461.

nected at each end with a metal style, which rests on a strip of chemically prepared paper, supported on the under side by a metal contact. The latter are connected to the + poles of batteries E, the — poles being to earth. Between the metal styles and contacts are inserted resistances, and secondary or compensating batteries, whose currents traverse the paper strips in the reverse direction to those of the line batteries, and prevent the decomposition of the salts contained in the paper.

Let the negative current of the line battery at station A go from E to earth, and the positive current from E through the metal supporting the paper strip, through the paper and the style to the line *a b*, in the direction of the arrows; at station *b* it will go through the style, paper, contact rest,

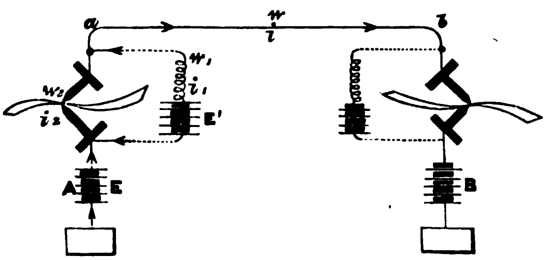


Fig. 86.

and line battery, to earth. In traversing the paper at station A, a decomposition of the salts would take place were it not for the counteracting battery E′, whose current, of equal strength, passes from E′ through *w′*, style, paper, &c., preventing the chemical action, until a current, arriving from *b*, or some such disturbance of the balance, causes an appreciable difference of the currents enough to affect the paper.

The value of the resistance *w′*, which is inserted in the circuit of the counteracting battery to balance the currents, may be calculated by the aid of Ohm's law, which will be explained in the second part.

Gintl subsequently employed a single key with five contacts, instead of the double key just described.

94. *Plan of Frischen and Siemens-Halske.*—About the same date (1854) these celebrated engineers invented, independently of each other, an improved system of telegraphing in opposite directions in a single wire at the same time; their plan, by which the counteracting batteries and double keys—both sources of difficulty—are entirely dispensed with, possesses important advantages over the methods of Gintl, and brings the problem of telegraphing in opposite directions as near to perfection as is possible with the conditions of so delicate an arrangement.

Fig. 87 represents the plan of connections of two stations, *A* and *B*. The negative pole of the battery E is connected to earth, and the positive pole to the working contact of the

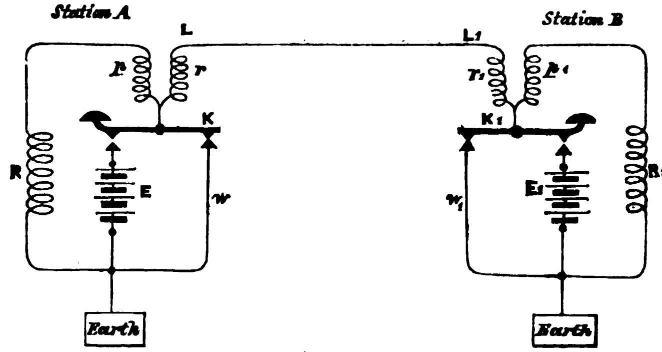


Fig. 87.

ordinary transmitting key K; the back contact being, as usual in the Morse plan, connected to earth. Instead of the common arrangement of putting the relay in the earth circuit from the back of the key, it is inserted above the lever of the key. The relay consists of two coils, *r* and *p*, of equal and opposite magnetic effects. The coil *r* is connected between the lever of the key and line; and the other coil, *p*, between the lever and a resistance, R, to earth.

When the resistance of *r* and *p* are equal to each other, and R equal to the sum of the resistance in the circuit of the line L L_1 and of one side, r_1, of the relay at station *B*, &c., to earth, then, on pressing down the key, the current of E will be equally divided between the coils *r* and *p*, which having equal and opposite magnetic effects on the needle or tongue of the relay, will produce no effect at *A*; but it will deflect the tongue of *B*'s relay by passing through the coil r_1. The same arrangements being made at station *B*, when the key K_1 is pressed down also, it is evident that the deflection of the armature of relay B will not be disturbed, because the magnetic effect of the home circuit is neutralised, as in the case of *A*.

But the current from *A* can now no longer pass so directly to earth, in consequence of the interruption at the back contact of the key K_1. It has, however, two paths open to it: the one through E_1, and other through p_1 and R_1 to earth. During the manipulation of the key in Gintl's apparatus, the circuit is interrupted during the instant which elapses between the breaking of one contact and the making of the other by the key. With the method before us this cannot be the case; the current passes from the line L_1, through both the coils r_1 and p_1 of the relay, and R_1, to earth. The current encounters, therefore, twice as much resistance—that is to say, that of the line, &c., and that of R_1 also, which are equal, and has, in consequence, only half the intensity it formerly had. The effect on the relay remains, however, the same, because the current has to pass through both the coils r_1 and p_1, which being wound in opposite spirals, work now in the same sense and with double force upon the armature. At *A* the relay is also deflected, since the balance between the currents in r and p has been destroyed by the opposing current from *B*, which passes, as in the case of the current arriving at station *B*, through both the coils r and p of the relay and the resistance R. When at this moment the key K is let go back on to its reposing contact, the arriving current is shunted from p and R to the back contact of the key and short-circuit w. Only half the resistance now opposes the current, whose intensity is, therefore, doubled, but to balance this, as before, only half the relay is traversed by the current.

One of the greatest benefits to be derived from this method of telegraphing in opposite directions is a system of repetition and control very necessary on some lines by an arrangement of translation, by which a message transmitted by the employé from station *A*, for example, is not only received on the relay and Morse at station *B*, but also retransmitted by the Morse apparatus at *B* to station *A*, where it can be examined at once to be sure of its correctness.

95. *Methods of Transmitting Two Messages along a Single Line in the Same Direction at the Same Time.*—The first success attained in this direction was by Stark of Vienna in 1855. His method consists of sending from the transmitting station, by two keys, two currents of different intensities, which, on arriving at the receiving station, each set a relay in motion.

The relays are arranged in such a way that when the weaker currents traverse the line, only one of the relays is put in motion; when the stronger current traverses the line the other relay is affected; and lastly, when both currents go together, both the relays respond to them.

At the sending station Stark arranged two keys, as in the plan Fig. 88; K being a simple Morse key, and K′ a similar lever, supplied at the back with an insulated earth contact, which it moves against the two anvils 5 and 6. The usual front and back contacts of the keys are marked in the figure 1 and 3 respectively, and the levers 2. The battery, which is connected up in series, or one element after the other, is used in two unequal parts, *a* and *b*, the number of elements represented by *b* being double that of *a*. The battery *a* is put into circuit with the line by pressing down the key K; *b*, by the key K′; and both together by depressing both the keys at the same time.

The copper-pole of *a* is, therefore, connected to the contact 1 of K, the zinc-pole of same to 5 of K′. Copper-pole of *b* is connected with 1, and zinc-pole with 6 of K′. Lever of K′ is in connection with the back contact 3 of K; line is brought to the lever 2 of K, and the back contact of K′ goes to relay, &c.

When K alone is depressed, the currents of *a* pass from Z (5 and 4 of K′) to earth, and from C (1 and 2 of K) to line.

When K′ is depressed alone, the currents of *b* pass from z (6 and 4 of K′) to earth, and from c (1 and 2 of K′) to line.

When both K and K′ are depressed, the united currents of *b* and *c* pass from zinc of *b* (6 and 4 of K′) to earth, and from copper of c (1 and 2 of K) to line.

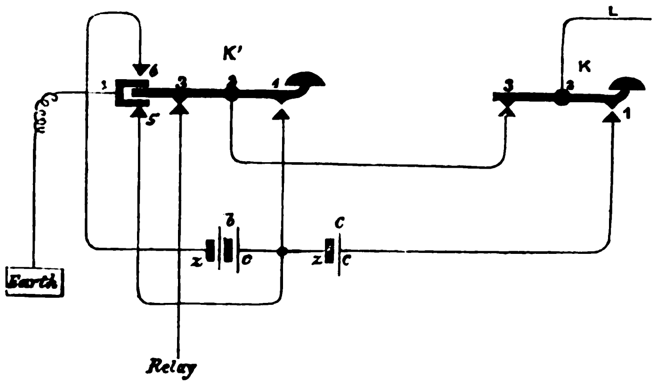


Fig. 88.

By the depression of one or other or both the keys at the sending station, three currents are therefore produced, whose intensities are in the relation of 1, 2, 3. These currents we will call s, s_1, and s_2.

At the receiving station all currents pass through two relays, I and II, Fig. 89. A common local battery E^1 serves both these instruments; its zinc-pole being connected with the tongue of each of them, and its copper-pole with their metal contacts. The relay II is furnished with outer coils, which are put into circuit with another local battery E and a resistance R, by means of the tongue of relay I.

The tongue of relay I is held on its insulated contact by a spiral spring, whose force is adjusted that the currents s, or those of the portion *c* of the battery, are unable to move it; but that it is easily moved by s_1 and s_2—the currents of section *b* and the whole. Relay II, on the contrary, was adjusted delicately, so as to be deflected by the weaker currents.

When, therefore, the key K at the sending station is pressed down, the current of c is sent through the line, and passes through the coils of relays I and II to earth. Relay I is unaffected, but relay II is put in action, and the Morse M_1 in the local circuit (E_1 z, relay II, 3, 2, M_1, c, &c.) prints whatever signals are given by K.

When K′ is depressed at the sending station, current s_1 is

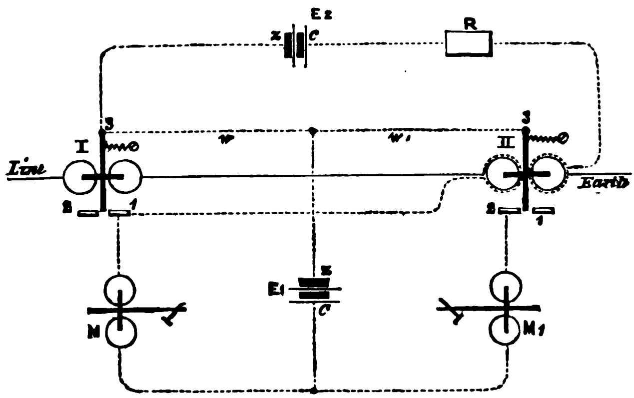


Fig. 89.

transmitted, and the tongue of relay I deflected against the local contact. Thus two local circuits are closed; the first is that including the battery E_2, R, and the extra coils of relay II, by which the action of the line current in this relay is counteracted, and the tongue held still against the insulated contact; therefore M_1 does not respond to these stronger currents. The second local circuit is that of the Morse M and battery E_1.

The intensity of the counteracting battery E_2, whose magnetic effect upon the armature of relay II we will call s_3, is regulated by the interposed resistance R until it balances the magnetising power of the line current sent by K′.

The third case is that in which, during the manipulation of the two keys, both happen to be pressed down together. When this occurs the current s_2 of the whole battery goes through both the relays I and II. Relay I is put in action as before, and closes its printing circuit, and that of the counteracting battery E_2. But as the opposite magnetic effect S_3 of the extra coils of relay II is only equalto that of S_1, and since S_2 is equal to the sum of S and S_1, it is evident that the relay II will be acted upon by the difference of the magnetic effects due to the line and the counteracting currents, or by S, which is precisely the same as that produced when K alone is depressed. The Morse M_1 will therefore also be set in motion. Combinations have been made, also, by which in a single line, at the same moment, two messages could be sent in one direction, whilst two were being received from the opposite direction; that thus four independent communications could be kept up.

Other arrangements have also been made for telegraphing in the same direction at the same time to different stations along the line, both directly and by translation.

Kramer, Bosscha, Maron, Edlund, and others have invented also many similar and equally beautiful methods, all of which have been tried, but none of which have found their way to any extent to practical application; and the reason is very simply to be found in the varying resistance of telegraph lines, and in the varying electro-motive forces of the batteries, which occasion the inconvenience of having to adjust the systems by means of resistances to compensate these disturbances. Both these systems of telegraphing in opposite directions, and of telegraphing in the same direction more than one message at a time, must be looked upon as little more than "feats of intellectual gymnastics"—very beautiful in their way, but quite useless in a practical point of view.

96. *Automatic Printing Telegraph.*—Professor Wheatstone, to whose inexhaustible fund of invention this modification owes its being, described it in a paper read before the Paris Academy in January, 1859.

It consists principally in the mechanical transmission of signals by means of contacts given by series of perforations in bands of paper previously prepared and drawn through the manipulator; the signals being printed by the recording instrument.

Three separate apparatus are required: the perforator, by which groups of holes are printed in the paper; the transmitting or contact key, which is worked by the perforated paper strip; and the recording instrument of peculiar construction.

The perforator has a guiding groove, through which a paper strip passes. At the bottom of the groove is an opening to admit of the to-and-fro motions of the upper end of a frame containing three punches, the extremities of which are in a line transverse to the direction of the paper. A separate lever or key is connected with each of the punches for the purpose of elevating them; the two external ones forming the groups of perforations which make up the message, and the middle one, which is smaller, marking the spaces between the letters and words. On pressing down one of these keys its punch is raised in order to perforate the paper; at the same time, a clip which holds the paper firmly in its position is lifted up, and the frame containing the punches advances in the groove, the paper being carried forward by the punch which has perforated it. On letting go the key, the paper is first secured by the clip, and then the frame falls back into its normal position.

The inventor has adopted the Morse alphabet by making the upper line of perforations represent the dots, and the lower the dashes.

The transmitter receives the slips of paper prepared by the perforator, and transmits voltaic currents corresponding to the holes: positive by the holes on one side, and negative by those on the other.

An eccentric in the interior produces and regulates the occurrence of three distinct motions:—1st (says the inventor) the to-and-fro motion of a small frame which contains a groove fitted to receive the slip of paper, and to carry it forward by its advancing motion; 2nd, the elevation and depression of a spring-clip, which holds the slip of paper firmly during the receding motion, but allows it to move freely during the advancing motion; 3rd, the simultaneous elevation of three wires placed parallel to each other, resting at one of their ends over the axis of the eccentric, and their free ends entering corresponding holes in the grooved frame. These three wires are not fixed to the axis of the eccentric, but each of them rests against it by the upward pressure of a spring, so that when a light pressure is exerted on the free ends of either of them, it is capable of being separately depressed. When the slip of paper is not inserted, and the eccentric is in action, a pin attached to each of the external wires touches, during the advancing and receding motion of the frame, a different spring, and an arrangement is adopted by means of insulation and contacts properly applied, by which, while one of the wires is elevated and the other remains depressed, the current passes from the voltaic battery to the telegraphic circuit in one direction, and passes in the other direction when the wire before elevated is depressed, and *vice versâ;* but while both wires are simultaneously elevated or depressed, the passing of the current is interrupted. When the prepared slip of paper is inserted in the groove and moved forward, whenever the end of one of the wires enters an aperture in its corresponding row, the current passes in one direction, and when the end of the other wire enters an aperture of the other row, it passes in the other direction. By this means the currents are made to succeed each other automatically, in their proper order and direction, to give the requisite variety of signals. The middle wire acts only as a guide during the operation of the current.

In the recording instrument a paper strip is drawn off a paper drum by revolving rollers, which are turned by means of a clockwork inside the case. The paper strip passes underneath a shallow reservoir about an eighth of an inch deep, containing ink. At the bottom of the reservoir are two holes, so small as to prevent, by capillary attraction, the escape of the ink through them. The ends of the printing styles are placed immediately above these holes, and, when deflected by means of the electro-magnet, they are pushed down through the holes, and carry with them sufficient ink to produce legible marks upon the paper.

Professor Wheatstone, in his description, shows also how the apparatus may be arranged for translation, and also how it may be used with a magneto-electric machine instead of a voltaic battery, as the source of electric power.

This excellent method is said to combine the advantages of a five-fold speed in transmission, with a considerably greater security for correctness and legibility. The great difficulty which many people find in acquiring dexterity in manipulating by the present system of Morse, would vanish were such a system of automatic transmission in general use, in which the demand for skill from the employés is reduced to a minimum.

97. *Siemens and Halske's Magneto-Electric Type Telegraph.*—Towards the end of the year 1861 Messrs. Siemens and Halske succeeded in the construction of a transmitting apparatus which is, at the present time, one of those instruments by which an immense amount of work may be got through, with little trouble, in a very short space of time.

The transmitter, which is automatic, like that of Morse's first electro-magnetic telegraph, is used in conjunction with the polarised ink-recorder already described.

The transmitter consists of a long insulated wire wound upon a soft iron armature, revolving between the poles of a number of permanent magnets like that of the magneto-electric dial instrument of the same inventors. Of the alternate currents thus generated, those which are required to form the signals go through the line to the receiving station; the others are cut off by an interruption.

This is effected by the motions of a contact-lever, raised by the teeth of a series of metal types drawn under the lever by the same mechanism which is used to turn the coil.

Fig. 90 represents a plan of the complete apparatus. L, L^1 is the angular contact lever turning on the axis *c*. When its point, L, is lifted up, the platinum face on the right side of the upper end, L^1, comes in contact with the metal screw 2; and when it falls, the back of L^1 rests against the agate point 1 and breaks the circuit. I, I^1 is the inductor or revolving coil of wire in close proximity to the poles of the permanent magnets M, M^1. C is a switch, the terminals *a*, *b*, and C of which are respectively connected with the transmitter, receiving instrument, and line. One end of the coil I, I^1 is in permanent connection with the centre *c* of the contact-lever L, and the other end with the terminal *a* of the switch. The contact-point 2, against which the lever L, L^1 plays, is to earth; and, lastly, the side *b* of the switch is connected by a wire to the coils of the polarised Morse, and thence to earth.

If the inductor I be turned round between the poles of the

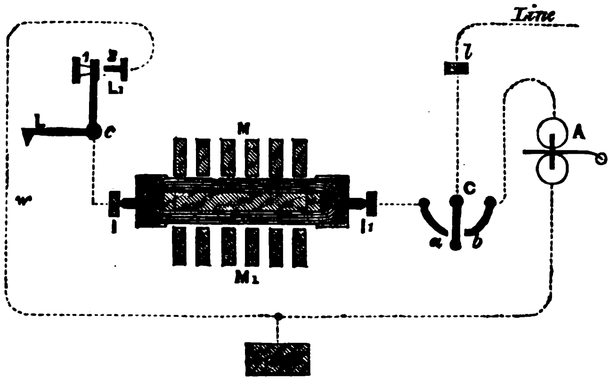


Fig. 90.

permanent magnets M, M^1, whilst L^1 rests against the insulated point 1, and the arm of the switch C is on *a*, the currents induced in the wire will meet with an infinite resistance between L^1 and 1, and no impulse will be transmitted through the line; but if L be lifted up, and the contact between L^1 and 2 established, the currents will pass from the coils I, I^1 (*c*, L^1, 2) to earth, and on the other side from I, I^1 (*a*, C, *l*) to line, and at the distant station, through the Morse instrument, to earth.

When the arm C is put on *b*, the transmitter is cut out of circuit, and the currents arriving pass from line (*l*, C, *b*, A) to Morse and earth.

The types, which are set up in a composing-rule in order, like printing-types, are made of thin pieces of metal cut in teeth, in forms resembling those shown in Fig. 92, representing the letters *a* and *b*. The bottom of the composing-stick is provided with a row of teeth, which lock into the worm of an endless screw on the shaft which turns the inductor-coil. Thus, while the inductor-coil is turned, and the alternate currents generated, the types are moved forward with a corresponding velocity, and make and break contact by lifting and letting fall respectively the point of the contact lever.

Fig. 91 gives an elevation of the contacts, with the lever and part of the composing-stick containing the three letters

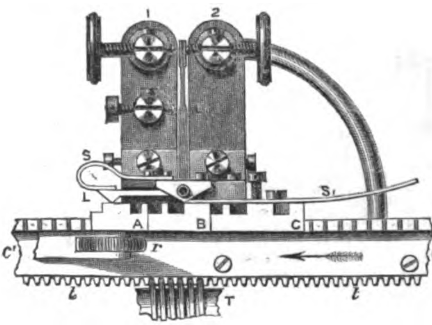


Fig. 91.

a, *b*, and *c*. C′, C″ is the composing-rule, moved along in the direction indicated by the arrow, by the rotation of the screw T, and is held in its place by the roller *r*. The lever L, L¹ is held back against the contact 1, when not raised by the types, by means of the spring *s*. The figure, however, shows the point L lifted up by the broad tooth of the letter A, and the arm L¹, therefore, pressed against the contact screw 2. The types are straightened, in the event of getting shifted upwards, by passing under the spring S¹.

The transmitter is fixed upon a table, underneath which is a fly-wheel and pulley, whose strap turns the shaft of the inductor and screw T. A common crank and treadle, like that of a lathe, imparts motion to the system.

The composing-rules are about two feet long, and consist each of a straight, rigid piece of metal one-sixteenth inch thick and one-half inch broad, with a thin elastic piece, not quite so broad, screwed on lengthways. The types are put in between the two, and are held, in some measure, tight by the elasticity of the first piece. The rigid bar is cut at regular intervals with vertical grooves or ribs, in which a corresponding elevation at the back of each of the types fits, to avoid shifting along the stick.

When the arm L^1 is against the contact 2, or the hook L lifted up, as in the figure, whilst T is revolving with the coil, currents, alternately positive and negative, traverse the line, and the polarised Morse at the receiving station gives a series of dots. But when the contact L^1 with 2 is interrupted, the armature of the printing magnet remains on one of the contacts, upper or lower, until a reverse current removes it. The last current before the interruption, positive or negative, determines on which contact the printing beam shall repose. On the upper contact a blank space, and on the lower a line, is the result.

It is the duty of the types, acting on the point of the lever L^1, L, to provide these interruptions after the different currents, so as to produce the required letters of the Morse alphabet at the receiving station.

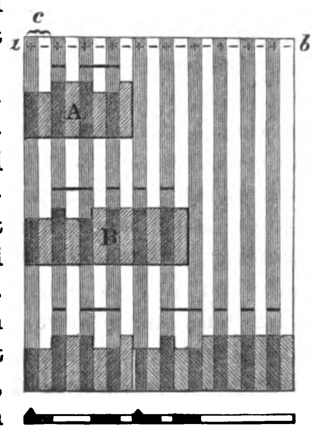


Fig. 92.

Suppose *a*, *b*, Fig. 92, to represent a series of alternate positive and negative waves, produced by the revolutions of the coil between the poles of the permanent magnets, whilst L^1, connected with earth, completes the circuit. During each complete revolution a positive and a negative current within the space C are developed, each succeeding half-revolution sending a different current into the line. At the receiving station, whilst this continues, the armature of the polarised Morse will vibrate up and down, and print a series of short lines corresponding to the intervals between the transmission of the positive currents and the negative which follow them.

If the composing-stick be not so far advanced along the stage as in Fig. 91, so that the types A, B, C are all on the right of the lever L, the arm L[1] will rest on the insulating contact 1, and the beam of the polarised Morse, at the receiving station, on the upper screw, by which no mark is made upon the paper. As soon as the hook L, however, touches the first tooth of the type A, it will be pushed up, and L[1] thrown on 2. A positive current will instantly afterwards traverse the line, and make a dot at the receiving instrument. A negative current succeeds, which makes a space; and then another positive current, which re-attracts the armature. Before the next following negative current is produced, the tooth has passed by, and L dropped into the space which corresponds to a whole revolution. The Morse-beam therefore prints a dash which continues till the next tooth pushes L up in time to complete the circuit for the negative current, which draws up the armature again, and produces a space which lasts until the first tooth of the letter B pushes up L, and allows a positive current to go to the Morse. This tooth is narrow, to break the circuit before the succeeding negative current is developed, so that the Morse prints a dash until the broad tooth of B pushes up L in time for the circulation of a negative current, which begins a space. The tooth in question is just so broad as to include three positive currents, and ends at a negative current. Each letter of the alphabet requires for its transmission an even number of waves. The shortest letter is the single dot representing the letter *e*, requiring two complete revolutions of the inductor-coil, equivalent to two positive and two negative currents, of which only one positive is used for marking. J, Q, and Y require each eight complete revolutions, or the time and space of sixteen currents each, some of which are interrupted at the proper places.

Each of the types begins with a depression which cuts off the first positive and negative currents, so that the first tooth of a letter invariably sends a positive current into the line. The types each end with a tooth after a negative current, so that the printing-beam is always drawn off by the types themselves before another type comes into play.

In this manner the indentation on the left of each type will always form a continuation of the space due to the last negative current.

The advantages, as stated by the inventors, of this beautiful system over the methods of automatic transmission by perforated paper bands and the ordinary Morse, consists, principally, in the greater speed with which a practised type-setter can set up a message, than an expert clerk could either manipulate his transmitting key or punch out the holes in the paper band; whilst the opportunities which it offers of controlling the correctness of each message when set up, by simply reading off the plain Roman letters which are engraved in the fronts of the types, gives it an important advantage over other systems.

The mechanical part of the transmission of a message consists in nothing else than in laying the composing-sticks, set up with the consecutive parts of the message, one after the other, on the stage appointed for their reception, removing those which have gone under the lever L, and in treading the lathe during the time.

This is accomplished so fast that the machine can transmit the work of six or seven type-setters; and, as the work of setting the types is much easier and requires less time than in manipulating the Morse letters with the ordinary key, such a machine will send comfortably eight times as many despatches as the ordinary key. The work of type-setting demands also little practice or intelligence. The types are marked with letters of the alphabet, and are put into their places in the composing-sticks from the boxes in which they are kept. It is true that, to keep the apparatus constantly at work, more employés would be necessary than are required for an ordinary Morse; but this is profitable on lines doing much business.

The almost mathematical precision of the signals facilitates immensely the work of reception by preventing the confusion and mistakes which sometimes arise in using the Morse, from irregular transmission.

The apparatus cannot be arranged for translation as it has been described. But this is scarcely necessary, as it can be worked easily through an overland line of from 500 to 750 miles. It is found to give marvellously good results on the line between Hamburg and Berlin—370 miles—even when an artificial resistance, equivalent to 1,000 miles, is added to the circuit.

By the employment, however, of two batteries and a commutating arrangement, translation would be easy.

The direct working polarised ink-recorder, constructed expressly for this system by Messrs. Siemens and Halske, is furnished with electro-magnets of somewhat larger dimensions, and contains a greater length of insulated wire than is necessary in ordinary circuits.

98. *Stoehrer's Double-style Apparatus.*—Stoehrer sought to remedy the inconveniences arising from the multiplicity of signals required in forming letters when only two elementary signals—the dot and dash, as in Morse's system—are employed, by the employment of two electro-magnets, with separate printing-beams acting upon the same strip of paper.

This method puts four elementary signals, instead of two, at his disposal for the construction of an alphabet; and thus places his method, in point of speed of working, on a level with the needle-apparatus of Wheatstone.

The two beams of the Morse are not moved by the currents of two batteries, but by that of a single local battery directed to the one or other electro-magnet by a delicate relay which differs in its construction from those generally used; the armatures being formed by two light permanent magnets whose opposite poles are alternately attracted or repelled according to the direction of the current in the coils. It is of necessity very delicate in its action in changing the local current from one to the other electro-magnet of the recording instrument.

The recording apparatus consists of a Morse with two electro-magnets and printing-beams. The styles at the ends of the beams press upon the paper strip in the same transverse line, about a quarter of an inch apart, underneath a common roller, in which two grooves are cut to receive the points.

A double transmitting key is used, each lever being of the ordinary construction.

A plan of the arrangement is shown in Fig. 93. K, K[1] are the two levers of the key. The lever K is to earth, and K[1] connected with a circuit breaker, U, thence to end 1 of the relay coils; the other end, 2, of the coils is connected to the opposite side of U, and thence to line. The front and back contacts of K and K[1] are made with metal bars, 1 and 2, common to both levers, and between 1 and 2 is inserted the line battery L B. The pole C of the local battery B goes to D, and

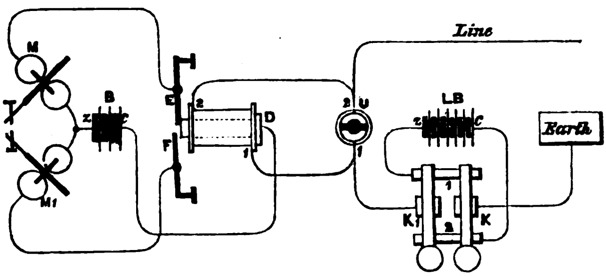


Fig. 93.

is therefore in permanent connection with the poles of the electro-magnet; the other pole, Z, goes to both the printing magnets M and M[1], and from the further ends of their coils to the armatures E and F of the relay magnets.

When the apparatus is to be used as transmitter and correspond with another station on the line, the contact peg is put into the hole of the circuit breaker U. The levers K and K[1] of the key are then pressed down, one at a time, according to arrangement of alphabet and words to be transmitted. When the knob of the lever K is pressed down, the current of L B goes from C (copper over 2 and lever of K) to earth, and from Z (zinc over bar 1, K[1], U) to zinc, and through the apparatus at the other station to earth. K being let go, and K[1] pressed down, the current of L B goes from C (bar 2, K^1, 1, U, contact peg, 2) to line, &c.; and from Z (through 1, K) to earth.

In case it is wished that the Morse apparatus print the message, for the sake of control the contact peg of U is not put into the hole. On pressing down the lever K, the current of L B passes from C (2, K) to earth, and from Z (1, K^1, 1 of U, coils of D, 1, 2, U 2) to line, &c. The other lever K^1 being pressed down, whilst K is at rest on the back contact, the positive current goes from C (2, K^1, 1 of U, coils of D, 1 and 2, U 2) to line; and the negative current from Z (1, K) to earth.

In this way the station apparatus M M^1 prints the message as well as that of the receiving station.

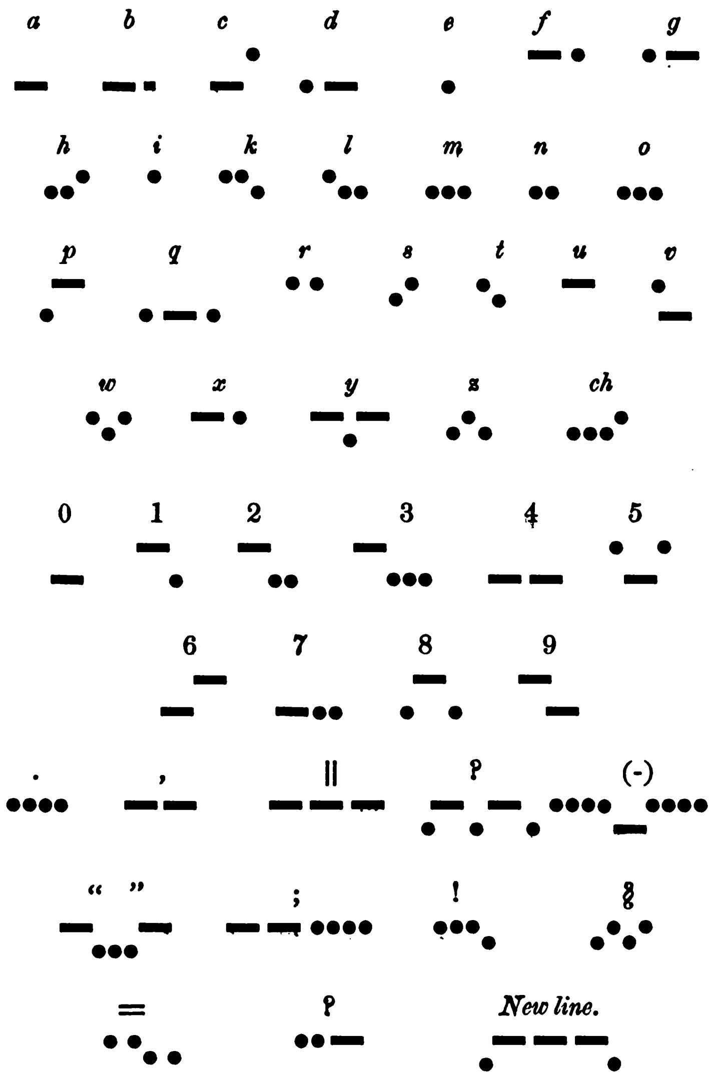
The apparatus is ready for the reception of messages when the contact stopper is out of U.

The currents arising from the line have to pass U 2, coils D, 2, 1, U 1, K^1, bar 1, K, to earth, and back to the sending station. The poles of the electro-magnet D become magnetic, and according to the direction of the current in the line attract one or other of the keepers, E, F.

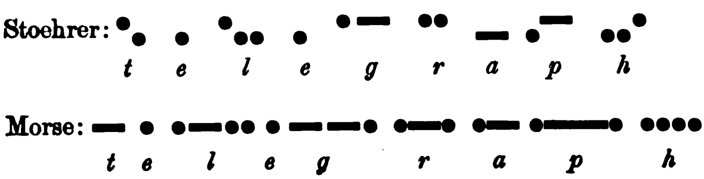
When a positive current arrives, F is attracted and E repelled. The result is that the local circuit of M^1 is closed; the current of the local battery B moves in the circuit C, cores of D, F, coils of M^1 Z. The beam of M^1 is attracted, and the style impresses the paper with marks on the lower side. When the sending station reverses the direction of the current by pressing down the other lever of his key, the keeper E of the relay is attracted, and F repelled. By this the current of M^1 is interrupted, and that of M established; the local current of B, now circulates in C, soft iron cores of D, E, coils of M, Z, by which the beam of M is acted upon, and the style marks the paper on the upper side.

The elementary signs, dot and dash, in each of the rows marked by the styles, give four elements for the composition of an alphabetical code. The consequence is that fewer signals are required for the formation of letters, &c., than in Morse's code.

The alphabet, numerals, signs of punctuation, &c.; arranged by Stoehrer are as follows:—



An idea of the time saved by this system may be gleaned from the signals representing the word "telegraph" by the Stoehrer and Morse codes respectively :—



Taking the dot as unit of time and the dash as equal to two of them, whilst the spaces between the dots and dashes of a letter are equal to one dot, and those between the different letters equal to the length of a dash, the time required for transmitting the word "telegraph" by Stoehrer's code will be 44 units, whereas by Morse's it will occupy 61.

VI. Electro-Chemical Telegraphs.

99. *Bain's Chemical Telegraph.*—Mr. Alexander Bain has been, since the year 1845, the author of several improvements and inventions in telegraphy. The most important of these is his electro-chemical telegraph, patented in England in 1846.

The sending apparatus is a simple Morse contact key. The receiving apparatus consists of a circular disc of chemically prepared paper stretched upon a similar disc of metal kept in rotation by clockwork. On the upper surface of the paper rests the point of a style, which, while the disc revolves, is drawn towards the periphery so as to travel over the paper in a spiral curve. When the circuit is closed, the salt with which the paper is prepared becomes decomposed under the style.

On a base board are erected the clockwork or driving portion of the instrument, and the recording disc which it turns round. The clockwork is regulated by the fly, and is connected with the recording disc by the shaft, to which it imparts motion by the friction of a small roller pressing upon its under surface.

When no current is moving in the line, the style rubs on the surface of the paper without producing any mark; but as soon as a current in the right direction is established, the salt solution with which the paper is saturated becomes decomposed, and leaves a blue mark upon the surface.

When the circuit of the current is made and broken repeatedly, a series of dots or dashes is imprinted upon the receiving disc, the lengths and succession of which depend upon the manipulation of the key or contact maker.

To render these dots and dashes intelligible, Bain has adopted an alphabetic code like that of Morse.

The paper is rendered sensitive by being saturated in a mixture of prussiate of potash dissolved in water, to which are added two parts of nitric-acid and two of ammonia.

An interesting rather than practical modification of this apparatus consists in substituting a revolving disc with style travelling in a spiral curve, exactly similar in form to that just described, at the sending station, for the key; only, instead of being covered with prepared paper, it is left naked, and letters or words written upon its surface, within the limits of the journey of the style, in some insulating material; so that, when the style passes over the insulating writing, the current is interrupted.

When both the discs are made to revolve synchronously, which is very difficult, it is evident that the paper at the receiving station will be marked with a dark spiral curve broken in just those places where the letter, written down on the transmitting dial, interrupts the passage of the current; and a facsimile of the writing will be obtained.

The same idea has been carried out, in a more convenient form, by the employment of short cylinders instead of the discs, on the sides of each of which are printers or styles running to and fro upon long screws as the cylinders are turned round.

But the apparatus by which Bain has earned most credit, is that with which Leverrier and Lardner experimented before the Committees of the Institute and Legislative Assembly at Paris. A band of paper, punched with groups of holes forming letters, conventional like those of the Morse alphabet, is passed between a metal roller and contact point in such a way that the point falls through the holes and comes in contact with the top of the cylinder, thereby closing the line.

The messages are received upon a strip of chemically-prepared paper passed between a style and metal cylinder.

Lardner thus describes his results* :—

"Two wires, extending from the room in which we operated to Lille, were united at the latter place so as to form one continuous wire, extending to Lille and back, making a total distance of 336 miles. This, however, not being deemed sufficient for the purpose, several coils of wire wrapped with silk were obtained, measuring in their total length 746 miles, and were joined to the extremity of the wire returning from Lille; thus making one continuous wire measuring 1,082 miles. A message, consisting of 282 words, was then transmitted from one end of the wire. A pen attached to the other end immediately began to write the message on a sheet of paper moved under it by a simple mechanism, and the entire message was written in full in the presence of the committee, each word being spelled completely and without abridgment, in *fifty-two seconds*, being at the average rate of *five words and four-tenths per second*. By this instrument, therefore, it is practicable to transmit intelligence to a distance of upwards of 1,000 miles at the rate of 19,500 words per hour."

The alarm used with Bain's telegraph consists of two round plates of glass of different sizes, struck by a hammer which vibrates between them. The glass discs are supported from their centres by two horizontal arms of an upright. The hammer consists of a vertical tongue of brass turning on a horizontal axis, and carrying, half-way up, a cross-bar of soft

* "Museum of Science and Art," vol. iii. p. 117.

iron, which serves as armature for the poles of an electro-magnet.

Bakewell's Copying Telegraph.—This is, properly speaking, only a better mechanical construction of Bain's electro-chemical telegraph.

A clockwork is supported between the plates M, M′ (Fig. 94), which puts the cylinder C in motion simultaneously with

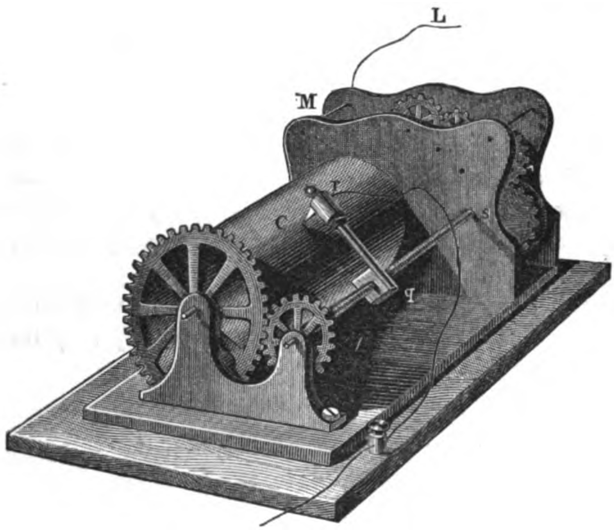


Fig. 94.

the screw S, of the same length as the cylinder, and carrying a nut, *q*, with style and connection, *r*.

When the cylinder is turned by the clockwork, therefore, the style travels up or down the cylinder according to the direction of rotation of the latter, thereby marking a spiral line whose convolutions are close together.

Bakewell used an electro-magnetic governor to attain synchronism in the movements of the two apparatus, without which it would certainly have been impossible to have obtained any dependable results.

100. Pouget-Maisonneuves, a native of France, writing in the *Comptes Rendues* in 1856, describes a method of electro-

chemical telegraph with which he proposed to supersede the Morse recorder. Instead of the style at the end of the printing beam moved by the electro-magnet, Pouget takes a simple fixed style, and records the messages by chemical decomposition instead of by embossing, thus dispensing with the printing magnet and beam: he, however, retains the relay and other arrangements of the Morse system.

His paper is prepared by being soaked in a mixture of—

150 parts crystallised nitrate ammonia;
5 „ ferro-cyan. potassium; and
10 „ water.

Before being used, the paper is moistened with dilute sulphuric acid sufficiently strong to make it conduct, but not to attack, the metal of the style. This paper is said to be cheap and easily prepared; the salts are easily decomposed and the traces permanent.

Gintl,* a German, in his method, dispenses with the relay, and records the messages on the prepared paper by the line current direct, in the same way as Bain.

His paper is prepared with a solution of—

1 part iodide of potassium and
20 „ starch paste, in
40 „ water.

The results of this process are very satisfactory, and recommend the apparatus as more convenient, in some respects, for long lines than Morse's. An experiment, on a line between Amsterdam and Berlin, made in 1853, with six Daniell's elements, gave very legible signals; and even with four elements the marks, although weak, were readable when no reliable signals could be read with a Morse.

The noiseless operation of the electro-chemical telegraphs may have assisted in keeping this method of recording out of more general use. It is always indispensably necessary to combine an alarm with the system, to call the attention of the manipulator; not so necessary with the Morse, which is,

* Brix's Journal, vol. i. p. 4.

in working, always accompanied by the rattle of the beam and armature. Another drawback from which the chemical

Fig. 95.

telegraphs suffer is in the want of an arrangement of translation which shall not, at the same time, weaken the current.

Otherwise the electro-chemical telegraphs are more convenient in manipulating, and much more simple and inexpensive as far as the apparatus goes, than the Morse.

101. *Bonelli's Chemical Telegraph.*—The Chevalier Bonelli has succeeded in the construction of a chemical telegraph by which messages are transmitted automatically, and facsimiles received at the station corresponding.

Bakewell seems to have considered the employment of one style as preferable to that of many; but he, nevertheless, mentions in his patent the possibility of using several. In the notice of his patent, published in the *Mechanics' Magazine*,* he says:—"Instead of one style for each cylinder, any convenient number may be employed, each isolated from the others, and fitted with separate wires having their ends inlaid in an ivory disc, so as to be isolated from each other."

The apparatus of Bonelli consists of a long stage or railroad on a table, as shown in Fig. 95, on which travels a waggon containing, on the left side of the lower half a box of raised metal types, and on the right side of the upper half

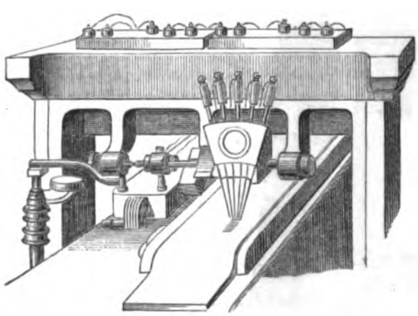


Fig. 96.

a strip of chemically-prepared paper. Over the middle of the railway is a bridge (shown on an enlarged scale in Fig. 96), under which the waggon has to pass when transmitting or receiving a message. A A′ are two buffers for receiving the waggon at the ends of its journeys. Just in front of the

* "Mechanics' Magazine," vol. l. p 544.

buffer A′, and level with the rail, is a hook, D, which engages with an eye at the upper end of the waggon, and holds it until a current traverses the line, and releases it by means of an electro-magnet.

On the left-hand side of the bridge, over the raised types, is a type-comb consisting of five movable teeth, insulated from each other, which are connected to the ends of five wires going to a similar number of styles at the receiving apparatus. As the waggon, with the types looking upwards, passes underneath the type-comb, the teeth come lightly into contact with the raised portions of the types, and close the circuits whilst the contact lasts. Thus letter after letter is transmitted. The right side of the bridge, which spans the middle of the rails, is appropriated to the reception of messages. It consists of a writing-comb composed of five teeth, made of platinum-iridium alloy, which is not liable to corrosion, insulated from each other, and pressing lightly upon the paper-strip. This comb would produce, if each tooth were traversed at the same time by an electric current, five lines something like the lines on music-paper. As, however, they are each only traversed by a current during the time some portion of a type is underneath the corresponding tooth of the type-comb at the sending station, they can only give lines at such intervals and of such length as is determined by the form of the type.

If the teeth of the type and writing-combs be equally far apart at each of the stations, and the waggons travel over the rails at the same speed, it is evident that a dotted, or rather lined, facsimile of the types on the transmitting waggon will be received on the paper carried by the waggon at the receiving station.

Any deviation from synchronism is, however, of very small importance, as the difference in one way or the other will only make the letters printed either a little narrower or broader than those of the fount from which the types have been taken, and in this consists the great advantage of the Bonelli arrangement over those of Bain and Bakewell.

C is an ordinary galvanoscope, and *m* a mercury trough, in which plunge five amalgamated contacts for short-circuiting the batteries when the type-box has passed through, and the prepared paper is going under the bridge. This is done by a catch on the waggon itself, which, passing by, turns the shaft carrying the five contacts.

The waggon when at rest is held at the top of the railway by the catch, which, being in communication with the electro-magnet, is released by the first current which passes through the line. This circuit is closed by means of the key, K. Thus the waggons of both stations are made to start together. They are impelled by similar weights, and their speed regulated by means of fans which enable the operators to adjust the two instruments to practical synchronism.

The waggons occupy from ten to twelve seconds in passing under the bridge. In this time, therefore, the message, set up in the type-box, is transmitted, and another received on the upper half on the prepared paper.

In the instrument shown in Fig. 95, the type-box passes first under the bridge; when the waggon has got half way, it short-circuits the batteries and leaves the line clear for the reception of a message on the paper on the farther half.

About twenty words are on the average set up in each type-box. Thus a speed of transmission and reception of twenty words in six seconds, or of two hundred words per minute, is easily attained, not counting the time lost in changing the type-boxes and removing the paper.

The paper intended for receiving permanent printing by the Bonelli instrument for distribution to the public, is prepared by being saturated in a solution of nitrate of manganese, which yields, under the action of the current, a light brown-coloured precipitate. That which is termed "fugitive printing," as for press work, by which the impressions are not necessarily of a permanent character, is done with paper prepared with a solution of iodide of potassium, which gives letters at first an iodine colour, but which in course of time lose their intensity.

The speed said by the operators to be attainable in permanent work is 300 words per minute, and the fugitive printing is stated to be got over at the almost incredible rate of 1,200 words in the same time.

The following facsimile of Bonelli printing is cut from a strip printed at the 1864 Conversazione at the Institution of Civil Engineers :—

BY THE BONELLI INSTRUMENT.

VII. Overland Lines.

102. The overland line wire, stretched between two stations, is suspended by insulated hooks from posts in the ground.

The first line of this nature, which was put to any useful purpose, was the double line-wire of Gauss and Weber, erected principally for researches into the laws of the galvanic current, between the physical cabinet and the Observatory at Göttingen, a length of 3,000 yards, suspended between the towers of the city and on cross-pieces on poles sunk in the ground. The insulation of the wire from the poles was effected by means of felt wrapped round the cross-pieces on which the wires were twisted. The insulation of this line was of course very imperfect.

The posts generally pressed into the service of the telegraph abroad are young firs (*pinus sylvestris*). They are selected from 25 to 30 feet long, and at the top seldom less than 5 inches diameter. The bark is stripped off and the posts smoothed, champhered off, and either impregnated or the lower ends charred up to about 8 feet from the bottom. Every tenth post is, or should be, a stretching post, stronger than the others.

The wooden posts mostly in use here are of English larch; but foreign timber, although dearer, is preferable on account of its greater durability.

Impregnation with a solution of sulphate of copper is the invention of a Frenchman, Dr. Boucherie. His process seems to possess important advantages over others, accomplishing as it does, at the same time, two essential objects—

that of expelling the sap, and that of filling the pores of the wood with the preservative solution.

In his experiments on the impregnation of timber, Dr. Boucherie has made the important discovery that no connection exists laterally between the tubes of a tree, and that by applying, under moderate pressure, a coloured solution to certain tubes at one end of a tree, the same tubes at the other end, and only these, are coloured. In this way, at one end of a felled tree, he applied a coloured solution to certain tubes forming the name "Faraday." The name was transmitted to the other end, and was perfect at every intermediate section.

When the tree is cut down and trimmed, a solution of sulphate of copper is forced into it from one end to the other by a moderate pressure. The sap and fermenting matter are thus expelled, and their place taken up by the solution. The small cost of the apparatus, ease of manipulating it, and the increased durability which it imparts to the wood treated by it, highly recommend the process. It is necessary, however, to take care that no ungalvanised iron comes in contact with wood so impregnated, otherwise the copper of the preservative solution will be reduced.

Chloride of zinc is also used in Germany with some success. The posts are put into wrought-iron cylinders of 4½ to 6 feet diameter, and 34 to 60 feet long, closed at one end, and covered at the other with tightly-fitting tops. The cylinders are provided with manometers, safety-valves, &c.; and connected with air and pressure pumps, and a reservoir of zinc-solution. The wood is prepared by being subjected to a great pressure of steam, which, penetrating into the interior, not only tends to displace the sap from the pores and prepare them for the preservative solution, but also to coagulate the albumen in the sap, and in this way to retard the subsequent rotting. After this the cylinders are exhausted, and immediately filled with a solution of one part of chloride of zinc and thirty parts of water, which is kept on, under a pressure of eight to ten atmospheres, for about three hours.

But it is questionable if this method is so good as that of Boucherie, as it is necessary to force the solution into the wood at right angles to its tubes, thereby injuring its strength and letting the sap, which is the immediate cause of decay, remain; the coagulation of the albumen in the sap, to any material depth below the surface, being a matter of doubt.

The method adopted by Sir Charles Bright is to have the poles well charred from the lower ends to a foot above the depth to which they are destined to be fixed into the ground, and the charred parts soaked in gas-tar for about twelve hours, the poles standing in tanks of tar, in a timber framing.

The sap ingredients being the prime movers in the rotting of dead wood, the idea has occurred to put up insulators on the stems of living trees—a method which has been found to answer well in Switzerland, America, and in some parts of Germany, where trees are to be found at convenient distances. The only drawback to this system is, the violence with which trees are sometimes moved in heavy storms. To obviate this difficulty, Lieut.-Col. Chauvin has constructed a swinging insulator, which will be described afterwards.

Wooden posts invariably decay first at the ground level—"the wind and water line"—where the surface is moist and in contact with the air. A method of retarding the decay by sheathing the post at this part has been tried in India with comparative success, the lower end, to a certain height above the ground, being covered by an iron casing. In Bengal such a line was erected, the posts being of large bamboo canes and the protection of the lower parts cast-iron sockets.

This brings us very near to a suggestion which has been much advocated—that of dispensing with wood, and conconstructing the posts entirely of iron, whose durability is so superior. The greater cost of such posts is the only objection to them.

Pillars of stone, or mason's work, would undoubtedly not only last longer, but would be less liable to accidents by violence of the weather. Such supports have repeatedly been constructed, but their cost has always been a bar to their further employment. In India, in the early days of telegraphy, many such pillars were erected, and in 1852 a line from Treviso to Tagliamento was entirely supported by obelisks 4½ metres high, as shown in Fig. 97. In Switzerland they have begun in good earnest the use of iron posts, the line from Olten to Sissach, lately erected, being supported entirely by iron posts. In Prussia also the necessity has been fully comprehended of discarding wood and taking to some more durable material. Mr. Borggreve has employed, on the line between Gera and Weissenfels, a pillar constructed of a wrought-iron tube, 1½ inch diameter, fixed with lead into a socket on the top of a freestone pillar, 6 feet high and 8 inches square.

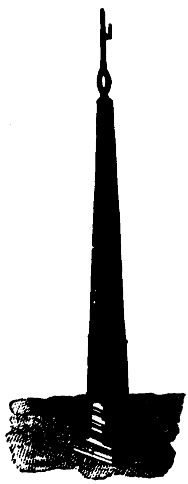


Fig. 97.

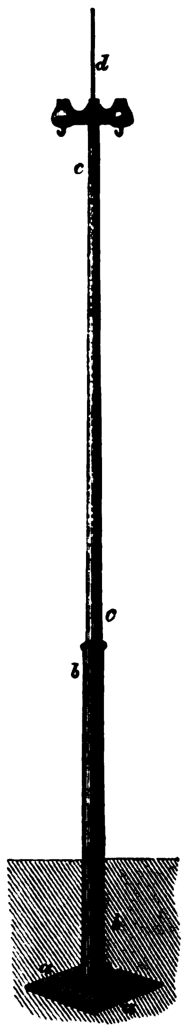


Fig. 98.

The iron post of Mr. W. Siemens is coming very generally into use abroad, and will no doubt find employment in England also, when the necessity of a durable post becomes thoroughly appreciated.

This post is formed of two tubes, one set upon the other, and the bottom of the lower one made fast to a bent plate of iron buried in the ground. One of them is shown in Fig. 98. The base consists of one of Mr. Robert Mallet's patent buckled wrought-iron plates, 1 foot 9 inches square, bent in a dish form. The buckled plate *a a* is secured by four bolts to the socket *b b*—a cast-iron cylindrical tube 7 feet long and 4 inches outside diameter. Near the top, inside, the socket is furnished with a flange, upon which the bottom of the upper or main-post, as it is called, rests. This upper post, *c c*, is of wrought iron with welded joints; it stands 12 feet high out of the socket, and is somewhat conical. At its upper end an iron ring is welded in to carry an iron rod, *d*, 20 inches long, forming the lightning guard. The stretching posts are of the same height, but of larger diameter and stronger than the ordinary ones.

Mr. Siemens' post derives much of its merit from the *rôle* played by the buckled plate at the bottom. These buckled plates are things of great engineering utility. They are squares of sheet-iron, which Mr. Mallet by a simple process presses into a form very slightly different, but endows them with a strength immensely superior; so strong indeed are they that if one of these posts were pulled up bodily out of the ground, it would bring up the superincumbent ground with it, and the buckled plate would not be deranged unless the bolts gave way; while the same piece of iron, as a simple sheet, would bend under a much less weight, offering no resistance worth speaking of against the strain.

There can be little doubt that, in course of time, only metal posts will be employed, on account of their superior durability, solidity, and freedom from damage by accidents. In some climates wooden posts require to be renewed every two or three years, and, in the most favourable, rarely last over six years; while an iron telegraph post is as durable as a lamp-post, and would certainly last ten times as long, and not cost five times as much as a wooden one; so that in the end an immense saving would be effected by their employment, although the first cost is so much greater.

103. *Line Insulators.*—Cook's insulator was the first used in England. It consisted of a body of earthenware the size and form of an egg, slightly flattened at the ends: the wire was passed through a hole in its longer axis.

Bright's insulator, used by the Magnetic Company, consists of a porcelain bell, Fig. 99, provided at the top with a notch for the reception of the line-wire, which is secured by a pin in a hole at right angles to it. One end of a bolt is cemented into a hole in the under-side of the insulator-cap, and by this it is secured to a cross-bar of wood screwed on to the post.

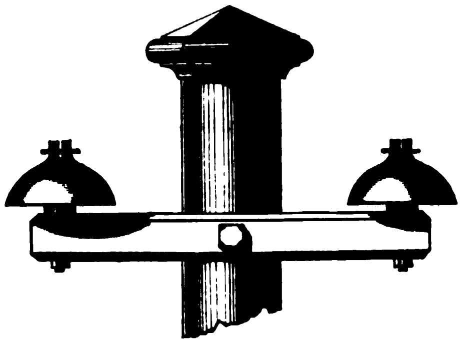


Fig. 99.

When a post has to carry a number of wires, the cross-bars are of different lengths, the longest being at the top, and each succeeding one shorter than the one above it, that, if a wire should break, it would fall clear of the insulator-caps beneath it.

In 1852, Siemens and Halske invented their bell-insulator, which is the strongest and one of the best-constructed supports. It consists of a cast-iron bell, *a a*, Fig. 100, with a flange, *b b*, by which it is screwed against the post. Inside the bell is cemented a porcelain cup, *c c*, ribbed inside and out to give a good hold to the cement. The cup, *c c*, in turn, carries the stalk or hook, *d d*, which supports the line-wire. The parts are put together, while hot, with a cement composed of sulphur and oxide of iron. As a further mode of insulation, the iron stalks or hooks are covered with vulcanite before

Fig. 100.

being cemented in; sometimes the porcelain cup is replaced by a cup of vulcanite. These insulators are a little heavy, but their superior solidity and insulation is ample compensation, the iron cap forming at once a perfect protection against injury and a screen against the deposit of dew on the porcelain.

In 1856 Mr. Clark patented an insulator in which he increased the length of surface of the porcelain over which the current escapes, without increasing its section. He attained this by a double bell formed in one piece. The insulator is supported by a stalk, D, Fig. 101, cemented into the interior of the inner cavity; the line-wire is carried through a deep groove on the top, and is tied to the bell by a binding wire.

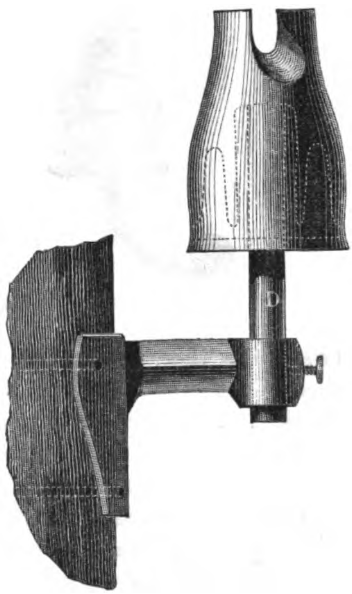


Fig. 101.

Lieut.-Col. Chauvin, Director of Prussian Telegraphs, has adopted this style of insulation for many of the lines under his charge. He has also made numerous experiments on the most favourable proportions between the length and section of the cups, and has given them a form differing slightly from Mr. Clark's only in an increased depth and narrowness of the inner cavity, by which the deposit of dampness from the atmosphere is still further guarded against, as well as the sudden cooling of the insulator bell.

Lieut.-Col. Chauvin has also constructed an insulator for attaching to the stems of living trees when these are used instead of posts for the support of telegraph lines. The insulator is hung upon a hook, free to swing about; and the stalk, or wire-carrier, bent in a curve away from the stem of the tree, that, when the latter is deflected by the wind, the line-wire, in swinging, may not come into contact with it. The hook Q, Fig. 102, held in the loop P of the bracket M M′, is

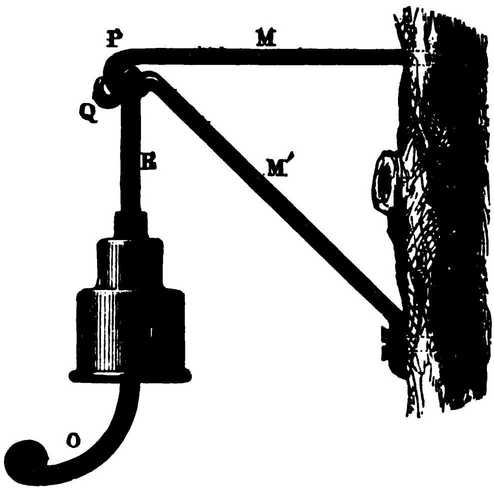


Fig. 102.

twisted so that, in case of a sudden jerk, the line cannot be thrown upwards and the insulator disengaged from the bracket. The carrier O is also bent over the wire, to prevent the line jumping out. The bracket is formed so that the insulator hangs quite free of the stem.

The Spanish insulator consists of a porcelain bell, *b*, Fig. 103, supported by a strap of hoop-iron fitting into the groove *g*, and screwed to the post. The line-wire is carried by a stalk cemented into the inner recess of the bell. The chief merit of this insulator is its cheapness. In climates like that of Spain it answers well enough, but would be utterly useless in England, where the atmosphere is always charged heavily with water vapour, which, condensing on the surface, would soon occasion a material loss of current.

Varley's insulator is that most commonly employed in England. It consists of two separate red-earthenware cups, *a* and *b*, Fig. 104, cemented together with sulphur. The outer cup *a* is provided with a groove to which the line wire is bound; in the recess of the inner cup *b*, a wrought iron bolt, *c*, is cemented, by which the insulator is attached to the bracket *d*, on the post. A further insulation is obtained by

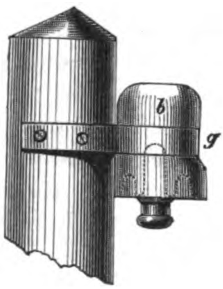


Fig. 103.

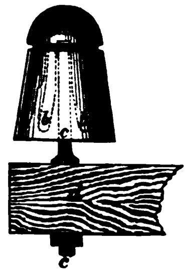


Fig. 104.

coating the stalk with vulcanite. The rim of the outer cup *a* is rounded off inside. The purpose of this is to avoid the sprinkling of the interior with rain-water, when a drop, hanging upon the bottom rim, is blown off by the wind. When a strong current of air separates a drop of water from a sharp corner, the drop is never carried bodily off, but bursts in the direction of the current. With the form given to the rim by Mr. Varley, however, when a drop happens to hang on that side from which the wind comes, it is driven a little way up between the two cups, and does not burst.

104. *Stretching Insulators.*—The weight of the wire in the space which it makes between two posts, assisted by the occasional pressure of the wind against it, causes it, after a time, to stretch and curve lower towards the earth. When a single wire is suspended, this is of no importance; but when several wires are supported between the same posts, by stretching, they are in danger of touching each other and causing interruptions of the service. To avoid this, the line is provided at intervals with insulators of larger and stronger make than the ordinary ones, to which the wire is made fast, thus giving, at intervals of half a mile or so, fixed points to the suspended line, while the intermediate insulator hooks

serve only to support it, without resisting any horizontal strain.

Siemens and Halske's stretching insulator is made with a stronger and larger cast-iron bell than the ordinary one. The porcelain boss or cup carries a stalk with two notches (Fig. 105), through which the wire is drawn and wedged on each side, leaving a loop between them. In cold weather, when the line contracts, this loop allows the wire between the posts to be slackened, and also, in case of a rupture, gives sufficient spare for making a joint.

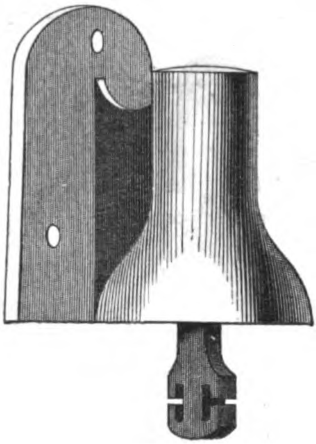


Fig. 105.

Kohl's stretching insulator is shown in Fig. 106. It is cemented upon the vertical bar or stalk *a* in its centre, and is turnable in the supporting bracket *b*, *b*', with the aid of a

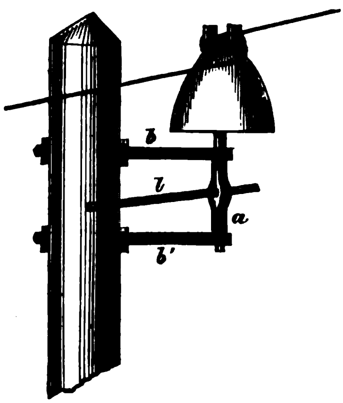


Fig. 106.

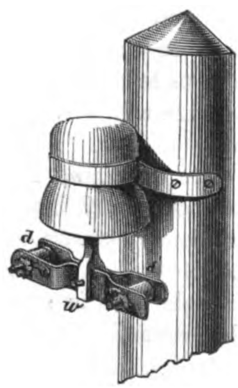


Fig. 107.

lever, *l*. The top of the porcelain bell is cut out in a deep groove, into which the line wire is placed and then bound up tightly by turning the lever. This insulator finds employment principally in Germany.

Another method of stretching with the insulator itself is by means of a wrought-iron winch, *w*, attached to the stalk, as in Fig. 107. The ends of the line wire on each side are passed through holes in the two drums *d d'*, and wound up tightly, the drums being prevented from running back by clicks and ratchet-wheels on their axles.

The Wire.—The line wires are of iron; very rarely of copper. The superior conducting power and durability of copper recommends it for employment, but the danger to which such a line is constantly exposed of being cut and the wire stolen is an argument against it. Were it not for this, a copper line would be much cheaper in the end than an iron one; iron having a comparatively small conducting-power, and, to give the same resistance for the same length, must have a section at least seven times as great as would be required for copper. This increased section increases, of course, the weight of the line, which, as a consequence, necessitates stronger posts and stronger insulators, in order to allow each wire to be strained tightly between the supports to keep it from touching the others.

Various plans have been proposed for coating iron wires in order to protect them from oxidation. The plan which has met with most favour in reward of its merits, is that of painting the wires with tar, or, as proposed by Romershausen, of varnishing them from time to time with a good coat of boiled linseed oil. By this method a thick crust is gradually formed, which protects the wire completely. The only objection to the process is its repetition, which renders it difficult in climates like that of England, for the painting can only be done successfully in fine weather.

The other methods consist of covering the wire with a coat of some metal which oxidises slowly. Zinc is frequently used for the purpose; it is applied by a process called "galvanising," by which the surface of the iron is covered with a thin film while the zinc is in a state of fusion. Dr. Siemens says that the "galvanising" of iron wire is only useful when the zinc is really melted together with the iron while the two metals are in contact under heat, which is the only security that the coating will not spring off or crack in bending the wire. When the wire is badly covered it rusts at those points most exposed to wear and tear, as at the points of suspension, just as soon as a naked wire. In the neighbourhood of manufacturing towns also, the best "galvanising" is of no use, as the sulphurous acid gas in the air quickly attacks the zinc, with which it combines, and the salt, washed off by the rain, leaves the iron exposed to the weather and the further action of the acid. In addition to this, the process of galvanising is said to alter the molecular structure of the iron and to render it brittle.

Instead of zinc, an alloy may be used, as proposed by Callan, which not only protects the wire against the attacks of acids and weather, but the coating is ductile and bends with the wire,—a condition essential to its success. The alloys which Callan tried and recommends are composed of one part of tin with from one to eight parts of lead.

A proposal has also been made by Mr. Bucklin, of New York, to dip the galvanised wires into molten copper or brass, by which means a protection, that may be increased to any required thickness by repeating the operation, can be obtained. This would be a cheaper way than that suggested by Professor Brix, the editor of the German *Telegraph Journal*—to cover a bar of iron in this way with brass or copper, and then to draw it down to the required guage.

Joints in land line wire are made by bringing the ends together and wrapping them with a binding wire, or by twisting them round each other.

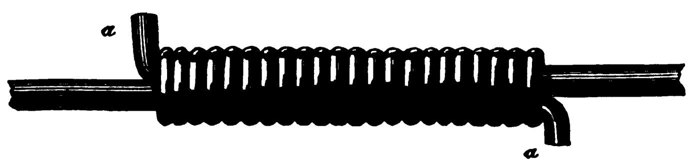


Fig. 108.

Figure 108 represents a joint made by the former method, called the Britannia joint. The wires to be joined are bent at right angles, about half an inch from the ends, as at *a a*.

They are then laid together and wrapped or bound with galvanised iron binding wire and soldered.

By the other method the two ends are laid side by side for about 5 inches, and each turned four or five times round the other, with a space between the two helices of about three-quarters of an inch. To make this joint, how-

Fig. 109.

ever, it is necessary that the wire should be quite soft at the ends, a condition which must be seen to beforehand. The ends are cleaned with emery paper or with a file, and twisted together by means of a lever arrangement made for the purpose. This consists of two bars of steel, *a a*

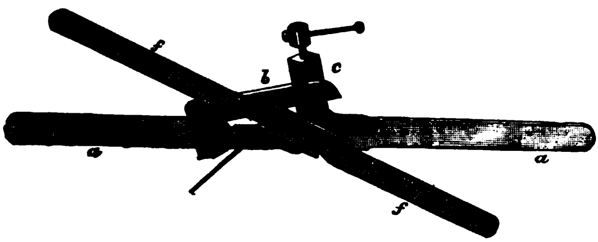


Fig. 110.

and *f f*, Fig. 110. In the middle of *a a* is a clip, *b*, with a vice-screw, *c*, for holding it down upon the wire. In the middle of *f f* is a block, perforated with a hole in the direction of the lever. The ends of wire to be joined together are laid into the half-circular cavity in the bed of the clip from opposite sides, each end projecting about 8 inches beyond the lever. They are secured in this position by screwing the clip down upon them by the screw *c*. The projecting end of one of the wires is then bent upwards at a right angle and put through the long hole in the block of the hand-lever. While one man holds the handles of the clip *a a*, another turns the lever *f f*, and with it the end of the bent wire, round the straight one as many times as its length will permit, keeping the hand-lever as close upon the joint as possible. When one end is completely twisted, the wires are taken out of the clip, the twisted part placed in the larger hole *d*, and screwed tight as before. The remaining end is then bent up at a right angle and twisted round in the same way. The complete joint, after being moistened with a solution of chloride of zinc, is dipped into tin-solder, care being taken that the solder adheres firmly to the wire and fills up all the spaces between the twists of the joints.

Erection of Overland Lines.—The erection of land lines embraces very little which affords scope for the display of anything beyond mere manual labour. The only work for the engineer is to point out where the line is to cross roadways and rivers, and when it is to make long spans and sharp angles.

When the line has been measured off and the materials distributed to different points, the posts are carried to their places for erection in the ground. It is sometimes preferable to affix the insulators to the posts before the latter are put up; but this depends upon the kind of insulator used. The posts are planted to a sufficient depth to give a firm hold—five or six feet for an ordinary wooden-post—and the earth well rammed down round it, with stones if they are to be had.

The posts which occur at angles, where a greater strain is exerted on them, are strengthened by stays or by struts.

The stays are of iron or of steel wire fastened by a ring or bolt to the top, or near to the top, of the posts, and to wooden pegs in the ground, fifteen or twenty feet from the post in the direction opposite to the strain which is to be counteracted.

The method of forming a strut by coupling two similar posts together is that preferred in France. The ordinary post has a notch about a foot below the top, on the side on which the strain is directed; into this notch is put the top of another similar post, planted about a foot and a half or two feet from the first one. The two are fastened together by an iron collar or by a bolt.

When Siemens' iron posts are used, they do not require to be planted so deep. The holes are dug about two feet and a half deep and two feet square, the bottom being levelled and rammed to make a firm foundation for supporting the buckled plate; and when the post is put up, the earth is rammed in, if possible with stones, above the level of the surrounding ground. In putting up these posts the lower tube, or socket, is first fixed, and afterwards the conical main, or upper tube, and the lightning guard.

This post is strengthened in points of unequal strain by means of stays. The stay consists of a length of steel wire held to the upper part of the post by a collar of wrought iron and looped at the lower end to a hook at the end of a stay-rod, attached to a plate of iron, buried in the earth at a distance of twelve feet or so from the post. The stay is tightened by pushing the iron collar up the post.

When the posts are erected and the insulators fixed, the wire is hung up and stretched. In open country the wire is coiled upon a drum mounted upon a carriage, and is paid out from post to post; but when the line is much obstructed by trees, etc., the coils of wire are set upon drums on three-legged stools.

Another arrangement for this purpose consists of a skeleton iron drum, one side of which is removable to admit of the coils being slipped on. The axis of the drum is hollow, for a pole to be put through it, that it may be carried by two or four men—one or two at each end of the pole. The end of the wire being made fast at starting, it is allowed to unwind as they walk along.

The wire is laid down along the line at the bottom of the posts, in which position it is examined and suspicious places repaired. The wire is made fast at one end, then lifted into the hooks of the insulators, or tied to the bells, according to their form, and stretched by means of the winch, shown in Fig. 111, made fast to the next ordinary post beyond the stretching post to which the wire is to be fastened. The end links of a chain are hooked on to the two vertical pins *a a*, at the sides of the winch, the curved frame between them and the foot *a′* resting upon the post. The wire is grasped by the "dutch tongs," or "devil's claw," *b*, attached to the leather strap *c*, which is wound upon the drum *d* of the winch by turning the handle *h*. A pair of pulley-blocks and line may be used for stretching, but the winch is more convenient.

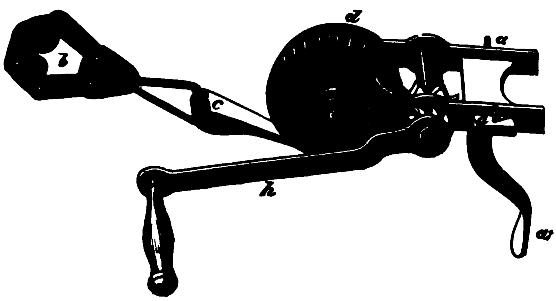


Fig. 111.

When the wire is sufficiently stretched, it is made fast to the insulator on the stretching-post, and the following length to the next stretching-post served in the same way.

Phenomenon of Charge in Overland Wires.—When a galvanic battery is connected to one end of an overland line, the other end being insulated, the wire becomes charged with electricity, whose tension depends upon the strength of the battery, just in the same way as a Leyden jar, or condenser, or submarine cable would under the same circumstances. The wire, stretched from post to post, forms the inner coating of a jar, the air acts as dielectric, and the earth, the neighbouring houses, trees, &c., form the outer coating.

Dr. Siemens has determined the distances of faults in overland lines by measuring the discharge currents. To determine the capacity of a jar formed by a line of telegraph, he erected, in the yard of his factory at Berlin, an iron wire, 121 metres long and 2 lines diameter, at an average height of 8 metres above the ground. The points of suspension were carefully insulated; one end of the wire was carried directly to the instrument with which the measurements were made, and the other insulated. In comparing the charge of this wire with that of a condenser formed by a glass plate, 1 millimetre thick and 2·25 square decimeters of coated surface, it was found that a length of 1 metre of the suspended wire had the same capacity as a plate of glass 1 millimetre thick, with 100 square millimetres or 0·0001 square metre coated surface; or that an English mile of wire would have a jar-capacity equal to that of a glass plate condenser of 1 millimetre thickness, with a coated surface of the 0·16 part of a square metre; or of such a plate, 1 metre long and 0·16 metre broad. Although the wire in this experiment was suspended much higher than is usual with line wires, the result cannot be far short of the truth, as the place where the experiment was made is in the immediate neighbourhood of tall buildings and trees, which also played their *rôle* in the phenomenon.

The Earth-plate.—A proper earth connection is as essential to the working of a telegraph line as the line itself. The earth connection is customarily obtained by a plate—some six or eight square feet—of sheet copper, buried in the earth at a depth that will insure it being always damp; it is connected with the apparatus by a stout insulated copper wire. In a large station it is well to employ several different earths parallel to each other. For instance, a wire soldered to the gas-pipe gives an excellent earth; a wire soldered to the water-pipe is still better. Both these give earth-plates of large surface, being connected with the gas and water mains of the town.

The want of a good earth connection can cause serious interruptions in the service.

In temporary stations, as for instance those in military service, difficulty has sometimes been found in burying the plates, and in getting other means of earth. Some of the Prussian and other military stations have therefore been supplied with earth posts which are more portable, and are said in the end to be cheaper than buried plates of metal.

The earth-post consists of a wrought-iron tube, 12 feet long and 1 inch outside diameter. The lower portion of the iron is covered with a copper tube, soldered to it to prevent an insulating coat of oxide being formed. To the extreme end is fastened a cast-iron screw, or bore, which is screwed into the earth; the upper end is surmounted by an ornament and lightning discharger, and is furnished with binding screws for receiving the wires leading to the apparatus.

VIII.—Atmospheric Electricity.

The experiments of Franklin, and various physicists since his time, have proved that the atmosphere is always more or less charged with electricity; that in some parts the charge is positive, in others negative. Accumulations of atmospheric electricity occur particularly in the clouds, which become charged in their formation, their passage, or otherwise, with high tension.

It is this charge of electricity which probably tends in a great measure to prevent the clouds falling readily in the form of rain. It is well-known that bodies charged with the same kind of electricity repel each other; and it must be the same with the water-particles of which a cloud is composed; when they are charged with electricity they repel each other, and this repulsion prevents them combining and falling to the earth. But when the electricity is discharged and the repulsion over, the water-particles are free to unite, and to descend to the earth in drops. This phenomenon we call a thunderstorm. It is the discharge and passage of such clouds which often prove destructive to telegraph lines and stations, and still more often disturb the regular service.

The most terrible effects are to be attributed to the electrical discharge into the line, or direct stroke of the lightning. This occurs when a charged cloud passes over and attracts, in the earth's surface immediately underneath it, the opposite electricity; and where points occur over the surface, or any object stands up high, these points and objects are charged with greater tension during the passage of the cloud. The induction between the cloud and the earth then resembles that of a Leyden jar, the dielectric being represented by the thickness of air intervening between the cloud and the nearest points above the surface of the earth. As soon as this thickness is so diminished that the tension of the electricity is able to overcome it, a neutralisation ensues in the form of lightning. The telegraph poles and line wires are especially favourable for the discharge of atmospheric electricity, being extended over an immense surface and offering numerous points.

As a cloud approaches, it induces an opposite charge in the earth's surface and in the line wire; this charge becoming greater and greater as the cloud nears the line. While this goes on, electricity of the same kind as the charge of the clouds is driven along the line in the form of a current to the earth-plates of the stations at each end. When the cloud is near enough, it discharges itself into the line, and, more than neutralising the electricity of the latter, leaves the line sometimes heavily charged with the fluid, which seeks the nearest road to earth. When the charge is very intense the lightning not unfrequently melts the line wire in its passage along it, and splinters several of the posts. Should it succeed in entering a station and reaching the apparatus, the usual consequence is that it melts the coils of the receiving apparatus, and perhaps shatters the station.

Schellen, who has written a beautiful chapter on this subject in his book,* says that the destruction of the posts is probably caused by the water, which during rain creeps into the numerous pores and cracks of the wood, being decomposed by the lightning, the sudden expansion following its conversion into gas bursting them asunder.

At times the earth plays no part in the discharge of the clouds. This is the case when two clouds charged with opposite electricities meet in the air and neutralise each other. A line of telegraph being underneath one of them is charged by induction, as we have already seen, in common with the surrounding earth's surface, although to a greater extent, with accumulated electricity. This charge does not change so long as the clouds remain tranquil; but

* Der Elektromagnetische Telegraph, p. 341.

the moment the discharge takes place the electricity with which the line is charged is suddenly set free and seeks the earth. It is not seldom that it takes its way over the posts and through the station, where, unless sufficiently protected, it does serious damage.

There are, of course, many ways in which the positions of the clouds and their motions, with respect to the direction of the line, modify the conditions of the current. The passage of the electric discharge between two clouds over the line is alone able to induce a powerful current, under certain circumstances, independent of the liberation of the static charge.

The remaining phenomena of atmospheric electricity confine themselves to the production of currents of more or less intensity in the line. These are also dangerous to the apparatus, but not to the same extent as the stroke of lightning.

These currents are produced in different ways. The atmosphere is everywhere electrical, either positive or negative; its electrical state depending partly upon the height above the surface of the earth, partly upon the hour of the day, and upon other causes of which our knowledge is limited. When a telegraph line runs through a region which, by reason of great difference of level or any other cause, at one end is positively electrical and at the other end negatively, the line taking the electrical tension of the atmosphere at all points, a constant current must pass through it so long as there are opposite electricities to combine in the circuit. Baumgartner, Henry, and others have made an especial study of this subject, and observed the phenomena under different conditions of height, weather, hour of the day, &c.

The passage of a single charged cloud over the line occasions sometimes also a considerable and long-continued current through the apparatus. As the cloud approaches the line it induces in it an opposite charge. To do this the natural electricity of the line must be decomposed; the electricity of the same kind as the cloud is repelled to earth through the apparatus, and a supply of the opposite kind fetched by the same road out of the earth, and held by induction. The one going to and the other coming from the earth form a single current. This continues as long as the cloud nears the line. If it stood still for any length of time the current would cease, but the line would retain its charge. As soon as it moves off, on the other side, the static charge of the line becomes gradually liberated, and endeavours to establish equilibrium with the earth through the coils of the apparatus and earth-plates. Then arises a current in the opposite direction to the previous one, which lasts until the electricity of the line is neutralised.

The last-mentioned phenomena are causes of annoyance rather than danger, but have been known frequently to interrupt the operations of an overland line for many hours in succession.

Atmospheric electricity is the great enemy of overland lines; and were it not for the protection which the present system of lightning-dischargers in some measure affords, it is probable that repeated sacrifices of apparatus, stations, and even the lives of the employés, would long since have compelled the rejection of the overland system and the adoption of the subterranean and submarine only. The latter are always free from danger, and can receive no injury from atmospheric electricity, so long as they are not in electrical connection with overland lines. When this is the case, and the latter are not supplied with lightning-dischargers, or they fail to do their duty, the lightning enters the insulated wire, and, bursting through the dielectric in its struggle to reach the earth, ruins the insulation in one or more places. This is always to be guarded against, particularly in dealing with long submarine wires, which may be irreparably injured by want of sufficient foresight in enabling the high-tension electricity to go to earth soon enough.

The way this protection is provided is by opening a way for the atmospheric electricity from the line to earth, which offers it less resistance, and which it therefore sooner strikes into than the legitimate circuit of the galvanic current.

105. *Steinheil's Lightning Discharger.*—Steinheil* seems to have been the first who supplied the receiving apparatus with an arrangement for protecting it from the effects of atmospheric electricity. The method of doing this probably was suggested to him from observing that sparks sprang over from convolution to convolution of the multiplier coils of the apparatus employed on the line between Munich and Nanhofen in preference to going through the whole lengths of the coils to earth. He concluded justly from this that atmospheric electricity which charged his line resembled, in its disposition to spring over short distances, the better known frictional electricity, and differed in this respect from galvanic electricity.

The behaviour of the two electricities is in no way more contrasted than in their choice of circuits. If, for example, a galvanic battery be inserted between the points *a* and *b*, Fig. 112, the same being already joined by the long spiral wire *w*, the whole current will pass through the latter and none will go over the space between *a* and *b*, however near they may be, if they do not make absolutely metallic contact with each other. But if, instead of the galvanic-battery, a charged electric-battery or Leyden jar be substituted, the inner coating, for instance, being connected to *a* and the outer to *b*, it would discharge itself immediately over the small space between *a* and *b*, and very little, if any, would pass through the coil *w*. Thus the way which for galvanic electricity offers an infinite resistance, is for static electricity a short circuit.

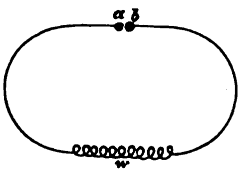


Fig. 112.

Steinheil based the construction of his lightning-guard on this physical law. Instead of bringing the two ends of the line wire into the station, he fixed each of them to a plate of metal 6 inches square, erected over the bureau in which the apparatus was contained. These two plates were insulated from each other by an intervening layer of silk-stuff, which offered an almost infinite resistance to the passage of a voltaic

* In 1846. Dingler's Journal, 109, p. 302.

current, but was at the same time so thin that a spark of static electricity of moderate tension could easily spring from one plate to the other. From the corners of each of the plates a conducting wire went to the apparatus below.

The whole was fixed on the roof by an insulated support, and, of course, protected by screens from rain and wind.

In the event of the passage of atmospheric electricity of high tension along the line on one side, for instance, it would spring over from plate to plate, rather than traverse the fine wire forming the coils of the apparatus, and would go on by the other line to the next station; Steinheil's intention being to conduct the high tension electricity along the line, and to allow the apparatus to escape.

106. *Meissner's Lightning Discharger.*—Steinheil's discharger had been constructed with the sole view of affording the static electricity a short circuit across the apparatus whilst the fluid passed in the same line circuit as the galvanic current, from end to end. Meissner introduced the method of conducting the electricity directly from the discharger to earth—a method much more in accordance with the nature of the electricity itself.

Fig. 113 gives a perspective view of Meissner's lightning discharger. The upper plate, A, is of copper, 8 inches long, 4 inches broad, and three-eighths of an inch thick;

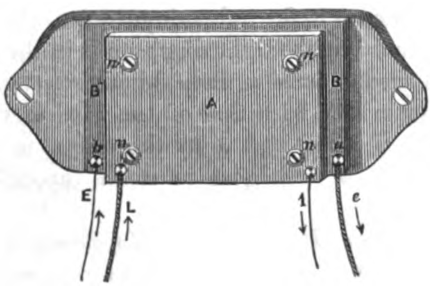


Fig. 113.

it is fastened to a second plate, B, of somewhat larger dimensions, by means of screws, *n n n n*. The two plates are, however, insulated from each other and from the coupling screws by the latter being contained in cylinders of ivory, and by the insertion of insulating rings of gutta-percha one-eighth of a line thick between the plates, outside each of the ivory cylinders. The coupling screws serve also to fasten the two plates to a base board, which is nailed or screwed against the wall.

The end of the line wire L is attached to the corner of the upper plate A, by means of a binding screw. From the opposite corner a finer wire, *l*, goes to one end of the wire forming the coils of the receiving apparatus; the other end of the coils is connected by the wire E with the terminal *b* on the plate B, which is put in communication with earth by means of a thick wire, *e*. The two thin wires *l* and E are covered with silk and are carried from the lightning discharger to the board twisted round each other. Should the tension electricity in the line, therefore, escape by any chance a passage across the plates A B, it will certainly pass from the wire *l* through the silk covering to the wire L, before it reaches the apparatus.

The galvanic currents from the sending station arriving by L, cross over the plate A to the wire *l*, by which they reach the apparatus; from the apparatus they come to the plate B, through the wire E, and, after crossing over B, go to earth by *e*. The intervening stratum of air between the plates offers an infinite resistance to the galvanic currents, which are therefore not weakened by the lightning guards in the circuit; but electricity of greater tension finds this air resistance infinitely small in comparison with that of the wire of the coil, and, therefore, on its arrival at A by the line L, it immediately springs over to B, and goes to earth through the thick wire *e*.

107. *Siemens and Halske's Plate Lightning Discharger.*—Fig. 114 gives a perspective view of a lightning-guard commonly supplied by Messrs. Siemens and Halske. Over a cast-iron plate, *a*, called an earth-plate, are placed as near as possible, but without making metallic contact, two smaller plates, *b b*, called conductors. Each plate has two screws for

attaching wires. To the screws f_1 and f_2 are attached the up and down line wires respectively; to the screws f_{I} and f_{II} the wires leading to the apparatus I and II; and, lastly, to the screw *g*, the earth wire.

The upper plates, *b b*, are kept in their places by small knobs, *c c*, fixed to them, and by the buttons *d d* on the

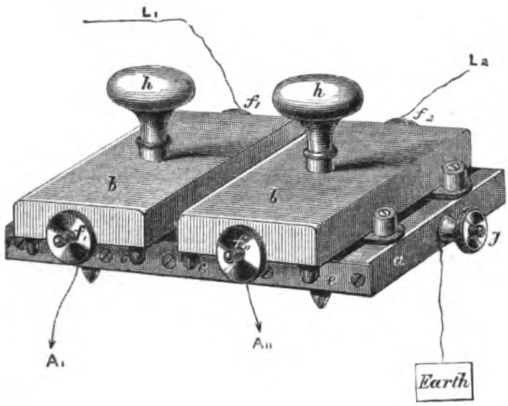


Fig. 114.

earth-plate. In order to prevent metallic contact, these buttons are covered with vulcanite, as are also the sides of the earth-plate.

The atmospheric electricity, on reaching the conductors springs over to the earth-plate, and thus escapes the apparatus.

Another form of lightning discharger used on the Continent, especially on railway lines, is a modification of the plate dischargers. It consists of three brass cylinders with platinum faces, supported in an insulating frame. The line wires are attached to the two end cylinders, between which the receiving apparatus is inserted. The middle cylinder is connected with earth.

108. *Bréguet's Wire Lightning-guard.*—An excellent idea was carried out by Bréguet in the construction of his first lightning discharger, in the employment of the power of the spark to melt a fine wire, and of making the lightning itself cut

the apparatus out of circuit and save it from injury in its own endeavour to force a passage through it. He was first reminded of the necessity of protecting the instruments from the effects of atmospheric electricity, by an accident which happened to the apparatus at the Vesinet station, on the 5th May, 1846, when all the wires were fused and the apparatus rendered useless.

His *paratonnerre* consisted of a piece of fine wire, fifteen to twenty feet long, which he carried from the apparatus to the termination of the line outside the telegraph bureau. The insertion of this fine wire in the circuit did not appreciably weaken the current by increasing the resistance of the line, and when a stroke occurred the electricity melted the wire on leaving the line before it could reach the apparatus.

109. *Fardley's Lightning Discharger.*—Fardley combined both the systems of discharging between plates of metal and of melting a fine wire, for better security for protecting a line of 65 miles, in 1847.

He divided the line wire at the station and brought the ends within a distance of half a millimetre of each other at the side of a stout wooden post, which supported also a wooden roof to shield the ends from wet and dirt, instead of inserting plates of metal in the line, as Steinheil and others had done. To each of the parts of the divided line he joined some twenty feet of fine metal wire, which formed the leading wires to the apparatus. The line on either side, if struck by atmospheric electricity, would then, in all probability, discharge itself across the small space between the divided line wire to the line on the other side; but, should this not be the case, and the fluid find its way along either of the leading wires, the wire would be fused before the electricity could reach the apparatus. The leading wires also terminated in a commutator, by which the operator, during a thunderstorm, could cut the apparatus entirely out of circuit, establishing at the same time another connection between line and earth whereby the line circuit remained entire.

110. *Nottebohm's Lightning Discharger.*—Nottebohm has constructed and introduced a lightning discharger for use on

the Prussian state telegraph. It consists of a double cone, supported by a stout metal bar, in connection with the earth. The points are in close proximity with the points of two metal cones, which are supported on a common base, and severally connected with the lines, and also with the two ends of the wire coils of the receiving apparatus. When the line contains free static electricity, the latter springs from the cone on the side on which the line is struck to the little double cone in the middle, and thus avoids the apparatus.

111. *Siemens and Halske's Point Lightning Discharger.*—A lightning-guard of beautiful construction, for protecting submarine wires which are connected with overland lines, is used by Messrs. Siemens and Halske, which, while sufficiently serving the same purpose as those already described, has the advantage of being fixed upon the instrument board, where no difficulty can arise in mounting it, and any disorder in which it may get will be more readily discovered. It is formed of a cube of brass connected with the earth, to three sides of which are presented sharp points of metal protruding from an arch in the circuit of the line wire. The brass prism is faced with three metal plates, carrying agate cones on the top and on each side under the arch. The purpose of the agate cones is to prevent the points being adjusted too close to the earth-block. The points are formed by three screws, the axes of which lie in the same plane, one running vertically through the top of the arch and the other two horizontally on opposite sides. Within each of the screws, along its axis, is a second screw of small diameter, terminating in a conical point of platinum.

112. *Bréguet's Lightning Discharger.*—Bréguet has constructed another lightning discharger, now used on all the French lines, in which he increases the means of discharging the static electricity from the line by increasing the number of points over which it can pass, and diminishing the resistance to its passage. For this purpose he arranges two plates of copper insulated from each other upon a common board. The opposite edges are cut out in the form of sharp teeth, so that the point of each tooth on one plate is opposite the

point of a tooth of the other. The plates are put as near to each other as possible without any of the teeth making contact with their neighbours opposite. The two line wires are attached to the plates by means of binding screws. A

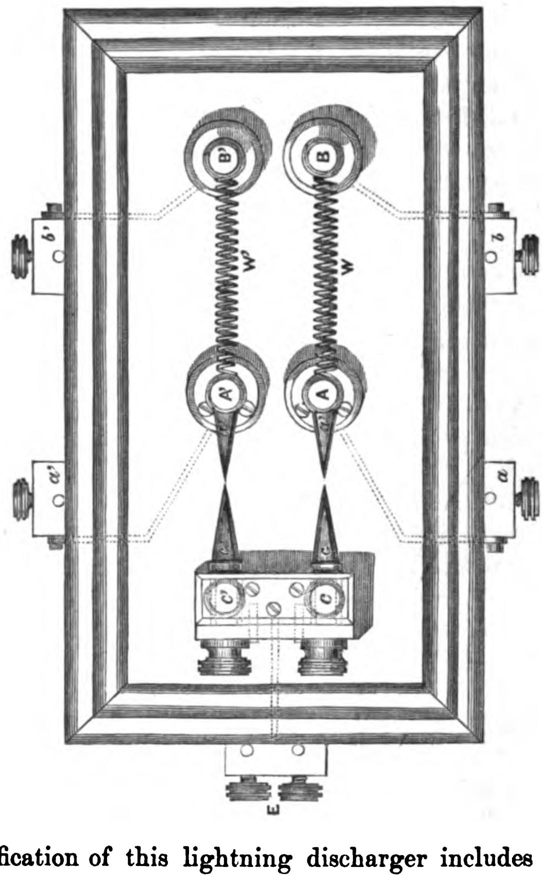


Fig. 115.

modification of this lightning discharger includes both the arrangements of Bréguet—the saw teeth and fine wire.

113. *Lightning Discharger of the Prussian and Austrian Telegraph Lines.*—This is described in detail in Brix's Journal. It is on the points principle, and is arranged for being placed on the instrument board. From a bar of metal, c, Fig. 115, on the left-hand side, project two points,

c and *c*′, with adjusting screws. Opposite these points are two similar ones, projecting from the terminals A and A′, which are connected by the spirals W and W′ with B and B′, respectively. On the margin of the board are five terminals for receiving the wires of lines, apparatus, and earth; the bar C is connected by a wire underneath the board, shown by dotted lines in the figure, with the back terminal E, destined for the earth connection; the terminal A is similarly connected with *a* on the one side, and A′ with *a*′ on the other; B and B′ are also in permanent connection with *b* and *b*′ on opposite sides. The two line wires are brought to *a* and *a*′, and the apparatus is inserted between B and B′.

114. *Kerckhoff's Lightning Discharger* includes arrangements for discharging the line both between surfaces and points. A hollow brass cylinder, supported by a bracket, is in permanent connection with earth. Inside the cylinder is a second metal cylinder, insulated from it by short ivory tubes at the ends, and held in its place by the screw-points. The annular space between the cylinders does not exceed one-fourth of a line, so that electricity of moderately low tension can easily spring over. The line wire is connected with one of the two terminal screws of the inner cylinder, and the wire leading to the apparatus with the other. The outer extremities of the screws are furnished with points by which, should the electricity fail to leap over the annular space between the cylinders, it will in all probability discharge itself to the opposite points on two screws connected to earth through their uprights and the common base-plate.

115. *Bianchi's Vacuum Lightning Discharger.*—Du Moncel describes this apparatus, which is of a novel but somewhat inconvenient construction. It consists of a brass globe inserted in the line circuit, covered and protected by two hemispheres of glass cemented into a broad metal ring, which is provided with radial spikes pointing inwards to within a very short distance of the surface of the globe. The latter is held in its place in the centre by an axis passing air-tight through the poles of the glass hemispheres

and ending in terminal screws. A tap is also inserted in the copper ring, through which the air is pumped out. The ring is supported by a metal plate at the back, connected to earth, and by which the lightning discharger is fixed against the outside of the building.

The foregoing are some of the best arrangements invented as yet for protecting the apparatus from the effects of atmospheric electricity. They all, in a more or less complete degree, fulfil their purpose, but none with entire certainty, as we from time to time observe in the damaging effects of a thunder-storm to the apparatus at stations which are supplied with dischargers of the best constructions. On other occasions, however, the dischargers do their duty in saving the stations and apparatus from serious damage. Such a case was mentioned in the *Electrician* in a letter from one of the officials of the Levant submarine telegraph line. The writer says that a heavy thunderstorm, passing over the Island of Metelin, completely destroyed eight poles, and was only prevented from going into the cable by a plate lightning discharger, the iron plates of which were fused together.

PART II.

ELEMENTS OF THE SCIENCE AND PRACTICE OF ELECTRIC TELEGRAPHY.

I. Origin of the Galvanic Current.

1. Any piece of metal, when partly immersed in a liquid, according to Pfaff's experiments, becomes polarised — the part above the liquid being negative, and that in the liquid positive. The strongest polarisations are those set up by zinc and tin in solutions containing free nitric or sulphuric acids; therefore zinc and tin are termed the most powerful electro-motors. The polarisation of the metal, a piece of zinc for instance, is communicated to the particles of the liquid which tend to arrange themselves in order according to their component atoms: thus, if the liquid be pure water, each of whose atoms is composed of one atom of hydrogen and one atom of oxygen, these atoms of water will probably so arrange themselves that the oxygen and hydrogen sides will stand alternately with regard to the zinc; for, according to Grotthuss, the atoms of oxygen and hydrogen composing the water are held together by electricity, the oxygen being negative and the hydrogen positive, to such a degree that they exactly balance each other, and produce no free electricity. This idea is shown in Fig. 117 with five neighbouring atoms of water, of very exaggerated dimensions of course.

The electro-motor is partly plunged into the water. It becomes polarised; the part immersed is positive, and attracts the negative or white components (the oxygen) of the atoms of water immediately in contact with it, repelling the black component (the hydrogen) which is positively electrified. The black, or positive component of atom No. 1, in its turn, attracts the white side and repels the black side of atom No. 2, and so on through the whole mass of the liquid.

Let us now suppose another plate of a different metal,—a good conductor, but a less powerful electro-motor than zinc, say copper,—similarly immersed in the liquid at a little distance from the first plate.

On entering the liquid its natural tendency is to polarise the atoms of water between itself and the zinc in the reverse direction to that done by the latter; and it would do so if it were as strong an electro-motor as zinc, and would depolarise all the atoms already polarised by the

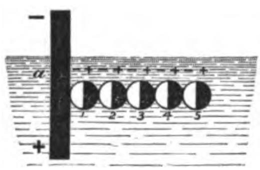


Fig. 116.

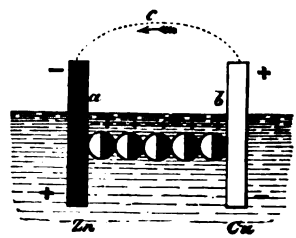


Fig. 117.

zinc. But not being so powerful an electro-motor, the feebler polarisation which it takes itself and tends to communicate to the atoms of water is overpowered by the stronger polarisation of the zinc, and they retain nearly the position given them by the latter. The black or negative sides of the atoms all face the copper plate, and induce a negative state in the part below the surface, while the natural electricity of the copper, being decomposed, its positive component takes refuge in that part which is above the surface of the liquid. An electrometer of sufficient delicacy, brought to the upper end of *a*, would indicate a negative tension, and in contact with *b* would show a state of positive tension. This is what is called the open circuit. If we close the circuit by connecting the upper end of *a* by a wire, *c*, with the upper end of *b*, a combination of their opposite electricities takes place in consequence. *The positive electricity goes from the copper pole to the zinc, and the negative from the zinc pole to the copper, outside the element.*

At the same time the component atom of oxygen is separated from the first atom of water and combines with an atom of zinc; the atom of hydrogen of No. 1 combines with its neighbouring atom of oxygen of No. 2; the hydrogen of 2 with the oxygen of 3; and so on, until the copper plate is reached, where an atom of hydrogen is liberated and, being positive, is attracted by the copper. The oxygen liberated from atom No. 1, combining with the more powerful electro-motor, zinc, forms oxide of zinc; and the hydrogen liberated at the copper collects on the plate in the form of gas until the bubbles are large enough to rise to the surface of the liquid. An essential condition to the formation of such an element is, therefore, mobility of the medium in which the plates are plunged. Were they, for example, contained in dry ice, or water in a solid state, no electro-motion could occur.

The polarisation of the atoms of water depends upon the difference in the degree of polarisation of the zinc and copper plates; and the rate of transfer of the atoms, or the galvanic current, depends upon the affinity of the more powerful electro-motor for the liberated oxygen.

The oxidation of the zinc plate is therefore a measure of the current as is also the volume of hydrogen liberated at the copper plate.

The hydrogen liberated at the copper plate collects here by degrees until it totally covers the immersed surface, attracted to it by its opposite polarity. Now Buff has proved that hydrogen is more positive than zinc; the consequence is that, after a time, the positive polarity of the zinc plate is opposed on the other side of the element by the greater positive polarisation of a large surface of hydrogen gas. The atoms, 1, 2, 3, &c., cease, therefore, to arrange themselves with the same tension in the order shown in the sketch, and the combination of the oxygen atoms with the zinc is retarded. The current of such an element, therefore, becomes gradually weaker from the moment of closing the circuit until the maximum collection of hydrogen gas on the copper plate is attained.

2. The current of a galvanic battery manifests itself in various ways, by some of which we are enabled to measure its intensity and to study its relations under different conditions.

The most important of these manifestations are: its production of light, its property of heating bodies, its physiological, its chemical, and its magnetical effects.

At the moment when the poles of a single pair of plates of large surface are separated, the experimenter observes a beautiful bright spark pass between them. If the poles have been amalgamated beforehand, the spark is very intense. This is, on a small scale, the celebrated electric light. By taking forty or fifty elements of large surface and high electro-motive force, such as the platinum-zinc battery of Mr. Grove, or the carbon-zinc battery of Robert Bunsen, having first furnished the poles of the system with carbon points, if we touch these points together for an instant and then separate them, we have an electric light too brilliant to be regarded, without danger, by the naked eye. By separating the points steadily for a short distance, the particles of carbon are built into a bridge by the current through which it circulates, and keeps it incandescent with a peculiar brilliancy until it is broken.

The heating power of the current may be observed with an element of large surface by inserting between its poles a short piece of platinum wire, which becomes, in a few moments, red hot. A battery of thirty Bunsen's elements easily melts pieces of platinum and of every other metal which are brought between its poles. So great indeed is the heat known to be generated by the galvanic current, that it has even been attempted to gasify carbon by it.

The physiological effects of the galvanic current were first observed by Sulzer and Galvani, and led to the discovery of galvanism. The experiment published by Sulzer of putting a piece of zinc under and a piece of copper upon the tongue, and letting them come into contact with each other, is the simplest arrangement by which we become acquainted with this effect. When the poles of a battery of a number of elements are taken hold of in the hands, the latter being moistened, a very unpleasant sensation in the arms and chest is felt whilst the current continues, and a still more unpleasant one when the circuit is interrupted and re-made. This effect is said to have been often used with advantage in medical cases, and has been employed in some highly interesting experiments with dead bodies, members of both human and brute creation.

A use to which the practical electricians of the gutta-percha factories put this property of the galvanic current is in the detection of faults in insulated wires. For this purpose the wire is connected at one end with one pole of a battery, the other pole of which is to earth. The further end of the wire is insulated. The wire is then drawn through a wet sponge or cloth held in the hand of a workman. The moment a bad place passes through his hand the water enters the fault, closes the circuit of the battery through the man to earth. Notice of the fact is given unfailingly when the battery is strong enough.

The epidermis is a little insensible to the action of the current, and becomes quite so after repeated shocks; but the tongue and wounds in any part of the body are highly electroscopic.

The physiological effect of the current has, we believe, only once been enlisted into the ranks of the telegraph. In 1839, Vorzelmann de Heer carried out a telegraph in which the operator received the signals in his fingers. Ten leading wires connected the corresponding stations. At the receiving end the operator placed his fingers and thumbs upon the ten metallic terminals of the lines. The signals were given by sending currents at the same time through two of the wires, and were observed—

(*a*) in one finger of the right hand and one finger of the left; or
(*b*) in two fingers of the right; or, lastly,
(*c*) in two fingers of the left hand.

To the remaining two effects of the galvanic current—the chemical and the magnetical—we are indebted for the opportunities which we have of measuring and studying more intimately its laws.

To the chemical effects, besides the galvano-plastic art and all the ramifications of industry which it has been the means of introducing, we owe the decomposition of water and the discovery of many of the metals.

The decomposition of water, made by M. Sömmering the basis of his telegraph, has been found to be a just measure of the current producing it, and has therefore been used as such. The decomposition of salts is employed in the chemical telegraphs of Gintl, Bonelli, and others, and promises to come ultimately into more extended use.

The magnetic effects of the galvanic current are manifested in the deflection of a magnetic needle suspended near a wire in which a current is moving; in the magnetisation of a soft iron, when a current circulates round it; and in the induction of currents in close circuits in the neighbourhood of a current, at the moment of its appearance and disappearance.

3. *Galvanic Batteries.*—Cruikshank remodelled the pile of Volta, and gave it the form of a trough divided into several compartments, each of which contained a pair of zinc-copper plates immersed in dilute sulphuric acid, instead of the cloth discs moistened with acidulated water, as in Volta's pile.

Wollaston improved this form of battery, first, by entirely surrounding each zinc plate by the copper plate, and secondly, by making it a plunge battery, the electro-motors being arranged at distances along a non-conducting bar, which, when lowered in its frame, plunged each of the plates into its proper vessel of acidulated water. These elements had a considerable electro-motive force when first set up, but went down very soon afterwards, through polarization of the copper plates, by the hydrogen gas collecting on their surfaces.

Many other improvements have been made in the forms of zinc-copper elements, the chief of which are those of Sturgeon and Daniell. Sturgeon recommended the use of amalgamated zinc as being more electro-positive than common zinc, and only dissolved when current passes; and Daniell succeeded in constructing a battery of more constancy than those hitherto employed.

4. *Daniell's Constant Battery.*—The principle of the electro-motive combination arrived at by Professor Daniell, as giving the best results, consists in immersing each of the electrodes or metallic plates in a different solution, by which the polarisation, rendering the working of the previous piles of so short duration, was in a great measure prevented; the element retained its electro-motive force for a longer period, and thence obtained the name, not absolutely correct, of a *constant* battery.

To prevent their mechanical mixture, the solutions in which the plates are placed are divided from each other by a porous diaphragm, whose pores are not so close, however, as to prevent the necessary transfer between the atoms. In the earlier forms of his battery, Daniell employed a diaphragm of ox-bladder; but this has been long since replaced by a cylinder, or vessel of unglazed porcelain.

A very ordinary form of Daniell's element at present in use is the cylindrical. The copper-plate is bent round to fit inside a cylindrical porous pot, filled with a saturated solution of sulphate of copper. A cylinder of amalgamated zinc is placed between the porous pot and outer glass vessel in a space filled with dilute sulphuric acid. Crystals of sulphate of copper are kept in the inner chamber, to insure the necessary degree of concentration, and for this purpose the copper cylinder is sometimes partly closed at the bottom to form a cup to contain the crystals. The dilute sulphuric acid in which the zinc is immersed contains usually about five per cent. of commercial sulphuric acid. When these elements are used in numbers, in the form of a battery, the copper cylinder of one element is generally connected permanently with the zinc cylinder of its neighbour, by casting the zinc on to a continuation of the copper plate. This saves trouble, and avoids the danger attending the coupling of the elements by metallic binding screws, from oxidation of the ends, or loosely made connections.

When the current passes the zinc is dissolved, and the copper receives an equivalent increase in weight. In the chamber containing the zinc and acidulated water, the oxygen of each atom of water decomposed unites with an atom of zinc, forming an atom of oxide of zinc, which in its turn combines with an atom of sulphuric acid, forming sulphate of zinc, which is dissolved in the water. The atom of hydrogen released is transferred, by means of decompositions and recompositions, towards the copper cylinder. In the interior of the porous pot an equivalent atom of sulphate of copper is decomposed into one atom of copper, one of oxygen, and one of sulphuric acid. The atom of copper is deposited upon the plate by the current; the atom of oxygen, moving towards the zinc plate, meets the atom of hydrogen travelling from the other compartment of the element, and combines with it, forming together an atom of water; while the atom of sulphuric acid goes to the zinc compartment to renew the supply there for the formation of sulphate of zinc, as that metal is dissolved.

When the circuit of such a battery is kept closed for a length of time without addition to its constituents, the sulphate of copper in the porous pot becomes all decomposed, and the water in the concentric chamber saturated with sulphate of zinc. In such a state it is evident that the advantages of the system are lost; the hydrogen liberated from the water, not meeting with the oxygen liberated from the copper salt, polarises the copper plate, and lessens the electro-motive force of the element.

The periodical addition of crystals of sulphate of copper, however, keeps up the saturation of the water in the inner vessel, and, consequently, the constancy of the element. But the water in the outer vessel should never be allowed to get too saturated.

A great inconvenience is always found in these elements arising from the deposit of metallic copper at the bottoms and on the sides of the porous pots. Sometimes, after a battery has stood unused for a while, the porous pots are found to be completely impregnated with metallic copper, filling up their pores, and forming short circuits between the solutions, reducing thus the action of the elements to almost nothing, while the consumption of zinc is, at the same time, increased.

This deposit of metallic copper is not the result of galvanic action, but of cementation. It would not occur if the plates were made of pure metal. As the common zinc is dissolved in forming the currents, the particles of iron and other metals mixed with it, fall to the bottom, and separate the copper from the solution of its salt as the latter comes through the pores of the diaphragm. A small local element is thus formed which goes on reducing the metallic copper and adding to the bulk of the deposit.

The method suggested by M. Place which is now employed to lessen this damaging effect, is to saturate the bottoms of the porous pots to the height of a quarter of an inch with hot wax or parafine, and, in setting up the battery, to fill the dilute sulphuric acid into the elements four or five hours before putting in the sulphate of copper solution. The pores of the pots become well filled with acidulated water before the sulphate comes into contact with them. No precaution can, however, entirely prevent this detrimental property.

Another cause of inconstancy in the action of Daniell's element arises from the solution of copper entering the chamber appointed for the solution of zinc. When this occurs the trespassing copper is precipitated out of the sulphate, and adheres to the zinc cylinder, the colour of which changes to red and black, and its electro-positive condition becomes weakened. The electro-motive force of the element is lessened in proportion as the copper covers the surface of the zinc; and the quantity of sulphate of copper and metallic zinc consumed represent a much greater strength of current or length of time that the circuit has been closed, than the operator has really had the benefit of.

Both these processes of destruction of the element take place faster during the time the circuit is open than when it is closed.

5. *Kramer's Modification of Daniell's Battery.*—Kramer has had these difficulties in view, and has succeeded partly in overcoming them by interposing, between the zinc and copper plates, two porous diaphragms, the space between them being filled with diluted sulphuric acid, and containing a copper plate of large surface in connection with the ordinary copper plate of the element.

The duties which the copper plate has to fulfil in the ordinary form of Daniell's element are in this way divided, the interposed copper plate acting, principally by reason of its large surface and proximity to the zinc plate, in conducting the current from the other elements when set up with others in a battery; while the other copper plate, immersed in the salt solution, fulfils mainly the functions of a copper electro-motor for the element itself.

The interior copper cup is first filled with crystals of sulphate, and then all three compartments are filled up to within an inch of the top with sulphuric acid diluted with 100 times its weight of water. The distance of the sulphate of copper from the zinc plate being considerable, little or none of the salt can reach it, and hence little or no loss of materials can take place by diffusion.

6. *Meidinger's Modification of Daniell's Battery.*—Professor Meidinger has introduced a still bolder modification of Daniell's battery, in which the members are so differently arranged as almost to claim the title of an original invention.

Instead of separating the solutions of the sulphates by a porous diaphragm to prevent their mechanical mixture, Meidinger depends wholly for their separation upon the difference of their specific gravities, by which the detrimental precipitation of metallic copper upon the zinc pole is prevented. A condition is, however, necessitated in the employment of Meidinger's element, which is not in that of any of the others; it is that, when once set up, the battery must remain entirely undisturbed, otherwise the evil which it is proposed to obviate is only increased.

Meidinger's element is set up in a cylindrical glass jar, A A, Fig. 118, on the bottom of which is cemented a glass cup, *d d*. The diameter of the outer vessel is larger above than below, being provided, at about a third of its height from the bottom, with a shoulder, *b b*. A cylinder, Z Z, of amalgamated zinc, sits upon this shoulder, and is of such dimensions as to fit comfortably into the upper part of the vessel. The interior of the cup *d d* is covered similarly with a cylinder, *e*, of copper, to which a copper wire, *g*, insulated with gutta-percha, is attached, and leads out of the element. The glass vessel A A is covered by a wooden disc, provided with a hole for the wire *g* to pass through, and one also for a glass tube, *h*, formed like a test-tube, pierced at the bottom with a few small holes. The glass tube *h* is fixed in the centre of the wooden cover, and reaches to about half-way down inside the cup *e*.

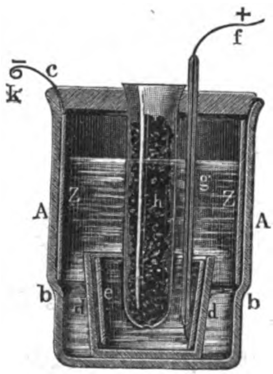


Fig. 118.

The element is charged by filling it to the top of the zinc cylinder with Epsom salts solution, and the tube *h* with crystals of sulphate of copper. The sulphate of copper dissolving, saturates the water containing Epsom salts, and the solution being specifically heavier, descends through the hole at the bottom of the tube into the cup *d d*, which it about half fills.

So long as the element remains unshaken, the fluids retain their respective places, and the diffusion of the sulphate of copper into the solution of sulphates of zinc and magnesia above takes place so slowly that, after a battery has stood a month or two, scarcely a trace of copper is to be observed on the zinc ring. Further, a great advantage is offered by the circular space between the cup *d d* and the sides of the vessel A A, into which the particles of iron and other foreign metals, divided from zinc, fall without coming into contact with the sulphate of copper.

The chemical action being identically the same as that of a common Daniell's element, the electro-motive force is necessarily the same. The resistance of the element is, however, a little greater, resulting from the inferior conducting power of the solution of Epsom salts, and the distance which the plates are apart; but even for local batteries this resistance does not interfere materially with its applicability to telegraphic purposes.

7. *Siemens and Halske's modification of Daniell's Battery.*—MM. Siemens and Halske of Berlin have set themselves the same task as Meidinger and others, and have produced the battery which bears their names, the constancy of which has been tried for some years, and found to answer their expectations.

These inventors directed their attention particularly to the improvement of the diaphragm, and sought for some substance which would prevent the mixing of the solutions and the unnecessary consumption of zinc and sulphate of copper. The substance recommended by them is paper-pulp. An element constructed with this material for a diaphragm is shown in section in Fig. 119.

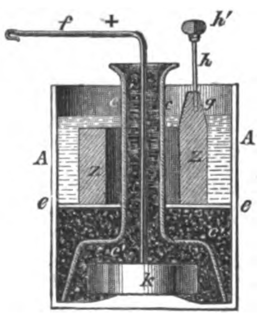


Fig. 119.

A A is a glass jar, at the bottom of which is placed a cross of sheet copper, K, attached to a copper wire, *f* +, and over this a tube, *c c*, of unglazed porcelain, the lower part of which is widened out bell-fashion at *c' c'*. Between the porous bell and the glass vessel, the paper-pulp is put to the height *e*, well stamped down.

The papier-maché as obtained from the paper-mills is prepared first by being well pressed, then treated with a quarter of its weight of English sulphuric acid, which is worked together with it until the whole acquires a homogeneous glutinous structure; after which four times as much water is worked up with it for a few minutes, and, lastly, the superfluous water is squeezed out by a press.

The pulp is put loosely into the space between the porous pot and glass jar, and then hammered down with wooden tool and mallet, until it forms a compact mass. When the element is filled to a sufficient height with pulp, an annular disc of brown paper or cotton cloth is put over it. The zinc ring *z* surrounds the tube *c c*, and rests upon the paper disc *e e*, over the pulp, reaching to within an inch or so of the top of the vessel. It is cast with a neck, *g*, which prevents the local action that would set in between the copper wire *h* and zinc, were the acidulated water to reach the former. As it is, the whole ring is immersed in the liquid; the connection with it is made by means of a copper terminal screw, *h'*, on the top of the wire *h*.

To charge the element, small crystals of sulphate of copper are dropped down the chimney *c c*, into the copper compartment *c' c'*; both compartments are then filled to the same height with water, which may be fresh, acidulated, or contain table salt.

When once set up, these elements require only to be supplied with sulphate of copper from time to time, and the water, which evaporates from the zinc compartment, replenished. When new, these batteries have a greater resistance than the common form of Daniell's, but not so much as to incapacitate them from employment in local circuits. Messrs. Siemens have during some years employed them to a great extent in measuring the insulation resistances of cables, and have found them, when regularly supplied with sulphate of copper and water, and cleaned occasionally, to possess ninety per cent. of their original electro-motive force at the end of six months.

8. If, instead of paper-pulp, oxide of zinc be used for forming the diaphragm, the zinc ring will remain for months free from traces of copper, whether the element be in closed or open circuit. This plan of employing oxide of zinc was communicated to the author by Mr. Varley, its inventor. An element properly constructed upon this principle affords, in our opinion, the best form of Daniell's element which exists. The particles of foreign metals, separated from the

zinc, fall upon the oxide of zinc and remain there unaltered; and the sulphate of copper which, by diffusion, makes its way through the porous pot, can only reach the zinc ring after traversing the whole body of the oxide of zinc; but the acid of the sulphate of copper, on entering the upper compartment, combines with the oxide, forming sulphate of zinc, which is dissolved in the liquid, and releasing the oxide of copper, which remains in the form of a black powder. So long, therefore, as there is oxide of zinc in the diaphragm, through which the sulphate of copper must pass, the zinc will retain its original lustre and its electro-positiveness unimpaired. Of course such a diaphragm gives rise to a great resistance—perhaps twenty times as much as an ordinary porous pot—but this is of no consequence when the resistance of the circuit outside is great.

9. *Sand Batteries.*—For the use of the Needle telegraphs, the element mostly in use consists of plates of amalgamated zinc and copper, the spaces between them being filled up with sand moistened with sulphuric acid and water.

Such batteries are mostly made up in boxes containing each ten or a dozen elements; they have a considerable resistance, and after being set up a short time, a very inconsiderable electromotive force. Such as it is, however, it lasts pretty constant for many weeks without requiring attention, and is by no means a "dirty" battery.

10. *Alum Battery.*—Stöhrer says that the most constant pile he has met with is that composed of carbon and unamalgamated zinc, when both plates are immersed in sand moistened with a saturated solution of alum in water, and separated by a porous diaphragm. Nine such elements which he used as a battery for telegraphic purposes, retained for two years very nearly their original strength. A disadvantage is found with these batteries which is common to all those which liberate hydrogen gas, that after the circuit has been closed for a time without much resistance, the battery exhausts itself. On breaking the circuit again, however, it recovers very speedily; and as the circuit in most telegraphic systems is open the greater part

of the time, and the periods of closed circuit are not of long duration, this inconstancy is of little importance, for which reason Stöhrer considers it well adapted to the general work of telegraph lines, particularly as it continues in good order for a very long time if treated with a little fresh alum water about once a month.

11. *Marié Davy's Proto-sulphate of Mercury Battery.*— Davy discovered the greater electro-motive force resulting from the decomposition of a mercury salt at a carbon plate than that of a copper salt at a copper plate, as in Daniell's arrangement. His battery is extensively used now in the French and in some of the English telegraph bureaux, where it is preferred to Daniell's on account of its greater electro-motive force, and the comparative ease with which it is kept in order.

The element is composed of a zinc-plate, immersed in pure water, separated by a porous diaphragm from a carbon plate immersed in a paste of proto-sulphate of mercury and water. The internal action is similar to that of Daniell's; the mercury salt is decomposed by the current, metallic mercury being precipitated upon the carbon.

These elements are commonly arranged in France in boxes of ten; the zinc cylinders packed in sponge, which holds the water and retards its evaporation; and the porous pots covered with cork, by which the carbon plates are suspended in the salt. The battery requires very little attention, and according to the inventor's statement, will retain its original force for six months. The intensity which a battery of these elements may have is limited in practice, because if the strength of the current exceeds a certain amount, the dissolution of the zinc goes on faster than the decomposition of the salt, and therefore there is an insufficiency of oxygen liberated to combine with the hydrogen, which, collecting upon the carbon, weakens the proper polarisation of the system; or, the mobility of the sulphate of mercury paste being small, the salt becomes quickly exhausted in the immediate vicinity of the carbon plates, and is replaced by a stratum of water. This is a phenomenon observable more or less with every kind of element when a great number are connected up in series.

12. *The Earth-element, or Terra-Voltaism.*—Steinheil says, speaking of this method of telegraphing, "On the repetition of the experiment of using the earth as conductor, M. Gauss provided the ends of the line wire at one station with a copper, at the other with a zinc plate. When these came into contact with the earth a powerful galvanic current traversed the circuit. The place of the acidulated cloth in the common voltaic pile was in this case taken by a thickness of 3,000 feet of earth."

Bain, in 1844, arranged a similar system in the hope of being able to work his telegraph with it; but the success attained was only moderate. He, as well as Robert Weare, however, succeeded better with the earth battery for working their electric clocks.

Two years later Steinheil employed an earth-pair for working his instruments on the ærial line between Munich and Nanhofen—a distance of more than twenty English miles—for both railway and general service. A copper plate of 120 square feet surface was buried in the earth at Munich, and in Nanhofen a plate of sheet zinc of the same dimensions. The current of this earth-pair was found to be amply sufficient to give the necessary signals by deflecting the magnet needles.

In later years, Mr. Septimus Beardmore, of London, has taken up the advocacy of this system, which he has christened "terra-voltaism," and although he has not pushed it much farther than it was when it left the hands of Steinheil, he has expended much time in its study and made some interesting experiments.

A very excellent suggestion of this gentleman to increase the electro-motive force of the pair, which he has found insufficient to overcome the resistance of a long line, is by the employment of an amalgam of potassium, moistened with diluted sulphuric acid, for the positive metal, and platinised graphite for the negative element, immersed in a solution of bi-chromate of potassium and sulphuric acid. The great cost of the potassium was found, however, to be an objection to its employment in practical telegraphy, and he consequently used, in some experiments made at Greenwich in 1860, a highly electro-positive alloy of sodium and zinc in porous pots in the earth.

The system never had, and probably never will have, a chance of being employed on a line of any length. It costs more than a single ordinary battery, is not so easy to control, and its electro-motive force can never be increased beyond that of a single element; whereas both the Morse and the pointer telegraphs require a current of considerable intensity to set them in motion.

The sole advantage to be gained by its employment would be its constancy, if very large plates were buried deep enough in the earth to ensure them being uniformly moist; the current would last until the whole of the electro-positive metal became converted into oxide—a process which would take a very long time.

An economical element is arranged by burying a copper plate in the damp earth, connected to an insulated wire, for the positive pole, and a wire connected to gas or water pipes for a negative. An iron-copper pair is thus obtained, which will continue active as long as the pipes last.

13. *Amalgamated Zinc.*—Sturgeon* it was who suggested the amalgamating of the zinc plates of galvanic elements. Two important advantages were proposed and obtained by it: first, amalgamated zinc is not soluble in dilute sulphuric acid when no galvanic current passes from the metal to the liquid, and then only to an amount which is exactly equivalent to the strength of the passing current: therefore, when the circuit is open the zinc is not wasted, as is the case when unamalgamated zinc is placed in acidulated water; and, secondly, amalgamated zinc is considerably more electro-positive than unamalgamated. To these advantages may be added that the zinc of commerce contains always metallic impurities, amongst which iron, lead, cadmium, and manganese are the foremost. When unamalgamated, these

* Researches, 1830.

metallic impurities, after a time, collect on its surface, and form an insoluble crust, which lessens the electro-motive force of the pair by preventing the dissolution of the zinc and by its different electric condition; while amalgamated zinc, on the contrary, separates the particles from its surface, and allows them to fall off to the bottom.

The way in which zinc plates or cylinders are amalgamated is by dipping them first, for a minute, into a vessel containing dilute muriatic acid, and then by plunging them into a bath of metallic mercury. After remaining here for a minute, they are taken out and thrown into a tub of clean water, where the superfluous mercury is allowed to drain off.

Berjot, in order to save the quantity of mercury which this method entails, has suggested a process of amalgamating without metallic mercury. He dips the zincs into a solution of mercury in nitro-muriatic acid for a few seconds only, to completely amalgamate them. He recommends the process as easy, cheap, and certain.*

II. Measurement of the Galvanic Current.

14. *The Voltameter.*—When two platinum wires—continuations of the poles of a galvanic battery—are plunged into water, bubbles of gas are observed to form on each of them, rising to the surface when their bulk becomes sufficiently great to overcome their adhesion to the metal. These gases are hydrogen and oxygen — the former is developed at the zinc electrode, and the latter at the copper.

The various forms of apparatus constructed for collecting and measuring the volumes of these gases are called voltameters. One of the handiest for measuring large quantities of gas developed in stated intervals is the following:—

* The solution is made by dissolving 200 grammes of mercury, at a moderate heat, in 1 kilogramme of nitro-muriatic acid (1 part NHO_3 to 3 parts H Cl.), and after complete solution, by the addition of another kilogramme of nitro-muriatic acid. This quantity of solution is said to be sufficient for amalgamating from 150 to 200 zincs.

A wide-mouthed bottle (Fig. 120) is three-quarters filled with sulphuric acid (sp. gr. 1·3). The mouth is filled up by a leaden stopper, A A, through which, in small glass tubes, two well-insulated copper wires, *c* and *d*, are led, their ends being soldered below to two plates of platinum foil, and protected by a coating of varnish or resin against

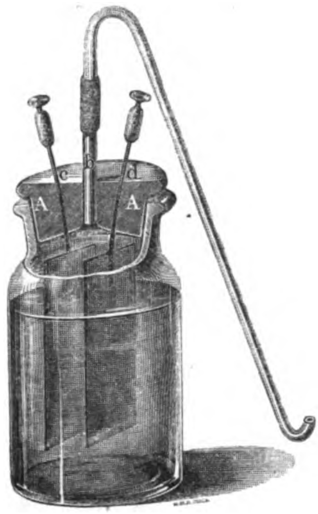


Fig. 120.

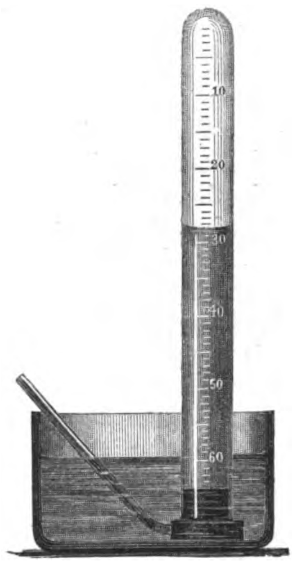


Fig. 121.

the corrosive action of the acid. The upper ends of the wires *c* and *d* are furnished with binding screws, by which they may be brought into contact with the poles of the galvanic battery. On a glass tube, *b*, also cemented into the cover A A, an S-shaped glass tube of the same diameter is attached by means of a short piece of india-rubber pipe. The lower curve of this S-shaped tube is placed in a pneumatic trough underneath the opening of a glass measure, graduated in cubic centimeters (Fig. 121). The poles of a battery being connected to *c* and *d* respectively, the current passes from one of the platinum plates to the acidulated water, and from the latter to the other platinum plate. In its passage the particles of water are decomposed and their constituents given off. Of these the bulk of hydrogen gas given off at the negative electrode, in a certain time, is double the volume of the oxygen given off by the positive. The bubbles rise to the surface of the acidulated water, mix, and form an explosive gas, and at the same time an equal volume is forced out of the bottom of the S-shaped tube, and rises up into the graduated measure (Fig. 121).

In calculating the intensity of the current from the volumes of water decomposed in given times, it is necessary to make allowance for temperature and barometric pressure. The common air is first expelled from the apparatus by letting the gas bubble out a few minutes before putting the graduated measure over the tube. The latter should have as small a bore as possible, without having too much resistance.

According to Marriotte's law, the volume of a confined gas is reciprocally proportional to the pressure upon it, and therefore to its tension. Thus, if under the mean pressure of the atmosphere—760 millimetres of mercury —the volume of the gas is v, under a pressure of two such atmospheres it would be only half as much, or $\frac{v}{2}$. More generally, if h express the height of the barometer column in millimetres, when the measurement of the volume v_h is made, and v_t the volume of the same gas corresponding to the mean pressure, 760^{mm}, the temperature being constant,

$$v_t : v_h = \frac{1}{760} : \frac{1}{h}$$

or,

$$v_t = \frac{h}{760} v_h .$$

Physicists are generally agreed that the expansions of all the gases are very nearly, if not absolutely, equal, with equal increments of temperature; in other words, that one co-efficient of expansion is common to all, and that this co-efficient for every degree of the centigrade scale, in the neighbourhood of the zero point, is equivalent to the 0,003665 part of the volume.

Therefore, v_t being the volume under mean atmospheric pressure, at the temperature t^o, its volume v_o at the temperature 0° will be

$$v_o = \frac{v_t}{1 + 0{,}003665\ t^o}.$$

As a numerical example, let the quantity of explosive gas developed in a minute be 25·64 cubic centimeters, measured in the graduated tube, the temperature of the gas 21° C., and the height of the barometer, at the moment, $775{\cdot}5^{mm}$, we have then

$$V = \frac{775{\cdot}5 \times 25{\cdot}64}{760(1 + 0{,}003665 \times 21^o)} = 24{\cdot}29 \text{ cubic centimetres}$$

for the volume of the explosive gas which would have been observed had the temperature been 0° and the barometer $760^{mm.}$

Faraday has proved that the chemical and magnetical effects of galvanic currents are proportional to their strengths and to the volumes of water decomposed by them in stated times. It is therefore only necessary, in order to compare the intensities of two currents, to compare the respective volumes of gas developed in the same time and under the same conditions. Unfortunately, however, we can only measure in this way the currents in circuits of which the measuring apparatus itself forms part, and as the conducting power of water, even when highly acidulated, is very small, the resistance of the voltameter quite overpowers it, when the electro-motive force is feeble, so that no decomposition, or very little, occurs, and no satisfactory result can be obtained.

15. For this reason we are obliged to have recourse to the deflection of a magnetic needle suspended within the coils of a multiplier; and when we know what function of its deflections is proportional to the currents producing them, the method affords us the most delicate measure we can desire.

The object of all measurement is the comparison of some unknown with some known magnitude; and this known magnitude is termed the unit of comparison. Jacobi, of St. Petersburg, compared the volumes of gas developed in his voltameter with an unit of volume developed in an unit of time by an unit of current at a certain temperature and tension. His expression was:—

"*The unit of current is that current which in one minute, at a temperature of* 0° C., *and under* 760^{mm} *pressure, develops one cubic centimetre of explosive gas.*"

The value of the deflections of magnetic needles suspended in multipliers of wire, inserted in the circuit of a battery and voltameter have been compared with the volumes of gas developed in certain times, and the laws of their deflection thus ascertained.

Ampère observed that when a positive current moved in a wire from south to north, over and parallel to a magnetic needle, the latter was deflected, with a tendency to place itself at right angles to the wire, the north pole pointing westward. Subsequently, Biot and Savart have occupied themselves with the task of establishing the relation between the deflection of the needle and the distance of the galvanic current moving in a straight conductor of infinite length, and have found that:—

"The total effect of an infinitely long and straight conductor upon any magnetic element is in inverse proportion to the distance of the element from the nearest point of the wire."

For the effect of a circular current upon a magnetic element, Weber has given a mathematical development, from which he proves that when the distance of the magnetic element from the centre point of the current circle is x, its diameter y, the intensity of the current g, and the magnetic intensity of the element which is deflected μ, the force J with which the deflection takes place is expressed by

$$J = \frac{2\pi g \mu y^2}{(x^2+y^2)^{\frac{3}{2}}}$$

which, translated into words, is, that a magnetic element in the axis of a circular current is attracted or repelled from the centre with a force which is directly proportional to the superficial contents of the circle, and inversely to third power of the distance of the element from the periphery.

16. *Tangent Galvanometer.*—When a magnetic needle is deflected by a ring in which a current is circulating, the force of the deflection is the resultant of the attraction and repulsion of the ring upon all the magnetic elements composing the needle; but as these attractions and repulsions depend upon the position of the needle with respect to the ring, and alter with it, when the former is turned from its normal position the resultant is evidently no longer the same. To reduce the difference, however, to an amount so minute as to be neglected, the diameter of the ring must be made so great in comparison with the length of the needle that the distance of each magnetic element from the periphery, in whatever position the needle may stand to the axis of the ring, may be said to be the same.

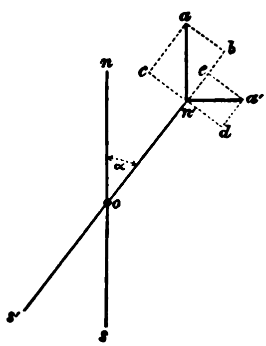


Fig. 122.

When the needle *n s*, Fig. 122, is at rest, and the ring surrounding it is in the plane of the magnetic meridian, any current in the ring which tends to deflect it from its position of rest acts at right angles to the direction of the horizontal component of the earth's magnetism, and its force may be represented by a line through the pole of the needle at right angles to magnetic north and south. Such a current will deflect the needle, which will take up a position, *n′ s′*, making an angle, *a*, with its former position. Suppose the whole magnetism of the needle to be collected in the pole *n*, and this to be acted upon, in the direction *n s* by the magnetism of the earth, and in a direction at right angles to *n s* by the magnetism of the ring; when the pole *n* takes its place at *n′*, these forces are balanced and equivalent to a force acting in the direction *n′ s′*. Let this force be decomposed into the forces *a n′* and *d′n′* at right angles to each other; each of these forces may be further decomposed into forces acting at right angles to the direction of the needle and parallel to it. Thus, the force $a\,n'$, the horizontal force of the earth's magnetism upon the pole, is equivalent to $c\,n'$ at right angles to the needle, combined with $b\,n'$ parallel to it, while, in the same way, $a'\,n'$ is equivalent to the forces $e\,n'$ and $d\,n'$. But as the forces $b\,n'$ and $e\,n'$ act parallel to the needle, they can produce no deflection, whilst $c\,n'$ and $d\,n'$, acting in opposite directions between which the needle is balanced, must be equal to each other.

The angle $a = n\,0\,n' = a\,n'\,b = a'\,n'\,d$;

by plane trigonometry,

$$n'\,d = n'\,a'.\ \cos.\ a.$$
$$n'\,c = n'\,a,\ \sin.\ a.$$

And since $n'd = n'c$,

$$n'\,a'\ \cos.\ a = n'\,a,\ \sin.\ a,$$

whence

$$n'\,a' = n'\,a\,\frac{\sin.\ a}{\cos.\ a} = n'\,a,\ \tan.\ a.$$

Putting, for the sake of clearness, the horizontal component of the magnetic force of the earth, $n'\,a = \mathrm{M}$, and the strength, or magnetic force of the current, $n'\,a' = \mathrm{S}$, we have

$$\mathrm{S} = \mathrm{M},\ \tan.\ a.$$

By the same reasoning, when the strength of the current is altered to S′, the angle of deflection will be altered to a'. M remains constant, and

$$\mathrm{S} : \mathrm{S}' = \mathrm{M}\ \tan.\ a : \mathrm{M}\ \tan.\ a';$$

or,

$$\mathrm{S} : \mathrm{S}' = \tan.\ a : \tan.\ a'.$$

Therefore the magnetic effects or strengths of two currents are proportional to the tangents of the angles through which the magnetic needle is deflected from the magnetic meridian.

But to compare the values of S and S′, measured with different rings and needles, we have the proportion

$$\mathrm{S} : \mathrm{S}' = \mathrm{C}\ \tan.\ a : \mathrm{C}'\ \tan.\ a',$$

C and C′ being constants of sensibility of the two arrangements. They are functions of the diameters of the rings, and of the distances of the magnetic poles. If $n\,s$ (Fig. 123) is the direction of the magnetic meridian and the plane of the deflecting ring, and $n' s'$ the direction taken up by the deflected needle, by plane trigonometry

$$\tan.\ \alpha = \frac{a\,b}{a\,n'}$$

Following Weber's equation, however,

$$a\,b = \frac{2\,\pi\,g\,\mu\,y^2}{(x^2 + y^2)^{\frac{3}{2}}}$$

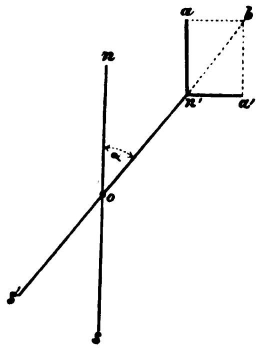


Fig. 123.

and, since $a\,n'$ is equal to μ M—the attraction between the magnetic pole and the earth—we get

$$\tan.\ \alpha = \frac{\mu\,g\,\frac{2\,\pi\,y^2}{(x^2 + y^2)^{\frac{3}{2}}}}{\mu\,\mathrm{M}}$$

in which g (or S), the strength of the current, is

$$g = \mathrm{M}\,\frac{(x^2+y^2)^{\frac{3}{2}}}{2\,\pi\,y^2}\,\tan.\ \alpha.$$

Therefore

$$\mathrm{C} = \mathrm{M}\,\frac{(x^2 + y^2)^{\frac{3}{2}}}{2\,\pi\,y^2}$$

and by the same reasoning

$$\mathrm{C}' = \mathrm{M}\,\frac{(x_1^2 + y_1^2)^{\frac{3}{2}}}{2\,\pi\,y_1^2}.$$

Pouillet's tangent galvanometer is constructed on these principles. It consists of a copper ring of large diameter erected in the plane of the magnetic meridian, and of a short magnetic needle in its centre.

A circular copper band, or ring, is bent outwards at the ends to form parallel connections, which are properly insulated from each other and attached to the terminal screws for receiving the wires of the galvanic circuit. In the lower half of the ring a wooden frame is supported, which keeps it in form, and carries a compass-box, containing the magnetic-needle. The latter is short and is cemented to the middle of a long glass fibre, which serves as a pointer, and allows the divisions of the scale over which it moves to be of a considerable size. The ring, with its continuations, is supported upon a tripod with levelling screws, in which it is turnable for facility of placing it in the plane of the magnetic meridian. The distance of the ring from the needle renders the latter perfectly insensible to weak currents, and a multiplier becomes necessary.

Messrs. Siemens have constructed a tangent galvanometer in which the copper ring is replaced by four separate, thick, well-insulated copper wires, bent in form of a circle of about the same diameter as the ring in Pouillet's instrument, and terminating round the pedestal on which they are supported in four pairs of brass terminal screws. With this arrangement the galvanometer can be made twice, thrice, or four times as sensitive by letting the current pass as many times round the needle. It may also be used as a differential galvanometer by letting the current pass in reverse directions through the convolutions.

The magnetic needle with its pointer of glass or aluminium is suspended at the end of a fibre of unspun silk hung from an adjusting screw, on the top of a glass tube, and is lowered on to the card by turning the screw when the instrument is not in use. The support turns upon a vertical axis, by which the coil may be placed north and south.

Gagain constructed a galvanometer in which he professes to have succeeded in reducing the error arising from the altered position of the magnet, by removing the plane of the ring to a distance of half its radius from the centre of the needle, by which, when the latter is deflected, the one half is just so much more as the other half is less strongly acted upon. Bravais, who undertook the mathematical demonstration of the correctness of Gagain's theory, has proved that when a magnetic needle is subjected to the action of a circular current in the magnetic meridian, the centre of the needle occupying the apex of a cone having the circular current for a base, the tangents of the angles of deflection are almost strictly proportional to the intensities, when the height of the cone is equal to a quarter of the diameter of the base.

17. *Sine Galvanometers.*—When the needle is deflected from the magnetic meridian by the action of the ring or coil, we have seen that the force $n' c$ with which the earth's magnetism strives to bring the needle back to the line $n\ s$ is equal to the product of the directive force, M, of the earth's magnetism on the needle and the sine of the angle of deflection, or

$$n' c = M \sin. a,$$

and $n' c = n' d$. M sin. a is therefore the value of each of the forces which pull in opposite directions and between which the needle comes to rest. If the convolutions of the ring, which have been hitherto supposed to remain in the same plane, be turned round the vertical axis of the galvanometer in the direction of the needle, the latter will be deflected still farther from the meridian, but always through a less angle than that through which the coil is turned after it. Hence, in time, a point is reached where the plane of the coil coincides with the direction of the needle, or they are parallel to each other.

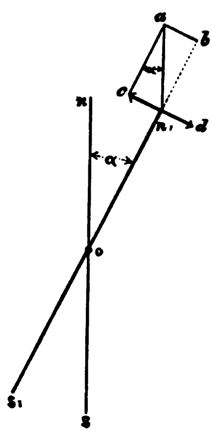


Fig. 124.

Let this be now the position of things in Fig. 124, the needle in the position $n'\ s'$ and the coil parallel to it having been turned through the angle a; the force with which the coil deflects the needle is now not only at right angles to its own plane, but also to the direction of the needle, and is represented, directly, by the line $n' d$, which is also the expression of the current moving in the coil, whilst that part of the earth's magnetism which balances this force is $n' c$, as before.

But

$$n' c = a n' \text{ sin. } a = \text{M sin. } a;$$

therefore also

$$\text{S} = \text{M. sin. } a.$$

Any other intensity of current, S', moving in the same ring, will require the instrument to be turned through another angle, a', in order to bring the needle to the zero point of the scale; and we get another equation, by the same reasoning—

$$\text{S}' = \text{M sin. } a'.$$

The relation of the two currents is

$$\text{S} : \text{S} = \text{sin. } a : \text{sin. } a'.$$

That is to say, the currents are proportional to the sines of the angles through which the galvanometer is turned to make the coil and needle parallel.

Instruments constructed on this principle are called Sine Galvanometers.

Multiplier Sine Galvanometer.—The galvanometer which Professor Du Bois Reymond uses in his beautiful experimental researches on animal electricity consists of a multiplier of from twenty to thirty thousand turns of fine insulated copper wire, which act upon a Nobili's astatic pair of magnets. The two magnetic needles are placed upon a common centre with reversed poles, and are of nearly equal directive forces, so that the difference between them, which determines the directive force of the system, is very small, whilst, being placed one in the centre and the other over the coil, they are deflected in the same sense.

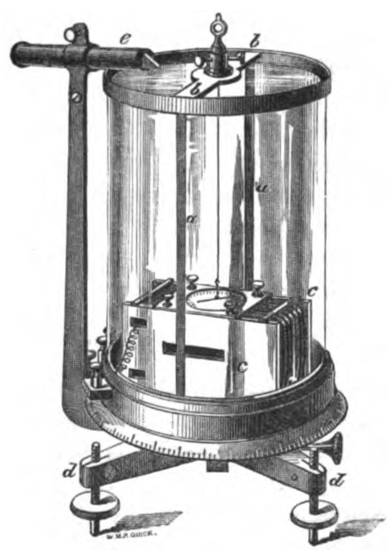


Fig. 125.

This galvanometer is shown in perspective in Fig. 125. The bed of the instrument supporting the coils, *c c*, is turnable about a centre in the tripod levelling stand, *d d*; its circumference is divided into degrees of arc.

The silk fibre by which the needle system is suspended is attached to an adjusting screw in the middle of the cross beam *b b*, resting upon the upright pillars, *a a*. A glass cylindrical case and glass top protect the instrument from dust and the fibre and needle from currents of air. The lower needle swings in the centre of the coils of wire; the upper one acts as a pointer to and is suspended over a graduated card; its position being observed through the telescope, *e*.

The multiplier is wound on two bobbins, which are placed side by side, with the needle system between them. They are of about the same length and magnetic action, and may be used either separately or together.

These instruments were used for testing the Malta-Alexandria cable and others, whose electrical conditions have been under the surveillance of Messrs. Siemens. In their instruments, each of the bobbins have about 3,500 units' resistance and about 12,000 turns, making a total resistance of 7,000 units, and, in all, 24,000 turns round the needle. The card inside is graduated from the line, 0° 0°, parallel to the direction of the coils, to 90° on each side.

These galvanometers may be made of almost any required sensitiveness for weak currents, by making the needle system sufficiently astatic.

18. The astatic condition of a pair of needles is measured by the time which it occupies in making an oscillation across the magnetic meridian. Matteucci had a pair which took seventy seconds to make a single oscillation; but from five to ten seconds is a very convenient degree of directive force to obtain for the measurement of high resistances by weak currents, otherwise the needle system is liable to change its zero by trifling disturbances over which the operator has no control.

An astatic pair of needles never takes the direction of the magnetic meridian, but assumes a position at an angle which increases as the difference between the force of the needles is diminished, or as they become more astatic. Dubois calls this the arbitrary deflection of the needle pair. The cause of this arbitrary deflection has been ascertained by Nobili to be that the two needles are never suspended absolutely in the same vertical plane, but that the vertical plane which coincides with one needle makes always an angle with that which coincides with the other. This will be easily understood from Fig. 126, where *n s* and *n′ s′* represent the horizontal projection of two needles of equal size and magnetic moment, and N S the line of the magnetic north and south.

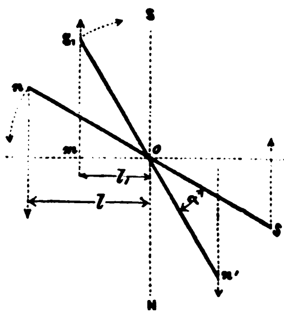


Fig. 126.

Suppose the force of all the magnetic elements of the needles which tend to turn them to the poles N and S to be collected in the ends *n*, *n′*, *s*, and *s′*, and to act in lines parallel to the line N S, then, if *f* represent the force acting on the end *n*, the product *f l* will be the static moment with which this force tends to turn the north end of this needle in the direction of the arrow, and 2 *f l* that exerted upon the whole needle, the south pole being attracted in the reverse direction, but in the same sense with regard to the point of suspension *o*. The other needle, *n′ s′*, having an equal amount of magnetism, but being at an angle *a* with *n s*, the total force with which it is drawn round in the other direction is $2 f l'$.

It is evident, therefore, that the needle system can only come to rest when the opposing forces

$$2 f l = 2 f l',$$

or when

$$l = l'$$

and this can only occur when the line bisecting the angle a stands at right angles to the line N S.

When the magnetism of the two needles is of different intensity, let $n\ s$ have the magnetism f, and $n'\ s'$ an amount equal to f'; then, in order that the needles take a certain direction, the forces must be balanced, or

$$2fl = 2f'l$$

$$\frac{l}{l'} = \frac{2f'}{2f}$$

Now the limits of the possible values of $\frac{l}{l'}$ are evidently 1 and ∞ on the same side of the line N S. The value of $\frac{l}{l'}$ is 1 when the line bisecting the angle a is at right angles to N S, and it will be infinite when $n'\ s'$ and N S coincide; but when this takes place it follows that the proportion $\frac{2f'}{2f}$ between the magnetism of the needles must also be infinite, that $2f$, the magnetism of the needle $n\ s$, must be very small—infinitely so—in comparison with $2f'$, the magnetism of the needle $n'\ s'$. Therefore, when the disproportion between the magnetisms of the two needles of an astatic pair is very great, the stronger magnet points magnetic north and south. Between these extremes, as the relation $\frac{2f'}{2f}$ becomes finite, the needle pair places itself at various angles between 0° and 90°.

19. *Magnetism of the Coils.*—Copper is not a magnetic metal; nevertheless, Dubois, Tyndall, Melloni, and others, have found large multipliers of insulated copper wire magnetic to a degree great enough to cause a permanent deflection of the astatic pair to 30° where no current passed through the circuit. Suspended within such magnetic coils, the needles usually show a disinclination to come to rest on the zero line, but take up with equal facility a position on either side of it. The magnetism of the copper coil has been variously attributed to the mixture of magnetic metals in the copper, to the iron which adheres to the wire as it leaves

the drawing plate, and to magnetic matter in the insulating covering. The impurity of the metal may be avoided by taking galvanic copper, or, as this is rather brittle and requires to be melted over and over again before it can be drawn, by taking copper which, when tested by being held in the neighbourhood of a delicate magnet, affords no trace of any magnetic metal. The adhesion of iron to the wire may be prevented by drawing it through holes in agate plates, or, if these are not to be had, by letting the wire drawn through ordinary steel dies be placed for a few hours in a bath of cold muriatic acid before being covered with silk. Professor Tyndall traced the magnetism of his coil to the silk, and believed that the green dye used in colouring contains some magnetic substance. When he substituted bleached silk, he found the disturbance vanish. For our part we have always found white silk injurious to the eyes of the workmen employed in winding the coils, and prefer green on that account. Mr. Vogel, of Berlin, whose wires are perhaps the most uniformly drawn and the best covered of any we have yet met with, has introduced the use of aniline for dyeing the silk with which he covers his wires, thus satisfactorily removing the last difficulty, as aniline is totally free from any perceptible magnetic influence upon the most delicate needle system.

20. *Sine and Tangent Galvanometer.*—A combination of both principles in one instrument has been made by Siemens and Halske. It is furnished with two separate coils of wire on the same ring—one of a few turns of thick wire, the other of many turns of thin wire. Two magnetic needles are also used with this instrument: that for tangent readings is short, and attached to a long brass or aluminium pointer; that for sine readings is longer, and attached to a similar pointer.

The ring round which the wire is coiled is supported by a circular plate, carrying in its centre the compass-box; and is turnable in a graduated metal ring, for the purpose of reading off the angles through which the coil is turned for sine readings. When the instrument is used as tangent galvanometer, the angle of deflection is read off on a card, inside the compass-box, with the shorter needle; when used as a sine instrument the other needle is used, and the circular plate, with the coils, turned in the same direction as the needle is deflected, until they coincide.

The thicker coil, whose resistance is about one-tenth of an unit, consists of sixteen convolutions of copper wire 1·34 millimètres diameter; the other coil has above a hundred and fifty units resistance, and consists of over a thousand convolutions of insulated copper wire of 0·25 millimètres diameter.

Should the deflection due to a current be too great to be read off, an arrangement is adopted by which a known fraction only of the current goes through the galvanometer, the other going through a shunt. This is done by inserting the shunting circuit parallel to the galvanometer coil.

21. *Weber's Mirror Galvanometer.*—In most of his experimental researches in galvanism, Professor Weber has employed a galvanometer, the magnetic needle of which is a circular steel mirror reflecting the divisions of an illuminated scale placed at some distance from it into a telescope

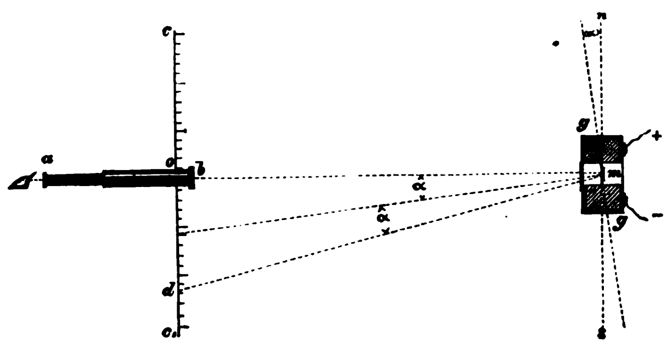


Fig. 127.

through which the observer reads off the deflections of the mirror. Its principle is precisely that of the receiving instrument used in Gauss and Weber's telegraph already explained.

Fig. 127 shows a plan of this arrangement. *c c'* is a paper scale divided into 1,000 equal parts, usually millimètres; *a b*, a telescope; *g g*, the multiplier; and *m* a magnetised steel mirror, about one-eighth of an inch thick and 1 inch diameter, polished on the side facing the telescope, and suspended by a long fibre of unspun silk. When undisturbed by the passage of a current through the coil, or from other causes, the mirror takes the direction of magnetic north and south, and reflects the central division of the scale into the telescope; but when a current passes through the coil the mirror is deflected, making an angle, a°, with the line *n s*, and reflecting some division *d* of the scale into the telescope, or that point in the line (*d m*) which makes with the line *a o m* the angle 2 *a*. Within 5°, the values of sines and tangents are, within a very small fraction, equal to their angles; so that, when the angles do not exceed this limit, they may be taken without further reduction as proportional to the currents producing them. With Weber's instrument this limit is never exceeded: the length *o c* being 0·5 metre, and *o m*, the distance of the scale from the mirror, usually more than 5 metres. Besides, where the diameter of the mirror is small in comparison with the diameter of the coil, we have seen that the currents are proportional to the tangents of the angles *a*. With this instrument $\frac{o\,d}{o\,m} = \tan. 2\,a$; but as, for very small angles, we may put $\tan. 2\,a = 2 \tan. a$ without appreciable error, we can accept also the values of *o d* as being proportional to the tangents, and therefore to the intensities also.

Fig. 128 shows a vertical section of such a galvanometer. *a a* and *a' a'* are two circular coils of fine copper wire insulated with a covering of silk, forming the multiplier. In some of these instruments the coils *a a* and *a' a'* are divided into a number of coils of different lengths and gauges of wire, terminating in a series of binding screws, *b b*, outside the frame of the coil. The frame on which the wire is wound is of vulcanite. The mirror *m* is suspended by a fibre, *f*, from a little windlass, *r*, on the cap *c* of the vertical glass tube *g g*. The mirror is raised or lowered in the coil by turning the milled head of the reel *r*, and may be removed entirely from the galvanometer after taking off the glass tube *g*, through a slit in the frame between the coils *a a* and *a′ a′*. *e* is a glass plate to guard the mirror from currents of air, and *d* a solid cylindrical block of copper put behind the mirror for the purpose of retarding the freedom of its oscillation, and bringing it quickly to repose. The checking action of a solid mass of non-magnetic metal in the presence of a moving magnet has already been alluded to. Arago believed this action to be due to the attraction and repulsion of currents of magneto-electricity set up in the mass by the moving magnet, and which have the effect of opposing its motion.

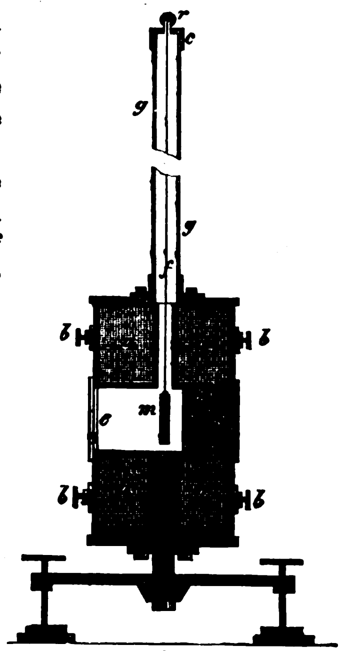


Fig. 128.

22. *Thomson's Mirror Galvanometer* is a modification of Weber's, differing from it in many important regards. Weber's instrument is admirable—in fact, necessary for a certain class of measurements; but for others the mass and sluggishness of the heavy steel mirror are objectionable, as well as the distance of the galvanometer from the observer, entailing as it does a length of connection wires which in fine measurements may be found to be inconvenient. In addition to this, the instruments, with all their adjuncts of telescope, scale, illuminators, &c., are expensive and cumbersome. Professor Thomson has avoided all this in taking a mirror whose weight does not exceed a few grains, and whose momentum is therefore very small, and in dispensing with the telescope by throwing a spot of light directly upon

the scale, and lessening its distance. For all measurements in which the instrument serves as a galvanoscope, as in Wheatstone's bridge, Poggendorff's compensation method of comparing electro-motive forces, &c., and when the readings are not very different in value, it must be confessed that this galvanometer is much to be preferred.

Mr. Becker has given it a very convenient form, by fixing the coil in the back of a brass barrel or cylinder, in the front of which a glass plate enables the interior to be seen from before, and prevents dust and currents of air getting to the needle.

In the centre of the coil is suspended, by a fine cocoon fibre, in a frame, a small silvered mirror* of microscope glass, between one-eighth and one-fourth of an inch diameter. A little magnet, made of a piece of thin watch-spring, is fastened to the back or silvered side of the glass, and, being magnetised, operates as the needle of the system. Above the brass barrel a vertical rod carries a curved permanent adjusting magnet, and a rack and pinion enables the latter to be turned round horizontally to bring the point of light to any part of the scale which may be desired.

The adjusting magnet is elevated or depressed on the vertical rod for the purpose of increasing or decreasing the directing force upon the magnet needle. When the ends of the adjusting magnet coincide with the poles of the earth's magnetism, it adds to the directive force of the latter, and the instrument becomes proportionally unsensitive. The magnet may, however, be turned round so as to oppose the directive force of the earth, and in this position be lowered towards the mirror, until it very nearly neutralises the earth's

* The process of depositing metallic silver upon glass is as follows:—(A) Dissolve 10 parts of nitrate of silver in 50 parts of water, and neutralise with (about) 6 parts of liquor ammonia; add to this a solution (B) of 1 part of tartaric acid in 4½ parts of water, and dilute the whole (A + B) with 500 parts of water. The things to be silvered should be placed conveniently in a vessel, the solution poured in, and then put away in a quiet place for a few hours, at a temperature of from 40° to 50° C. When silvered they may be washed by a gentle stream of water, dried, and varnished with a solution of amber in chloroform.

directive force. The instrument so placed has its maximum sensibility.

The scale, divided from the middle towards the ends into equal parts, is fixed upon a wooden stand at a distance of two or three feet from the mirror. Behind the scale is a paraffin lamp, whose light falls through an adjustable slit underneath on to the mirror, which reflects it back upon the scale; and in order that the point of light shall be as well defined as possible, a small plano-convex lens is placed before the mirror, through which the rays converge into a focus, throwing a sharp image of the slit upon the scale.

Mr. Varley has made some of these instruments for the measurements of the Atlantic cable, and has substituted a plano-convex lens, silvered on the curved side, for the mirror in Professor Thomson's instrument, dispensing of course with the lens in front.

23. *Rheostats.*—In the early experimental investigation of the laws of the galvanic current, the comparison of resistances was made by lengths of metal wire, which becoming sometimes rather great, an inconvenience was very soon felt in handling them. Wheatstone first overcame this by rolling the wire round a cylinder of dry boxwood, on which a worm was cut just deep enough to receive it comfortably, and to facilitate the variation of its length; the other end of the wire was coiled upon a cylinder of brass in such a way that the point where the wire touched the cylinder as a tangent to its circumference should be the point of contact, and from this point the length of the wire on the non-conducting roller to the end was measured. The cylinders of boxwood and brass were fixed in bearings parallel to each other upon a wooden board. The worm on the wooden roller was cut from end to end, comprising about forty turns to the inch. The wire, whose thickness did not exceed the one-hundredth of an inch, was connected at one end to a metal cap which covered the nearer end of the wooden roller, round which it followed the course of the worm until it left it to be wound upon the metal cylinder, to the further

end of which the other end of the wire was connected. The metal cap was in permanent connection, through a spring pressing upon its periphery, with a terminal screw; while a similar spring-contact kept the brass cylinder connected with another terminal screw forming the ends of the system. The axis of the wooden roller was furnished with a pointer or index which turned with it over a circular dial, and indicated the fractions of turns, whilst a straight bar between the roller and cylinder, graduated correspondingly with the worm of the former, showed the number of whole turns upon it.

If, in the point where the wire met the brass roller, perfect contact had been made, the length indicated by the rule and index would have represented the resistance; but this was never strictly the case: there was always a resistance to passage at the point in question, which, being nearly constant, had more effect when the length of the wire in circuit was small than when it was great.

24. *Jacobi's Rheostat.*—Jacobi, of St. Petersburg, also invented a Rheostat, whose purpose, like that of Wheatstone's, was to render the handling of lengths of wire for resistances convenient to the operator. It consisted of a roller of dry wood, in the worm of which, from end to end, a long German-silver wire was wound tightly. One end of the roller was furnished with a metal cap, to which that end of the wire was permanently attached; the other end of the wire was insulated. In front of the roller was fixed a straight round bar of brass, on which a metal jockey wheel, with a groove in its rim, rode over the German-silver wire, pressing upon it sufficiently to make a tolerably good contact. The Rheostat was put into a galvanic circuit by means of terminals: the one in connection, through the metal bearing and cap, with the wire, and the other forming one of the supports of the guide-rod. The current passed through the support and cap and through the convolutions of the wire, until it reached the jockey wheel, by which it left the wire. By turning the handle on the axis of the roller, the jockey wheel travelled along the guide-rod, and more or less resistance was intro-

duced by bringing, in this way, the jockey wheel towards one end or the other of the roller.

25. *Poggendorff's Rheostat.*—Professor Poggendorff called the instrument which he arranged for the same purpose a Rheocord. Four parallel wires were stretched on a board between terminal screws, the two middle ones being connected permanently together. Between the two on the one side and the two on the other, sliding contacts were introduced, which could be brought to the extremes at each end. The current from the terminal went therefore through No. 1, crossed over the sliding contact, went down No. 2, crossed to 3, traversed 3 as far as the other sliding contact, crossed to 4, and left 4 at the terminal on that side. When the sliding contacts were brought down to the bottom, the current passed from terminal to terminal over the contacts without going through any length of the four wires; whereas, when the slides were at the top, the current had to pass through the whole length. The places of the contacts were read off by their distances from the bottom. These distances being l and l', the resistance R, between the terminals, expressed in length, was, therefore—

$$R = 2\,(l + l')$$

We have spoken of these arrangements in the past tense, as we believe they are one and all superseded by those which follow.

26. *Siemens' Resistance Boxes.*—A much more handy method of varying the length of the interposed resistance wire is by means of a succession of short circuits between different points of its length, the wire being stationary instead of being continually wound and unwound or touched by contact rollers, as is the case with the Rheostats, by which the wire may easily become elongated and hardened, and is always liable to be damaged.

The method we speak of is best understood by supposing a length of wire (Fig. 129) between the terminals *a* and *b*, so arranged that a point *c*, at the distance *a c* from the end *a*, equal to one unit, can be put into direct communication, by means of a short circuit, with the terminal *b*. A current passing between *a* and *b* will encounter only one unit of resistance. In the same way, if the point *g*, midway between *a* and *b*, be put in short circuit with either *a* or *b*, the current will meet on its way between *a* and *b* with only half the total resistance of the wire. In the same way the intermediate

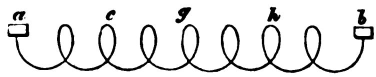


Fig. 129.

points, *g* and *h*, being connected by a shunt, the resistance between the ends will be equal to the sum of that between *a* and *g* and that between *h* and *b*. The resistance of the shunt in each case being infinitely small, its resistance does not appear in the result.

By this means a considerably greater length of wire can be made use of, and the body of the wire be protected by a case or otherwise, the points *c*, *d*, *g*, *h*, &c., only being necessarily at the command of the operator.

A highly useful arrangement, for this purpose, is shown in Fig. 130, where the various points in question are con-

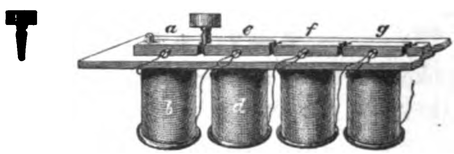


Fig. 130.

nected to a series of brass terminals, *e*, *f*, *g*, &c., so placed that, by inserting a metallic wedge or plug between any two of them, the length of wire contained between them is short-circuited. If a plug be thus inserted in the hole between *e* and *f*, for instance, the resistance *d* will disappear—the current passing through the plug, the resistance of which is infinitely small.

Between the two first terminals, *a* and *e*, a length of wire, whose resistance is equal to one unit upon the reel *b*, is inserted; between *e* and *f* upon the reel *d*, twice that length; the same between *f* and *g*, and so on, in the following order:—

1, 2, 2, 5, 10, 10, 20, 50, 100, 100, 200, 500, 1000, 1000, 2000 and 5000;

making a sum total, when all the plugs are out and the current passes from terminal to terminal through all the intervening lengths, of 10,000 units.

This simple arrangement enables the operator to make the resistance of his apparatus infinitely small by inserting all the contact plugs, or to open any resistance in whole numbers between one unit and ten thousand of them at pleasure.

The lengths of wire *b d*, &c., are of German-silver, insulated with two coatings of silk, sometimes further guarded from the air by a protecting varnish, and wound double upon bobbins of dry wood or vulcanite. The purpose of this method of double winding is to avoid the effect of induction currents in the bobbins on making or breaking contact with the battery; induction takes place, of course, but the currents circulating everywhere in opposite directions, the effect is eliminated. The coils or bobbins are arranged in a mahogany case and the terminals put upon a thick slab of vulcanite. There is a difficulty which must not be overlooked in using these resistance scales, which is not met with in using the Rheostat. It is the *spring* which the current makes on changing the contact pegs. When measuring resistances of insulation where the capacity of a jar for charge is present, this evil is principally felt, and it becomes necessary to put the galvanometer out of circuit before making any change, in testing both the insulation and resistance of conductors of long cables, in order to avoid the strong charge and discharge currents which would otherwise alter the magnetism of the needle.

27. *Eisenlohr's Resistance Column.*—Another form of resistance scale is that arranged by Professor Eisenlohr. Seven brass rings are fixed upon a cylinder of dry wood, at equal distances from end to end. In the space between each two of these rings is coiled a length of well-insulated wire, one end being soldered to the upper and the other end to the lower ring. The length in the first space has a resistance equal to one German mile of telegraph wire, that is to

say, about 64 of Siemens' units; that in the second space has a resistance representing two such miles, and so on to the sixth space, the wire of which has a resistance of six miles. Any two neighbouring rings can be brought into short-circuit by means of the brass contact pieces which turn on pins in the upper rings. In this way either or all of the coils may be short-circuited—the current passing only through those which are open. When all the brass contact pieces are closed the resistances are all short-circuited; when all are open the resistance between the top and bottom rings is equal to $1 + 2 + 3 + 4 + 5 + 6 = 21$ miles.

28. *Ohm's Law.*—Until the end of the first quarter of the present century physicists were still in darkness as to the mode and laws of the propagation of the galvanic current. The immense velocity with which the galvanic impulse is transmitted led to the seeking an analogy between it and light; and on this wrong scent much time and labour were lost, when Ohm, a German physicist, conceived the happy idea that a juster analogy was to be found in the propagation of heat, and proceeded to apply to galvanic electricity the formulæ of Fourrier and Poisson. He expressed the intensity of an electric current as directly proportional to the electro-motive force, and inversely to the resistance of the circuit. Algebraically, if E is the electro-motive force, R the resistance, and I the intensity,

$$I = \frac{E}{R} \quad . \quad . \quad . \quad . \quad . \quad (I.$$

Of these magnitudes R is made up of two resistances—that interior and that exterior to the element. The internal resistance, or resistance of the element, is, again, the sum of the several resistances due to the passage of the current from one plate to the liquid, to its passage through the liquid, and to its passage from the liquid to the other plate. We will call this resistance of the element, *r*. The remaining component—the external resistance—is that due to the passage of the current through the interiors of the plates, the wire connecting them, and through whatever conductor may be otherwise inserted between them. Let this be ρ. Substituting these values for R in (I.,

$$I = \frac{E}{r + \rho} \quad . \quad . \quad . \quad . \quad . \text{(II.}$$

The truth of this equation may be proved experimentally, as follows :—

Evidence of the direct proportion of the intensity to the electro-motive force is obtained by comparing the known function of the deflections of a magnetic needle of a galvanometer due to the current in a circuit in which r and ρ—the circuit resistances—remain constant while the number of pairs is charged. The resistance r of a pair of plates of equal surface, at the same distance, diminishes as their surface is increased, and *vice versâ*; but the resistance of more pairs joined up in series, increases proportionally to their number. Therefore, we take a single pair of plates of known surface and connect them in the circuit of a galvanometer, and of a length of wire determined by a Rheocord, or other adjustable resistance, and note the deflection, ϕ°. Then we double the electro-motive force, E, by inserting, in the place of these, two pairs of plates of each double the surface of the former, by which the resistance r remains unchanged; the wire ρ remains also the same, but we have another deflection, $\phi_1{}^{\circ}$. For the intensity I, with the single pair, we have the expression

$$1) \quad . \quad . \quad . \; I = F(\phi^{\circ}) = \frac{E}{\rho + r}$$

and by the second reading, with two pairs,

$$2) \quad . \quad . \quad . \; I_1 = F(\phi_1{}^{\circ}) = \frac{2\,E}{\rho + r}$$

F being the function—sine, tangent, or whatever it may be —which connects degrees of arc with those of force. From these two equations it follows, and will also be found, that

$$F(\phi_1{}^{\circ}) = 2\,F(\phi^{\circ})$$
$$I \;= 2\,I$$

The same method of experimental proof may be extended to n elements connected in series, by increasing their surfaces n times.

The remaining relation expressed by Ohm's law—that of current and resistance—is proved experimentally by obtaining a deflection ϕ_1°, with a certain inserted resistance, ρ, and electro-motive force, E, and then doubling the length of the wire, ρ, diminishing the size of the plates to half, and doubling their distance from each other, by which the total resistance of the circuit is doubled, while the electro-motive force remains the same, and the needle is deflected a smaller angle, ϕ_1°. Expressed algebraically the first observation gives

$$1) \quad . \quad . \quad . \quad I = F(\phi^\circ) = \frac{E}{r + \rho}$$

and the second,

$$2) \quad . \quad . \quad . \quad I_1 = F(\phi_1^\circ) = \frac{E}{2\rho + 2r}$$

from which it follows that

$$F(\phi^\circ) = 2\,F(\phi_1^\circ)$$
$$I = 2\,I_1$$

which will be verified by reducing the deflections to degrees of force.

A law upon which the truth of both these results depends has still to be proved. It is that the resistance is reciprocal, and the intensity thereof directly proportional to the surface of the plates and to the section of the conductor. If the plates be first immersed a known fraction of their surface in the solution, and afterwards other fractions, and completely, and at the same time the sectional area of the conductor be similarly increased by taking thicker wire, or two or more wires of the same length and diameter parallel to each other, the intensity, as indicated by the functions of the galvanometer, will be found to increase, other things being equal, as the section of the conductor and surface of the exciting plates increases.

The application of Ohm's law in the solution of different problems which the electrician finds it necessary to answer is very extended. It forms, in fact, the basis upon which all exact inquiry in electrical science is built up. We will see now, as an instance, what it affords us when we combine elements together in different ways.

When the poles of a pair of plates are joined together, the intensity, I, of the current passing in every section of the circuit is, $I = \frac{E}{r + \rho}$. There are two principal ways in which a number of galvanic pairs may be connected together. 1st. They may be connected in series for intensity, so as to add their electro-motive forces and resistances together; and, 2ndly, they may be connected parallel to each other for quantity, as it is called, so that the electro-motive force of the combination remains the same, but the surface of the plates is increased, and hence the resistance, in the same measure, diminished.

First, let n elements be connected so that the negative pole of the first element is joined to the positive pole of the second, the negative pole of the second to the positive pole of the third, and so on, up to the nth element. We have then what is vulgarly called an "intensity battery," and the intensity of the current of each individual element of the series, if they are of the same kind and size, will be

$$I = \frac{E}{\rho + r + (n - 1) r} = \frac{E}{\rho + n r} \quad . \quad . \quad . \quad \text{(III.}$$

and that of the whole battery,

$$I_n = n \frac{E}{\rho + n r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(IV.}$$

When the resistance $n r$ of the battery is so small in comparison with ρ that we can, without appreciable error, neglect it, the intensity of the whole battery becomes

$$I_n = \frac{n E}{\rho} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(V.}$$

that is to say, that when the resistance of the battery is very small in comparison with the resistance of the circuit exterior to the battery, the strength of the current is increased in direct proportion to the number of elements added to it.

Dividing both numerator and denominator of the above fraction, (IV., by the number of elements, n, we get

$$I_n = \frac{E}{\frac{\rho}{n} + r}$$

which becomes, if we set $\rho = 0$,

$$I_n = \frac{E}{r} \quad . \quad . \quad . \quad . \quad . \text{(VI.}$$

affording us light upon another relation of the galvanic current, viz., that when the resistance exterior to the battery is so small that it may be neglected, the current of a number of elements will do no more work than that of a single pair.

The first of these laws applies to a battery used for working a long line of telegraph, whose resistance with the coils of the apparatus is very great in comparison with that of the elements, and where it is evident a large battery is necessary. The second law applies to a local circuit, where the resistance of the circuit is small and a few elements do as well as a great number.

Secondly, let n elements be so combined that all the copper poles are connected together to form a common positive pole, and all the zincs to form a common negative pole. In this case we have still a single element, but of n times larger surface. Theory and experiment prove alike that the electro-motive force of the system is exactly that of a single element, and, according to Ohm's law, the intensity is expressed by

$$I_n = \frac{E}{\rho + \frac{r}{n}} = \frac{n\,E}{n\,\rho + r} \quad . \quad . \quad . \quad \text{(VII.}$$

Here the external resistance ρ remains the same, but that of the battery is reduced to $\frac{r}{n}$. And now by setting, in turn, the resistances ρ and r as very small in comparison with each other, we find mathematically what good the combination can do us.

When $\rho = 0$,

$$I_n = \frac{nE}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{VIII.}$$

or, when the circuit resistance external to the battery is inappreciably small, the intensity increases as the number of parallel plates increases, and in working with such circuits it proves that we do well to take elements of large surface.

When $r = 0$,

$$I_n = \frac{nE}{n\rho} = \frac{E}{\rho} \quad . \quad . \quad . \quad . \quad (\text{IX.}$$

a very important result, which says that when the external resistance ρ is very great in comparison with that of the element, no greater intensity is obtained by increasing the surface of its plates.

Two other cases belong under the same head, but seldom occur, viz., that of combining similar elements of different sizes, and of combining elements of different electro-motive forces in series and parallel.

The resistance of similar elements of different sizes will, of course, be different—let them be $r_1, r_2, r_3 \ . \ . \ . \ r_n$; but the electro-motive forces will be equal, and the intensity of the current of each element joined up in series will be

$$I = \frac{E}{\rho + r_1 + r_2 + r_3 \ . \ . \ . \ . \ r_n} \quad . \quad (\text{X.}$$

and that of any section in the circuit, the product of this with the number of elements, or,

$$I_n = \frac{nE}{\rho + r_1 + r_2 + r_3 \ . \ . \ . \ . \ r_n} \quad . \quad (\text{XI.}$$

But where these elements are connected up parallel, the intensity of the circuit becomes

$$I = \frac{E\left(\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \ . \ . \ . \ . \ \frac{1}{r_n}\right.}{1 + \rho\left(\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \ . \ . \ . \ . \ \frac{1}{r_n}\right.} \quad . \quad (\text{X.}$$

In the other case, where the electro-motive forces of each of the elements, E_1, E_2, E_3 . . . E_n, are different, and resistances, r_1, r_2, r_3 . . . r_n, also, the intensity of the current is

$$I = \frac{E_1 + E_2 + E_3 + \ldots . E_n}{\rho + r_1 + r_2 + r_3 + \ldots r_n} \quad . \ . \ . \ . \ (XI.$$

the elements being connected together in series, and,

$$I = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2} + \frac{E_3}{r_3} + \ldots\ldots + \frac{E_n}{r_n}}{1 + \rho\left(\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \ldots\ldots \frac{1}{r_n}\right)} \quad . \ . \ (XII.$$

when they are connected together parallel.

Lastly, in addition to these methods, it is sometimes necessary to determine the best combination and number of elements for a battery, under given circumstances, in order to produce a given effect. For this, some of the elements may be connected parallel, and then these combinations connected together in series. This problem of finding the most advantageous combinations is solved nearly as follows by Eisenlohr :—

If we call the surface of the exciting plates $= 1$, and connect the same in equal elements, the surface of each element will be $\frac{1}{x}$ of the whole surface; and if the resistance of the whole parallel $= 1$, that of each of the elements separately $= x$, and that of all the elements, in series, $= x^2$; then, ρ being the external resistance,

$$I = \frac{x\,E}{x^2 + \rho} = \frac{E}{x + \frac{\rho}{x}} \quad . \ . \ . \ . \ . \ . \ (XIII.$$

The denominator $x + \frac{\rho}{x}$ of this fraction evidently attains its minimum, the value of x being variable, when $\rho = x^2$; but when the denominator of a fraction is minimum, the fraction itself has its maximum value; therefore, *the strength of the current of a battery of given surface of plates is at its maximum* *when the external resistance of the circuit is equal to that of the battery.**

Now, let the given battery consist of N elements, the resistance of each of which is r units, and the external resistance ρ as before; to determine the manner in which we must couple them in order to get their maximum intensity we must arrange x rows of each $\frac{N}{x}$ elements parallel. The resistance of each row must therefore be

$$\frac{\rho}{x} = \frac{r\,x}{N}$$

whence the number of rows,

$$x = \sqrt{\frac{N\,\rho}{r}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{XIV.}$$

As a numerical example: We have a galvanometer, the resistance (ρ) of whose coil is 16 units, and wish to arrange ($N =$) 100 elements, each of which has ($r =$) 4 units resistance, in such a way that the galvanometer needle is deflected to the maximum. Inserting these numbers in (XIV., we find for the number of rows,

$$x = \sqrt{\frac{100 \times 16}{4}} = 20;$$

and by dividing the total number of elements by the rows,

$$\frac{N}{x} = \frac{100}{20} = 5,$$

we have the number of elements in each row.

The practical limits are evidently when $x = N$ and when $x = 1$. In the first case the elements are all connected up in series, in the other they are all parallel. It very frequently

* If ρ represents the surface of a rectangle whose sides are a and b, $\rho = a\,b$; and, if one side of another rectangle of the same superficial area $= x$, the remaining side must be $\frac{a\,b}{x}$, because $x\,\frac{a\,b}{x} = a\,b$. But the sum of the sides of a rectangle of given surface are least when the sides are equal, as in this case, when $x = \frac{a\,b}{x}$, which can only occur when $a\,b = x^2 = \rho$. (Dub. p. 63.)

occurs, however, that the value of x comes out greater than N, which is no absurdity; as it proves only that then N is not great enough to give us the maximum which x expresses, and in this case we must take all the elements in series.

III.—Conducting Powers of Materials.

29. *Specific Conducting Powers.*—The conducting power of a material is independent of the form and dimensions of the body measured. We have already seen that the resistance of a geometrical body of any material is directly proportional to its length and inversely to its sectional area; it is also inversely proportional to its conducting power. By length is understood the distance between the points where a current enters and where it leaves the body; by sectional area, the section at right angles to the direction of the current through the body, or to the line joining these two points; and by its conducting power, the ability which the material has to communicate the electricity from atom to atom along its length.

Algebraically expressed, therefore, the resistance r of any body is

$$r = \frac{l}{s c},$$

l being its length, s its section, and c its conducting power. From this we have the value of c,

$$c = \frac{}{s r} \quad . \quad . \qquad . \quad . \quad . \quad \text{(I.}$$

There is no absolute measure of conducting power any more than there is of specific gravity; and it becomes in consequence, necessary to refer the conducting powers of all materials to that of some one as unit, just as we refer the specific gravities of bodies to that of water. Physicists are not quite agreed what they shall take as unit of conducting power. Lenz, Siemens, and others have adopted pure mercury, and Matthiessen has advocated an alloy of gold and silver, or pure silver.

In this way we have to compare the conducting power c' of any given body with the conducting power c'' of another, which we take as unit, and we may do this by a simple proportion,

$$c' : c'' = \frac{l'}{s' r'} : \frac{l''}{s'' r''}$$

when we know the lengths l' and l'', the sections s' and s'', and the resistances r' and r'', of the two bodies in common measure. We can prevent errors arising from the measurement of these dimensions if we take all the bodies to be compared with each other of a common length and section, by which the proportion becomes simply,

$$c' : c'' = \frac{1}{r'} : \frac{1}{r''};$$

or, the dimensions being the same, the conducting powers are to each other inversely as the resistances. The section of the wires, when the materials under inquiry are metals, is obtained, the same for all, by drawing them all through the same die, usually an agate plate, and they are easily cut to the same length.

When this is not possible, the section is arrived at by measuring the length, weight, and specific gravity. If W is the weight, l the length, σ the specific gravity, and s the section, we know that the volume, $l s$, multiplied by the specific gravity, is the weight of the body; or,

$$W = l s \sigma,$$

$$s = \frac{W}{\sigma}.$$

Setting this value of s in (I., we have,

$$c = \frac{l^2 \sigma}{W r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(II.}$$

The resistances of the wires of metals are measured by one of the methods which will be given further on, at an uniform temperature, generally the freezing point of water, and the conducting power found by means of one of the above formulæ.

30. *Pure Metals.*—The most recent determinations are those of Dr. Matthiessen, who, setting the conducting power of pure silver at 0° C. = 100, makes the conducting powers of the other metals at that temperature and at 100° C. as follows:—

Metals.	Conducting Powers.	
	At 0° C.	At 100° C.
Silver, hard	100	71·56
Copper, hard............	99·95	70·27
Gold, hard..............	77·96	55·90
Zinc	29·02	20·67
Cadmium	23·72	16·77
Tin.....................	12·36	8·67
Lead	8·32	5·86
Arsenic	4·76	3·33
Antimony	4·62	3·26
Bismuth	1·245	0·878

Still more convenient is the comparison of the conducting powers with that of pure mercury at 0° C., on account of its low conducting power.

31. *Influence of Temperature.*—The resistance which a body of any material whatever offers to the passage of an electric current varies when the temperature of the body is changed. The conducting powers of the metals decrease as their temperature is increased; but those of the oils, gums, most dielectrics, and metalloids, increase as their temperature is raised.

For this reason it is essential, in all quantitative electrical measurements, to know the temperature of the body which is measured as well as of that with which it is compared; which enables us, being provided with the co-efficients of variation of the materials, to reduce the value found to some fixed point of temperature, at which alone the standard of comparison is just.

The conducting power of a metal, at any temperature, t° C., whose conducting power at the freezing point of water is 100, is expressed by

$$C = 100 + \alpha t + \beta t^{2} + \gamma t^{3} \ldots \text{etc.}$$

Arndsten, Matthiessen, and others, have made very elaborate experiments to determine the constants, α, β, &c. for the different metals. Matthiessen's experiments being of later date are the most trustworthy. The means of his results for some of the metals, reduced from many observations by the method of least squares, are given in the following table:—

Metals.	Co-efficients.
Silver	$c = 100 - 0{,}38278\, t + 0{,}0009848\, t^{2}$
Copper	$c = 100 - 0{,}38701\, t + 0{,}0009009\, t^{2}$
Gold	$c = 100 - 0{,}36745\, t + 0{,}0008443\, t^{2}$
Zinc	$c = 100 - 0{,}37047\, t + 0{,}0008274\, t^{2}$
Cadmium	$c = 100 - 0{,}36871\, t + 0{,}0007575\, t^{2}$
Tin	$c = 100 - 0{,}36029\, t + 0{,}0006136\, t^{2}$
Lead	$c = 100 - 0{,}38756\, t + 0{,}0009146\, t^{2}$
Arsenic	$c = 100 - 0{,}38996\, t + 0{,}0008879\, t^{2}$
Antimony	$c = 100 - 0{,}39826\, t + 0{,}0010364\, t^{2}$
Bismuth	$c = 100 - 0{,}35216\, t + 0{,}0005728\, t^{2}$
Mean of all...	$c = 100 - 0{,}37647\, t + 0{,}0008340\, t^{2}$

From the above table it becomes evident that for all the pure metals, in a solid state, the values of the constants α and β are nearly uniform, and agree, within the limit which may reasonably be assigned to errors of observation, with the mean of all given at the foot of the table. The law may therefore be considered as established that the conducting powers of all pure metals, in a solid state, decrease, in the same ratio, between 0° C. and 100° C. A still better agreement between the values found and calculated is obtained when the constant γ is not neglected, as in these calculations, but the member containing it ($\gamma\, t^3$) introduced, by which the coincidence of the found with the calculated curve extends far beyond the limits of 0° C. and 100° C. But within these limits it is near enough to take the values of the constants α, β, γ, &c., alternately positive and negative, and to regard those beyond β as $= 0$.

Hence the resistance, R_t, of a pure metal wire, at the temperature t°, whose resistance at 0° C. is R_0, is

$$R_t = R_0 \left(\frac{100}{100 - 0{,}37647\, t + 0{,}000834\, t^2}\right)$$

Two exceptions are found to this rule, in the metals iron and thallium: the per-centage variation of the conducting power of pure iron between 0° and 100° is 39·2, and that of pure thallium between the same limits, 31·4, while the other pure metals vary only 29·3 per cent.

32. *Alloys.*—The conducting powers of alloys of lead, tin, cadmium, zinc, and some other metals, with each other, are proportional to the volumes of the metals entering into their compositions. These metals form a class separate from the others, and are of limited number. For the most part the metals belong to the other class,—those which, when alloyed with each other or with one of the metals above mentioned, have smaller conducting powers than are proportional to their respective volumes. To this class belong bismuth, antimony, platinum, palladium, iron, aluminium, sodium, gold, copper, silver, and so on

This difference is the result of the different natures of the alloys, and depends upon the nature of the combination of the metals forming them. Many alloys are unquestionably chemical combinations, others are solutions of one metal in another, others, perhaps, only mechanical moistures, and others, again, solutions of one of these in an excess of one of the metals.

Of the alloys which enter most largely into matters connected with telegraphy, German-silver deserves to be especially mentioned. It is from this alloy that, at present, almost exclusively resistance-coils are manufactured. The conducting power of a specimen when hard-drawn, as determined by Dr. Arndsten, is only 10,532 times as great as that of pure mercury at 0° C., whilst that of a specimen when annealed, according to Dr. Siemens, is still less. Another advantage which this alloy has in common with most of the others is that temperature exerts a comparatively small effect upon its resistance. The conducting power c at a temperature t, according to Arndsten, of this alloy, whose conducting power at 0° C. is 100, is expressed by

$$c = 100 - 0{,}0387\, t + 0{,}0000557\, t^2$$

which is very little over a tenth part of the change found for the pure metals.

33. *Metals annealed.*—The degree of hardness or softness of a metal or alloy affects materially its conducting power. That of a hard-drawn wire is not the same as when the wire has been made hot and let cool again; and to the fact that not sufficient importance was attached to this property has been justly attributed the differences between the results of different observers.

Dr. Matthiessen has found it necessary, in order to obtain comparable results, not only to heat wires to 100° C. before measuring their resistances, but even to keep them during several days at that temperature before their resistances became constant below that point.

The conducting powers of the metals and alloys are increased by annealing.

Peltier first pointed out this phenomenon in the behaviour of copper; and Matthiessen repeated his experiments with copper and silver, with the following results:—

Metals.	Temp.	Conducting Power.	
		Hard.	Annealed.
Copper	11·0°	95·31	97·83
Silver	14·6°	95·36	103·33

The comparison being made with pure silver at 100° C., from which it appears that the conducting power of copper increases 2·5 per cent., and that of silver nearly 8 per cent., by annealing.

According to Dr. Siemens, the conducting powers of copper, silver, and brass, hard and annealed, are as follows, compared with pure mercury at 0° C.:—

Metal.	Hard.	Annealed.
Copper	52·207	55·253
Silver	56·252	64·380
Brass...............	11·439	13·502

This property of copper is especially of advantage in the manufacture of telegraph cables, galvanometers, &c., where a great length of conductor is required with little resistance, and where the metal must be as soft and as little liable to change its molecular condition as possible.

34. *Metals fused.*—Although not strictly within the domain of telegraphy, the conducting power of fused metals is interesting, and brings us to a material most important in the reproduction of standards of resistance—mercury.

Of the metals which have been subjected to electrical measurement when in a state of fusion, all, as far as we know, with the exception of bismuth, lose their high conducting power, and at the point of solidification regain it very rapidly. Tin may be taken as a fair example of this behaviour of the metals. A determination, which we made in 1862, with some pure tin, melted in a glass spiral surrounded by hot oil, gave the following results as compared with the conducting power of pure mercury at 0° C.:—

Temperature, C.	Conducting Powers.	
280°	1·879	fused.
273°	1·880	
263°	1·894	
227°	1·990	
220°	4·211	solid.
70°	6·631	
24°	7·892	

This is shown graphically by the curve *a, b, c, d,* Fig. 131, the curve *e f* showing the corresponding conducting powers of mercury at the different temperatures.

Mattecci first observed that bismuth behaved differently at its point of solidification to the other metals. At the freezing point of water the conducting power of this metal is about 0·74 times that of mercury; between this point and 250° C. —the melting point—its conducting power follows the law common to pure metals; at its fusing point its conducting power increases suddenly until it equals that of pure mercury at the same temperature, very nearly; from which point it decreases again in conducting power as the temperature increases. This behaviour is probably due to its crystalline structure.

Under the head of fused metals we come to mercury, which is always in this state at ordinary temperatures.

Dr. Werner Siemens proposed to employ a body of this metal as unit of resistance. He considered it of the greatest importance to have the unit of resistance expressed as a geometrical body of that material, which is commonly referred to as unit when speaking of conducting powers, by which all practical problems are facilitated. As an instance, if it be required to know the resistance of a certain length and section of any metal, it is only necessary to calculate what it would be in mercury, knowing the length and section of a body of the latter representing the unit, and to multiply the result with the conducting power of the metal required.

A great point in favour of mercury is the ease with which it may be procured in a chemically pure state.

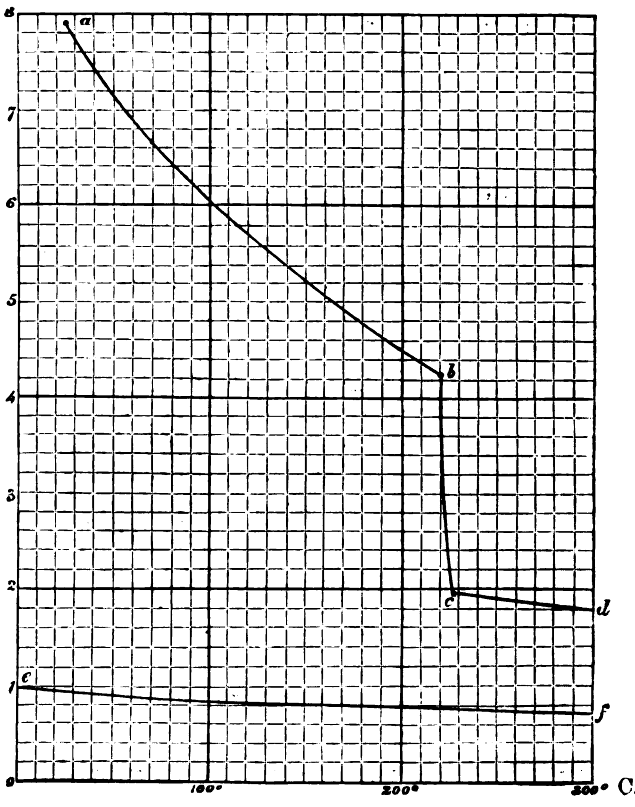


Fig. 131.

There are two ways which are highly recommended:—one followed by Dr. Werner Siemens; the other followed by Dr. A. Matthiessen with equally good results. By the former method the mercury is placed in an evaporating dish, with about three-quarters of an inch thickness of concentrated sulphuric acid over it. It is then carefully boiled for some hours, adding sulphuric acid when necessary, and, from time to time, a few drops of nitric acid. Dr. Matthiessen allows his mercury to stand some weeks under a cover of dilute nitric acid, with which it is frequently agitated.

Another recommendation in favour of mercury is the fact that, being fluid, its molecular condition cannot be subject to changes, as may be the case with the solid metals, especially in the process of drawing, and that, so long as it is pure, it must always have the same conducting power at the same temperature.

Lastly, the variation of the conducting power of mercury with difference of temperature is considerably less than that of the pure metals in a solid state. The amount of this variation, as determined by Becquerel, for all temperature degrees between 0° and 100° C., may be taken, without sensible error, as directly proportional to the difference of temperature, being equal to the 0,00104th part of the conducting power for each degree of the centigrade scale. A more recent determination by Dr. Matthiessen, which has been equated by the method of least squares, with two members, taking the conducting power of mercury at 0° C. as = 1, gives the conducting power C_t, at the temperature t° C.

$$C_t = 1 - 0{,}00074432t - 0{,}0000008261\,t^2.$$

The conducting power of mercury alloyed with even a very minute quantity of foreign metal is greater than that of pure mercury; hence great care is necessary, in using this metal, to procure it as free from impurities as possible.

35. *Electric Permanency of Metals.*—The conducting powers of some of the metals in a solid state at the same temperature seem to be pretty permanent; others, again, appear to alter their conducting powers materially in the course of a few months. As a rule, the hard-drawn wires are the least permanent, by reason of their becoming gradually annealed by exposure to variations of temperature. Dr. Mat-

thiessen's experiments, undertaken for the Unit Committee of the British Association, show that annealed German-silver increased its conducting power in the course of a year at the rate of nearly 0·2 per cent.; some specimens of gold, silver, and copper, both annealed and hard-drawn, also altered their conducting powers. The change in the conducting power of hard-drawn silver was the most considerable, the two specimens experimented upon having been found to have increased at the rate of over 3·9 and 2·8 per cent. respectively.

That some of the specimens of metals experimented with should have shown no change is no argument that they would not do so if allowed to get older; and errors of observation may sometimes, especially in measuring such minute differences, as well be taken to account for agreement as for disagreement. At present the question must be considered an open one, whether metals do change their conducting powers by age; and if so, if the change in the same wire is always in the same sense; and if so, what becomes of the conducting power at last, has still to be determined.

Another vexed question to be set at rest is, whether the passing of electric currents through a wire is able to alter its conducting power?

Professor Kirchoff says that the conducting power of any wire, at a given temperature, certainly undergoes changes if electric currents are transmitted through it and it is exposed to fluctuations of temperature. Schröder van der Kolk also says that the conducting power of a copper wire undergoes a change whenever weak currents are allowed to pass through it.

If this were the case, of what use would be our resistance-scales? Dr. Matthiessen has happily found this to be a fallacy. He allowed a current from two Bunsen's cells to pass through a series of wires of different metals for six days, at the end of which no change in their conducting powers had taken place—a result which some experiments of our own, undertaken in the winter of 1862-3, in Germany, with the view of determining the same question, completely corroborate. We connected a finely-adjusted annealed German-silver (wire) resistance to a self-acting make-and-break apparatus, or "Wippe," which sent reversed currents from a battery of large Daniell's elements, at an immense speed through it both night and day. In addition to this, the wire was kept in a recess in an iron stove in the laboratory, so that, without any interference on our part, its temperature was raised by day at least to the temperature of boiling water, and during the night descended to within a few degrees of the freezing point. The battery was varied at intervals from one cell to twenty, during about six weeks, but the conducting power of the metal did not vary in the least. Suspecting that this constancy might be due to the reversals, we repeated the experiment with a zinc current made and interrupted with great rapidity, with the same result.

The belief in the inconstancy of metals may have its origin in the discovery that all the old resistance-scales and rheostats are no longer exact. This may have its origin in three causes: 1st, the greater perfection of our systems of measurement enabling us to detect differences which may have existed before, but which we were unable to appreciate; 2nd, the process of annealing, which, when commencing with a hard-drawn wire, may extend over a very long time if the wire is only exposed to variations of the temperature of the atmosphere; and 3rd, the oxidation of the surface when the air has access to it.

There can be no question that much has still to be learned in this branch of science. Wires of German-silver and some other alloys become, when exposed freely to the air for some years, so brittle as to be incapable of being wound up on reels without danger of occasional ruptures of continuity. That this brittleness is accompanied by a change in conducting power is probable. It remains, however, to find whether the exclusion of air by means of some such material as paraffine will prevent the brittleness in question, or if it is due to molecular changes of the alloy.

36. *Conducting Powers of Fluids.* — In constructing a battery for any given work, it is necessary frequently to consider the resistance of the fluids used. Wheatstone, Horseford, and others, have invented apparatus for the determination of the conducting powers of solutions, &c. That of Horseford is the best and simplest. It consists of an oblong wooden trough, varnished inside with shellac. On the top are two cross-bars of wood, with guides, overlapping the sides, to keep them straight. To each of these cross-bars is attached a plate of platinum, only so much smaller than the interior section of the trough as to allow it to be moved freely, with its cross-bar, from end to end. Usually one of the bars, with its platinum plate, is fixed, and the other movable. A divided scale on the upper edge of the trough facilitates the observation of the distance between the plates. Copper wires are soldered to the platinum plates, and serve as connections with the measuring apparatus. When the apparatus is to be used, it is placed as level as may be upon a table, and filled to a convenient height with the solution whose resistance is to be measured. If the relation of the resistance to the distance between the plates is to be determined, the solution is poured in, and the resistances measured with various distances. By this measurement it becomes evident that the resistance of a conductor is directly proportional to its length. By keeping the distance between the plates unaltered, and varying the height of the solution in the trough, the experimenter may convince himself of the truth of another law, namely, that the resistance of a conductor is inversely proportional to its transverse section.

But the experiments which are most important are the conducting powers of solutions of the various salts and of the acids. For these measurements, of course, the distance between the plates and the height of the solution in the trough must be constant through the whole series.

Becquerel has determined the conducting powers of some of the concentrated solutions, and also of the same diluted with water. When the conducting power of pure silver is taken as 100 millions, those of some of the concentrated solutions are as follows:—

1. Concentrated solution of sulphate copper, specific gravity =1·1707 at 9° C. .... 5·42
2. Concentrated solution of sulphate zinc, specific gravity = 1·441, at 14·4° C. .... 5·77
3. Concentrated solution of chloride sodium, at 9·5° C. ..... 31·52
4. Concentrated solution of chloride copper, specific gravity = 1·4308, at 9·25° C. .... 10·35
5. Concentrated solution of nitrate copper, specific gravity, =1·5790, at 10° C. .... 8·40

A striking property of sulphuric acid is that when diluted to a certain point it attains its maximum conducting power; this point is when the solution has a specific gravity of about 1·215, or when 100 parts, by weight, of the solution contain 29·6 parts of acid, after which its conducting power again diminishes, as appears by the following table of some of Saweljev's determinations given by Wiedemann in his elaborate treatise:—

Specific gravity.	SO_3 HO, in 100 parts by weight.	Temperature. C.	Resistance.
1,003	0·5	16·1°	16·01
1·018	2·2	15·2	5·47
1·053	7·9	13·7	1·884
1·080	12·0	12·8	1·368
1·147	20·8	13·6	0·960
1·190	26·4	13·0	0·871
1·215	29·6	12·3	0·830
1·225	30·9	13·6	0·862
1·252	34·3	13·5	0·874
1·277	37·3	—	0·930
1·348	45·4	17·9	0·973
1 393	50·5	14·5	1·086
1·492	60·6	13 8	1·549
1·638	73·7	14·3	2·786
1·726	81·2	16·3	4·337
1·827	92·7	14·3	5·320

37. *Determination of Galvanic Polarisation.*—The determination of the resistances of fluids cannot always be made by the direct substitution of a metallic resistance giving the same deflection of the needle of the measuring instrument, because the electro-motive force in the circuit of a fluid resistance is not always that of the cell or battery by which the resistance is measured, but generally this minus the electro-motive force of a polarising layer of gas forming on the plates or electrodes immersed in the fluid.

In a circuit, therefore, containing a metal resistance, R, and the resistance of a fluid column, r, the current, I, measured by the galvanometer, is—

$$I = \frac{E - e}{R + r} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (I.$$

E being the electro-motive force of the measuring battery, and e that of the polarisation of the plates with the reverse sign. The truth of this employment of the law of Ohm may be proved by varying the two members of the denominator: R, by varying the length of wire, and r by varying the distance between the electrodes. Whereas, when the fluid conductor is removed, and a metallic resistance ($=r$) of the same value introduced in its stead, the deflection indicates another current, say I′, and we have—

$$I' = \frac{E}{R + r}$$

To find now the value of e, we put so much extra resistance, r', into circuit Number 1, that the needle's deflection is sensibly diminished, indicating a current of some inferior strength, I_1, expressed by—

$$I_1 = \frac{E - e}{R + r + r'} \quad . \; . \; . \; . \; . \quad (II.$$

Equations (I. and (II. combined give the value of the difference, E — e, between the two opposite electro-motive forces, by an expression from which the unknown resistances, R and r, of the wire and fluid columns are eliminated:—

$$E - e = \frac{II_1}{I - I_1} r' \quad . \; . \; . \; . \; . \quad (III.$$

To arrive at e, we must eliminate E, in order to do which two other observations are necessary. First, the constant cell, E, is connected in the circuit of the galvanometer, and a resistance, $= W$, is added by degrees until the needle indicates again the intensity I, whence

$$I = \frac{E}{W}$$

and still more resistance, ρ, until the intensity is further reduced to I_1, the same as in equation (II., by which

$$I_1 = \frac{E}{W + \rho}$$

From these two equations the value of E is obtained—

$$E = \frac{II_1}{I - I_1} \rho \quad . \quad . \quad . \quad . \quad . \text{(IV.}$$

which, subtracted from (III., leaves the value of e—

$$e = \frac{II_1}{I - I_1} (r' - \rho) \quad . \quad . \quad . \quad . \text{(V.}$$

The polarisation is, therefore, equal to the product of the two indications of the galvanometer divided by their difference, and multiplied by the difference of the resistances added to the circuits, to reduce the deflections each time from I to I_1.

Lenz and Saweljev found the polarisation of plates of different metals in different fluids to be as follows:—

1.	Platinum plates in diluted sulphuric acid (6 parts acid to 100 parts water)	1185
2.	Platinum plates in nitric acid	538
3.	Copper plates in sulphuric acid	466
4.	Zinc plates in sulphuric acid	315
5.	Graphite plates in nitric acid	273
6.	Amalgamated zinc plates in sulphuric acid	217
7.	Iron plates in sulphuric acid	72

When, however, the fluids are of such a nature that no gas is formed on either of them, that is to say, when the gases are recombined in the moment of their formation, little or no polarisation is observed.

The following three determinations in the same unit will illustrate this :—

1.	Copper plates in sulphate copper solution	15
2.	Amalgamated zinc plates in nitric acid............	6
3.	Copper plates in nitric acid..........................	2

The electro-motive forces observed in these instances were probably due to differences between the metal plates themselves, and not to polarisation by gas.

In the same unit in which the above values are expressed, the electro-motive force of an ordinary Daniell's element is only 470, or less than that due to polarisation by gas of the platinum plates of an ordinary voltameter. It can be no matter of wonder, therefore, that an element with an electromotive force so small as that of Daniell's should be found incompetent to effect the decomposition of large volumes of water, and that for this purpose we are obliged to employ elements of greater force, such as Grove's or Bunsen's.

With the continuation of the current the polarisation increases, and its amount depends, within a certain limit, upon the strength of the decomposing battery; but it attains a maximum. Increase of temperature of the fluid which is decomposed is followed by a decrease of the polarisation.

38. *Insulating Substances.*—The conducting powers of insulating materials have been determined by various observers qualitatively. The only quantitative measurements to be relied upon are those made with the telegraph cables where a great and uniform surface is at the command of the experimenter. Necessarily, therefore, the information which these determinations afford us comprehends only a limited number of materials. At a temperature of 72° F. the conducting power of gutta-percha has been found to be about forty-five times that of india-rubber, while at 92° F. the relation between their conducting powers is almost double this.

To calculate the conducting powers of insulating materials from their resistances as dielectrics of cables, we must suppose the propagation of the electric current from the central conductor through the insulating covering to take place in concentric cylinders. It is evident then, from what has gone before, that the resistance through such a cylinder concentric with the conductor will be directly proportional to its thickness and inversely proportional to its surface, that is to say, of its length and circumference, and to the conducting power of the material. If we have a metallic conductor insulated with a material whose conducting power is c, the diameter of the conductor, $2\,r$, and the outer diameter of the insulating covering, $2\,R$, the resistance, $d\,W$, of a differential cylinder, whose thickness is $d\,x$, diameter $2\,x$, and length l, will be

$$d\,W = \frac{d\,x}{2\,x\,\pi\,l\,c};$$

and by integration between the limits of $x = r$ and $x = R$, the sum of all the differential cylinders which make up the space occupied by the insulator, or, in other words, the resistance of insulation will be

$$W = \int_r^R \frac{d\,x}{2\,x\,\pi\,l\,c} = \frac{\log._e \frac{R}{r}}{2\,\pi\,l\,c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (I.$$

whence the conducting power, c, is

$$c = \frac{\log._e \frac{R}{r}}{2\,\pi\,l\,W}$$

By measuring the value of W by any of the known methods of determinating great resistances (which will be treated of further on), and being in possession of the dimensions of the cable, we can calculate the conducting power.

Having another cable, insulated with a different material whose conducting power is c', length l', resistance W', and ratio of diameters $\frac{R'}{r'}$, the conducting power of these two cables will obviously stand in the relation—

$$c : c' = \frac{\log._e \frac{R}{r}}{l\,W} : \frac{\log._e \frac{R'}{r'}}{l'\,W'} \quad . \quad . \quad (II.$$

Or, if the two cables have the same length, these conducting powers will be as

$$c : c' = \frac{\log._e \frac{R}{r}}{W} : \frac{\log._e \frac{R'}{r'}}{W'}$$

And if, further, the relation of their diameters be $\frac{R}{r} = \frac{R'}{r'}$

$$c : c' = W' : W,$$

inversely, therefore, as the resistances.

With the aid of (I., it is easy to calculate the insulation resistance of a wire covered with any insulating material whose conducting power is known in comparison with that of some other material; or, when the material is the same, as, for instance, when gutta-percha is used to insulate both cables, for any unit of length (a knot, for example), the resistances will be as

$$W : W' = \text{log. nat.} \frac{R}{r} : \text{log. nat.} \frac{R'}{r'}$$

$$W = W' \frac{\text{log. nat.} \frac{R}{r}}{\text{log. nat.} \frac{R'}{r'}} \quad . \quad : \quad . \quad . \quad . \quad \text{(III.}$$

39. *Variation of the Conducting Power of Gutta-Percha with Temperature.*—The per-centage variations of the conducting powers of insulating materials are considerably more than those of the metals. The conducting power of gutta-percha, for example, at a temperature of 20° C., is about twelve times as great as at the freezing point of water.

The conditions under which the cores of submarine cables had been tested were too uncertain, until the date of the Persian Gulf cable, to justify any dependence upon the quantitative results obtained in measuring under various temperatures. A tolerable idea of the curve which the conducting power of gutta-percha made when, in a graphic representation of the measurements, the temperatures were taken as abscissæ and the conducting powers as ordinates, was arrived at by us from tests of the Malta-Alexandria cable during the process of sheathing. The difficulty of ascertaining accurately the length of the cable and temperature of its interior at any moment, however, precluded the possibility of any mathematical expression with confidence. The first, and so far as we believe, the only good results hitherto obtained, are those published by Sir Charles Bright in a paper read recently before the Institution of Civil Engineers.

Experiments were made by Messrs. Bright and Clark upon four coils of the insulated core destined for the Persian Gulf cable. Each coil had a length of one nautical mile. They were placed in a felted iron tank holding about 1,200 gallons. At starting, the coils were maintained for three days in water kept in motion, containing a large quantity of melting ice, and may therefore, at the end of that time, when their resistances were measured, be presumed to have taken throughout the temperature of the water. After the first measurements were made, the water was allowed to increase in temperature very gradually up to 38° C., the gutta-percha resistance being measured at regular intervals. These experiments occupied thirty-three days, during which time nineteen series of observations were made, the mean results of which, reducing the observed resistances at 0° C. uniformly to 100, are as follows:—

Temperature.	Resistance.	Temperature.	Resistance.
0° C.	100·00	20° C.	8·45
2	84·14	22	6·82
4	64·66	24	5·51
6	47·65	26	4·47
8	37·15	28	3·51
10	28·97	30	2·99
12	23·18	32	2·48
14	16·89	34	1·92
16	14·37	36	1·68
18	11·05	38	1·43

From these results Messrs. Bright and Clark find that the curve between the resistance and temperature is a logarithmic one, and have arrived at the empirical formula,

$$R_{t_1} = R_t\,(0{,}8944)^{(t_1 - t)};$$

expressing the resistance R_{t_1}, at a temperature $t_1°$, as equal to the product of the resistance R_t at some lower temperature, $t°$, and the $(t_1 - t)$ power of a constant base, 0,8944.

That this empirical formula is only an approximation to

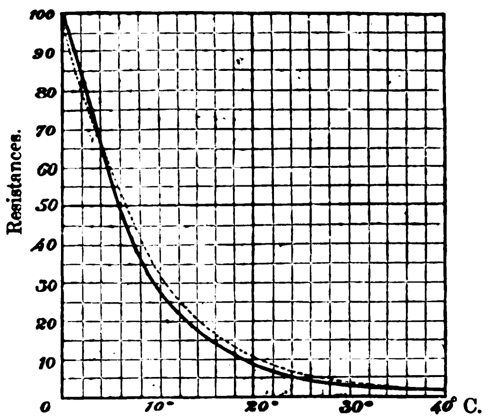


Fig. 132.

the true expression is obvious from the curves shown graphically in Fig. 132, the black line representing the values obtained from the foregoing table, and the dotted line those given by the above formula. The agreement is nevertheless sufficient to enable us to calculate, by means of the given formula, the resistance of a gutta-percha covered wire for any temperature between 0° C. and 38° C., with very slight error, from the resistance at any given temperature. Hence it becomes needless to test the cores of cables at the gutta-percha works at an uniform temperature of 24° C., as has been customary with cables hitherto made, since the resistances may be reduced to a standard temperature, and thus save the expense and trouble of keeping up warming tanks.

The difference of temperature, in combination with the influence of pressure, is strikingly observed in submerging a cable. As the cable reaches the bottom the copper resistance becomes gradually less, showing a lower temperature; the insulation resistance increases at the same time, owing to the pressure, to a marked extent, and afterwards further increases as the gutta-percha becomes electrically sensible of its altered temperature.

IV. Methods of Measurement.

40. *Kirchhoff's Laws.*—Hitherto we have regarded the current as traversing simple closed circuits. Problems often occur in practice in which it is necessary to consider the circuit as made up of several parallel branches, or shunt circuits. The question, for example, whether a single battery could be used for telegraphing at the same time to Bristol, to Hull, and to Paris, belongs to this branch of the subject, as do also the mathematical solutions of the Wheatstone's bridge, Poggendorff's, and other methods indispensable in electrical measurements.

Kirchhoff* has provided for the solution of such questions two propositions, which he has proved mathematically and experimentally.

The first is, that—

"*The sum of the intensities in all those wires which meet in a point is equal to nothing.*"

O (Fig. 133) is the point in which seven wires meet; the currents I_1, I_2, and I_3, approach, and i_1, i_2, i_3, and i_4, recede from it. If we give the plus sign to those currents which approach and the negative to those which recede from the point, the sum of all the intensities is,

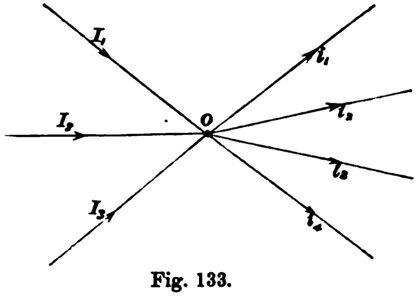


Fig. 133.

$$I_1 + I_2 + I_3 - i_1 - i_2 - i_3 - i_4 = 0.$$

* Pogg. Ann. 64, p. 513.

In other words, the sum of those currents which approach the point is equal to the sum of those which recede from it. The truth of this is evident at the first glance; for, otherwise, the point must be a reservoir, which is contrary to all our notions of electricity.

The second proposition is that—

"*The sum of all the products of the intensities and resistances in all the wires which form an enclosed figure is equal to the sum of all the electro-motive forces in the same circuit.*"

A circuit by which this law is illustrated is shown in plan in Fig. 134. E is a galvanic battery, whose circuit divides itself, in the points *a* and *b*, into the parallel ways r_1 and r_2 respectively. Let the intensities in the three sections of the conductor be I, i_1, and i_2; according to the law just expressed, the sum of the product of the intensity of the current in each of the branch circuits between *a* and *b*, multiplied by its resistance, will equal nothing, since no electro-motive force is found in this circuit, or,

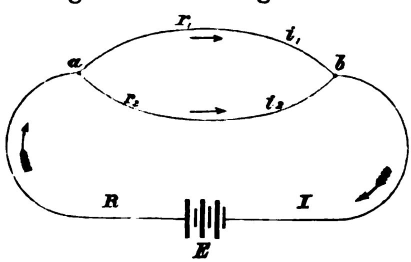


Fig. 134.

$$i_1 r_1 - i_2 r_2 = 0 \quad . \quad . \quad . \quad (1.$$

whence,

$$\frac{i_1}{i_2} = \frac{r_2}{r}$$

that is, the currents in these circuits are inversely proportional to the resistances.

Further, by the same law,

$$I R + i_1 r_1 = E \quad . \quad . \quad . \quad (2.$$

$$I R + i_2 r_2 = E \quad . \quad . \quad . \quad (3.$$

and by the first proposition,

$$I - i_1 - i_2 = 0 \quad . \quad . \quad . \quad (4.$$

By knowing the electro-motive force, E, and the three resistances, we are now in a position to find the value of the current in any part of the circuit.

Substituting in (4. the value of

$$i_1 = \frac{E - IR}{r_1};$$

and of

$$i_2 = \frac{E - IR}{r_2}$$

we have

$$I - \frac{E - RI}{r_1} - \frac{E - RI}{r_2} = 0.$$

Whence the current in the lower circuit, between *a* and *b*, is

$$I = E\frac{r_1 + r_2}{Rr_1 + Rr_2 + r_1 r_2} \quad . \quad . \quad . \quad (5.$$

which, inserted in the equations (2. and (3., gives us the currents in the branch circuits:—

$$i_1 = E\frac{r_2}{Rr_1 + Rr_2 + r_1 r_2} \quad . \quad . \quad . \quad (6.$$

and

$$i_2 = E\frac{r_1}{Rr_1 + Rr_2 + r_1 r_2} \quad . \quad . \quad . \quad (7.$$

If, further, we desire to find the resistance R′ of the whole circuit, we must insert the value of I, (5. in the fundamental formula, $I = \frac{E}{R'}$, from which

$$R' = \frac{E}{I} = \frac{Rr_1 + Rr_2 + r_1 r_2}{r_1 + r_2},$$

$$R' = R + \frac{r_1 r_2}{r + r_2} \quad . \quad . \quad . \quad . \quad (8.$$

Of this, R is the resistance of the undivided circuit between *a* and *b*, and the fraction $\frac{r_1 r_2}{r_1 + r_2}$ expresses the resistance of the shunt circuit between the same points; therefore, the resistance of two parallel conductors is equal to the product divided by the sum of their resistances.

This must be true for every value of r_2 between 0 and ∞;

so that, if we take away the shunt, the resistance r^3 becomes infinite; and giving this value to it in the above equation, which may be written also

$$R' = R + \frac{r_1}{\frac{r_1}{r_2} + 1}$$

the whole circuit resistance becomes,

$$R' = R + r_1.$$

The circuits and resistances of three or more parallel circuits are calculated in the same way.

It happens sometimes that several lines leave the same station, and the question has been raised under what conditions a single battery suffices to work them all at the same time.

Let the resistances of three lines, for instance, be r_1, r_2, and r_3, (Fig. 135), and the intensities in them i_1, i_2, and i_3, respectively, when the current of a battery, whose electro-motive force is E and resistance R, passes parallel through them. We must now find the values of these intensities, and compare them with those which would be obtained if only one of the lines were inserted at a time.

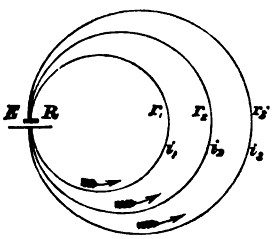


Fig. 135.

By Kirchoff's second law,

$$I R + i_1 r_1 = E,$$
$$I R + i_2 r_2 = E,$$
$$I R + i_3 r_3 = E;$$

whence the intensities in the three lines are,

$$i_1 = \frac{E - I R}{r_1}$$

$$i_2 = \frac{E - I R}{r_2}$$

and

$$i_3 = \frac{E - I R}{r_3}$$

for which expressions, if we can consider $R = 0$, we obtain the same values for the intensities in the three branches, which would be due were only one branch inserted at a time, or,

$$i_1 = \frac{E}{r_1}$$

$$i_2 = \frac{E}{r_2}$$

and

$$i_3 = \frac{E}{r_3}$$

Therefore, we can accept as a law that when the resistance (R) of the battery is inappreciably small in comparison with that of the lines, or other circuits, the current in each of the latter is of the same intensity as it would be were the battery in circuit with that line alone, and that when the resistances of the lines are equal, the currents circulating in them will be equal also.

It more seldom happens, however, that the resistances of several lines are equal than that the currents traversing them from a common battery are required to be so. In the latter case it is necessary to distribute the battery in such a way as to make the intensity in each branch as nearly the same as possible. To find how this distribution is to be made, let us suppose the three lines r_1, r_2, and r_3, (Fig. 136), in which we have to put three parts, E_1, E_2, and E_3, of the whole battery; E_1 being common to all the lines, E_2 common to r_2 and r_3, and E_3 serving r_3 only. Retaining the same designations, we have the following equations for the three lines:—

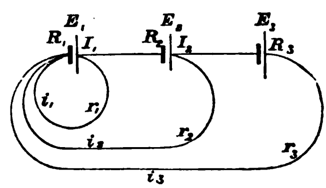


Fig. 136.

$$I_1 R_1 + i_1 r_1 = E'$$
$$I_1 R_1 + I_2 R_2 + i_2 r_2 = E_2 + E_1.$$
$$I_1 R_1 + I_2 R_2 + i_3 (R_3 + r_3) = E_3 + E_2 + E_1$$

in which, when the resistances of the lines are considerable in proportion to the resistances of the elements, we can set $R_1 = R_2 = R_3 = 0$, and the expressions become,

$$i_1 r_1 = E_1$$
$$i_2 r_2 = E_2 + E_1$$
$$i_3 r_3 = E_3 + E_2 + E_1$$

Dividing the two last equations by the first,

$$\frac{E_2}{E_1} = \frac{r_2 - r_1}{r_1}$$
$$\frac{E_3}{E_1} = \frac{r_3 - r_1}{r_1}$$

whence

$$E_2 : E_1 = r_2 - r_1 : r_1$$

and

$$E_3 : E_1 = r_3 - r_1 : r_1$$

proportions which imply that the number of elements E_1 in the circuit of smallest resistance being given, the numbers E_2, E_3, &c., to be added to each of the other circuits must bear the same proportion to E_1 which the difference between their resistances bears to the smallest resistance. More generally if the resistances of the lines were equal, the single battery would produce a like current in each of them; but if not, the battery power which must be added to the lines of superior resistances to produce the same current as in the smallest line, must be exactly proportioned to the superiority of their resistances.

41. *Wheatstone's Balance.*—On the same laws depend the mathematical proof of the truth of the beautiful and useful system of resistance measurement invented by Professor Wheatstone, a description of which appeared in the Philosophical Transactions of 1843.

The poles of a battery, E, Fig. 137, are connected to the points of union *c* and *d* of parallel circuits, r_1, r_3, and r_2, r_4, and between some points, *a* and *b*, in these two conductors a wire, r_5, is inserted. The current takes the course indicated by the arrows, and several complete circuits are formed, for which Kirchhoff's laws provide expressions. I, i_1, i_2, i_3, i_4, and i_5 are the currents, R, r_1, r_2, r_3, r_4, and r_5 the resistances in the several circuits, and E the electromotive force of the battery.

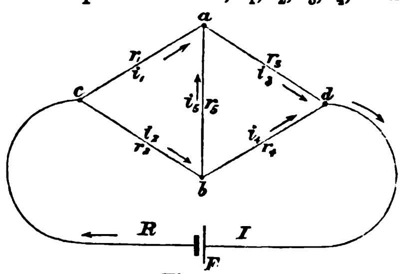


Fig. 137.

For the currents approaching and receding from the points a and b,

$$1) \quad . \quad . \; i_3 - i_5 - i_1 = 0$$

and

$$2) \quad . \quad . \; i_2 - i_4 - i_5 = 0$$

for the circuit r_3, r_4, and r_5,

$$3) \quad . \quad . \; i_3 r_3 - i_4 r_4 + i_5 r_5 = 0$$

and, lastly, for the two parallel circuits,

$$4) \quad . \quad . \; i_1 r_1 + i_3 r_3 - i_2 r_2 - i_4 r_4 = 0.$$

The principle of Wheatstone's balance is based upon the relation which must exist between the resistance r_1, r_2, r_3, and r_4, when the position of the points a and b is so arranged that their electrical tensions are the same, or that no current passes between them when they are joined by a conductor. Supposing this to be the case, the value of i_5 in the above equation becomes = 0, and from 1, 2, and 3 we obtain the values of the intensities in three of the sides, in terms of the remaining one,

$$i_1 = i_3 = i_4 \frac{r_4}{r_3}$$

$$i_2 = i_4$$

These values we set in 4, and have

$$i_4 \frac{r_4}{r_3} r_1 + i_4 \frac{r_4}{r_3} r_3 - i_4 r_2 - i_4 r_4 = 0,$$

and, dividing each side by i_4 and clearing away the fractions, obtain the expression,

$$r_1 r_4 - r_2 r_3 = 0.$$

$$\frac{r_1}{r_2} = \frac{r_3}{r_4}$$

This is, therefore, the relation which must be established between the four sides r_1, r_2, r_3, and r_4 before the condition can be fulfilled that the intensity of the current in the bridge *a b* is null.

The way in which this system is applied for the measurement of resistances will be explained directly. Before we come to that, however, there is a case worth considering which often occurs in testing cables or conductors whose ends have different temperatures—that of a foreign electromotive force in one of the branches of the system. With cables, this arises mostly from earth currents or from electromotive force between the earth plates; in other instances, from thermo-currents.

Let the four resistances A, B, C, and D (Fig. 138) be adjusted so that the current in the balance *a b* is inappreciable, while the intensities of the currents due to the battery E, inserted between the points *c* and *d* in the several branches, are increased or diminished by the current of the element, E_1, set up in the side C. If the intensities of the currents in the circuits under these conditions are α, β, γ, δ, and ε, and R the resistance of the battery between *c* and *d*,

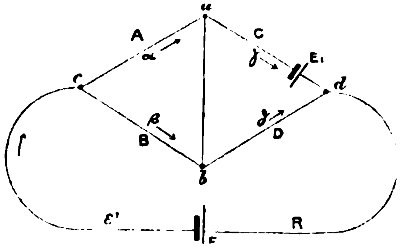


Fig. 138.

1) . . $\alpha - \gamma = 0$

2) . . $\beta - \delta = 0$

3) . . $\varepsilon - \gamma - \delta = 0$

4) . . $A\alpha - B\beta = 0$

5) . . $C\gamma - D\delta = \pm E'$

6) . . $R\varepsilon + D\delta + B\beta = E.$

By eliminating β, δ, and ε with the aid of 1), 2), 3), and 4), we obtain the value of the intensity, γ, in the side c, containing the strange element, in terms of both the electromotive forces E′ and E.

$$\gamma = \pm \frac{E'}{C - \frac{A D}{B}}$$

$$\gamma = \frac{E}{\frac{A(D+R) + B(A+R)}{B}}$$

And from these, the relation between the two electro-motive forces

$$\pm \frac{E'}{E} = \frac{B C - A D}{A(D+R) + B(A+R)}$$

which supplies a method of comparing the electro-motive forces of two batteries. The value of the resistance C, when the relation $\pm \frac{E'}{E}$ is known, is found by the formula

$$C = \frac{A D}{B} \pm \frac{E'}{E} \frac{A(D+R) + B(A+R)}{B}$$

or, when the resistances A, B, C, and D are very great in proportion to R (the battery resistance), the latter may be neglected, and C becomes

$$C = \frac{A D}{B} \pm \frac{E'}{E} \frac{A(D+B)}{B}$$

Lastly, if we suppose E′ = 0, or that there is no electromotive force in the side C, the member

$$\frac{E'}{E} \cdot \frac{A(D+R) + B(A+R)}{R}$$

of the above falls away, and we get the common expression of relations of Wheatstone's balance—

$$C = \frac{A D}{B}$$

Four corollaries from the two laws developed by Kirchhoff have been published by Bosscha, which in many calculations of galvanic circuits are found of great value, frequently saving time in developments.

These corollaries are:—

1. If, in any system of circuits, containing any electro-motive forces, a conductor exists in which the current = 0, the currents in the remaining circuits are not altered in the least degree if the circuit of the conductor in question is divided, or it is removed, together with whatever electro-motive force it may contain, from the system.

2. If the conductor in question contains no electro-motive force, the currents will not be altered, if, after its removal the points between which it previously existed are connected directly with each other. If, on the other hand, it contain an electro-motive force, the points can only be joined again by inserting between them an equivalent electro-motive force.

3. In a system of linear conductors containing electro-motive forces, the current set up in any conductor, *a*, by an electro-motive force contained in any other conductor, *b*, will be identically the same as that which would be set up in *b* by an equal electro-motive force in *a*.

4. If in a system of linear conductors there are two of them, *a* and *b*, in which the electro-motive force in *a* occasions no current in *b*, whatever current may be circulating in *b* will not be altered if *a* is divided or removed, nor will the current in *a* be altered if *b* is divided or removed, however the electro-motive forces in the remaining circuits may be arranged.

42. *Siemens's Apparatus for Testing Cables.*—The testing apparatus, as at present used in the testing-room of Messrs. Siemens, is a modification of their old plan. It was rearranged and endowed with its present form in order to render it available, not only for measurement by the bridge method, but also for measurements of great resistance by deflection of the galvanometer needle, of sensibility of the instrument, of the electro-motive force of the battery, and of charge and discharge of a cable.

For the construction of such an apparatus, the following parts are necessary:—An adjustable resistance coil of 1 to

10,000 units; two branch or proportion resistance coils, of each 10, 100, and 1000 units; a coil of 10,000 units; a galvanometer, two four-sided commutators, a battery commutator, a contact key, a constant element (Daniell's), a battery of *n* elements, and the necessary terminal screws for connecting earth, galvanometer, and cables.

The testing-board, fitted up with the more portable of these articles, is shown in plan, in Fig. 139, with the connections between the various members in dotted lines.

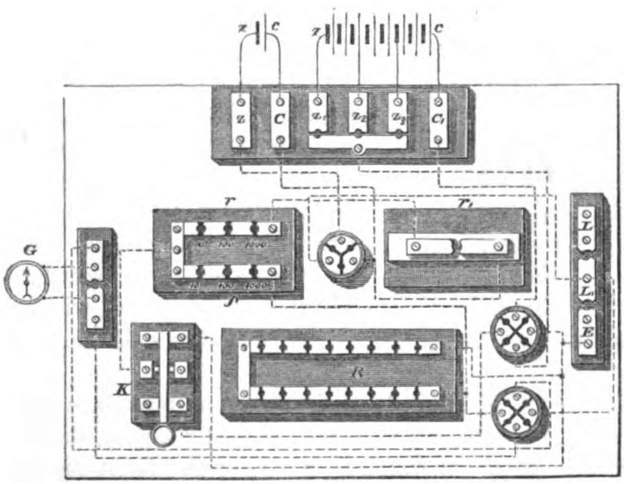


Fig. 139.

These connections are made of thick copper wire, well insulated with gutta-percha; they are led from one point to another, underneath, and their directions indicated by strips of ebony or other wood, let into the top of the board, and polished with it. In the laboratory, however, the operator does better to make these connections in the air, because, in the event of a leakage anywhere, he has them more immediately under his inspection, and can eradicate the disturbing cause with greater ease than if the wires were fixtures.

Fig. 140 shows a general plan of the same, arranged in a more theoretical way. The resistance r_1 (= 10,000 units) is connected in the same circuit as the upper branch, r, of the proportion resistances r and ρ, by which the resistances in these branches may be—

$$r = 10, 100, 1000, \text{ or } 10000,$$

in the upper, and

$$\rho = 10, 100, \text{ or } 1000,$$

in the lower side.

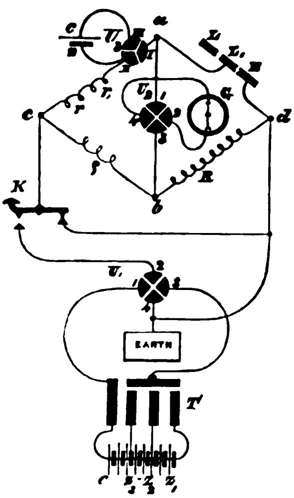


Fig. 140.

The upper circuit includes, also, a triangular commutator, U_3, for completing this circuit, with or without the inclusion of a Daniell's element. The triangular commutator consists of three brass slabs—I, II, and III. The Daniell's cell is connected between II and III, while I and II are in circuit of the bridge. Between I—II and I—III are holes for a contact plug, which, when put in the hole I—II, completes the circuit without the element; and when in I—III, introduces the element into the circuit.

The point of contact, c, of the upper branch, r, with the lower, ρ, is connected with the beam of a key, k, the back or reposing contact of which is to earth; the front or working contact to one corner of the four-sided current director, U_1. The ends of the galvanometer coil are not connected immediately to the corners of the parallelogram, but are intercepted by a current-director, U_2, for enabling the operator to observe the deflection of the needle on either side of the Zero line. Three metal slabs, L, L_1, and E, with holes between them, for the insertion of contact plugs, form the upper right-hand side of the bridge. The earth-plate is connected by a wire to E; L_1 is connected with the upper corner of the bridge; L with the conductor of the cable, at one end, and should both ends be at the disposition of the operator, he connects the other end to E, when he wishes to measure the copper resistance. The purpose of these three slabs is for removing the cable end from the bridge for a certain time, and being able to replace it for the observation of charge and discharge currents. The bar terminals T allow either one-third, two-thirds, or the whole of the battery to be brought into circuit. It remains now to arrange the board for various cable measurements.

43. *Copper Resistance, when both ends of the Cable are on the Board.*—One end of the cable to be measured is attached to L, the other end to E, and a plug is put in the hole L—L_1; a plug is also put into the hole s_1 of the battery commutator T, by which one-third of the battery is put into circuit. The plug in hole I—II of the triangular commutator, U_3, completes the upper branch, $r\ r_1$, without the constant element. The plugs of U_1 are put into the holes, so that either the zinc or the copper current shall enter the cable, as may be required. In U_2, also, two plugs are inserted. In measuring the resistance of a cable conductor, the lever of the key is kept down on its front contact the whole time, and, whenever the resistance, R, is altered, the plug between the slabs, G and G^1 (forming a short circuit across the galvanometer coils), is inserted to prevent the charge and discharge currents passing through and disturbing the needle of the galvanometer.

The current diverges into two circuits from the point *c*, converging again in the point *d* into the main line, *d*, U_1, *c*. The upper circuit includes so much of the resistance, $r\ r^1$, as is left unstoppered, the triangular commutator, U_3, the point of junction, *a*, the terminals L^1, L, cable, E, and *d*. The lower circuit is from *c*, through ρ, *b*, R, to *c*. Between *c* and *d* the circuit is made up of U_1, T battery, U_1, K, &c.

Having obtained a balance of the galvanometer needle, or when the current in the circuit *a*, U_2, G, U_2, *b* is null, the proportion

$$\frac{r}{\rho} = \frac{x}{R}$$

or,

$$x = R\,\frac{r}{\rho}$$

is established. The values which this proportion may have are, obviously—

1. When $r = \rho$

$$\frac{r}{\rho} \text{ may be } = \frac{10}{10}, \frac{100}{100}, \text{ or } \frac{1,000}{1,000}.$$

2. When $r > \rho$,

$$\frac{r}{\rho} \text{ may be } = \frac{100}{10}, \frac{1,000}{100}, \frac{10,000}{1,000}, \frac{1,000}{10}, \frac{10,000}{100}, \text{ or } \frac{10.000}{10}$$

3. When $r < \rho$,

$$\frac{r}{\rho} \text{ may be } = \frac{10}{100}, \frac{100}{1,000}, \text{ or } \frac{10}{10,000}.$$

The limits within which these proportions are confined are therefore, $\frac{10,000}{10} = 1,000$, and $\frac{10}{1,000} = 0,01$; and, since the greatest value of the adjustable resistance, R, is 10,000 units, and the least value one unit, the limits of the measureable value of x with the bridge system so arranged, are—

Maximum: $x = 10,000 \times 1,000 = 10,000,000$
Minimum: $x = 1 \times 0,001 = 0,001$.

Whenever it is possible to do so, it is to be preferred to make the ratio $\frac{r}{\rho} = 1$, and r as nearly equal to R as can be, by which the greatest sensibility of the system is obtained.

44. *Copper Resistance, when only one end of the Cable is on the Board.*—The connections of the board remain the same, except that, instead of the second end of the cable being connected to E, it is connected to earth. The upper circuit is then from c through r, U_3, a, L_1, L, cable and earth; and the lower from c through ρ, b, R, d, and earth.

In measuring the copper resistance of a cable with earth-plates in the circuit, it is necessary (1) to have the plates, both of the apparatus and cable-end, sufficiently large, and buried in moist ground, or sunk in water to avoid the introduction of resistance into the cable circuit; and (2) to have both the plates of the same metal, and of the same quality of metal, at the same temperature, and, as nearly as possible, in water of the same kind, or a current will be set up between them which will make the observed resistance smaller or greater, according as the current due to the plates is in the same, or in the opposite direction to the current of the measuring battery.

45. *Insulation Resistance by Bridge.*—As the resistance of insulation is generally very great, in comparison with that of the conductor of a cable, the proportion $\frac{r}{\rho}$ has to be made as large as possible. The limit to which we may go, in this direction, we have seen is when

$$\frac{r}{\rho} = \frac{10{,}000}{10} = 1{,}000;$$

and, as the greatest value of R is 10,000, cable resistances under ten millions of units may be measured by this method.

The whole force of the battery is introduced by inserting the contact plug in hole z_3 of T. One end of the cable is connected to L, the other insulated. The direction of the current is determined by the position of the two plugs in U_1. The circuits of the currents are obvious.

When the cables are long, or badly insulated, this method of measuring the resistance of their dielectrics is the best; but for short or well-insulated cables it would not be found sufficiently delicate, and the method by comparison of the deflections of the galvanometer needle is to be preferred.

46. *Insulation-resistance by Deflection of Galvanometer Needle.*—The bridge system is interrupted for this measurement, and the current of the whole battery allowed to go in a simple circuit through the galvanometer coils, and into the cable. The resistances r and R are made infinite, and o null, as in Fig. 142, by which the current of the battery goes from the key k, through c, ρ, U_2, coil of galvanometer, the other side of U_2, a, L′ L, cable, through the insulating material to earth, and from earth through U_1, battery, U_1, to key. During the whole time of measuring insulation resistance, the beam of the key is depressed upon the working contact. The plugs of U_1 are placed so as to put the

copper or zinc pole of the battery to earth at pleasure, and those of U_2 so as to determine to which side of the zero line of the galvanometer the needle shall be deflected.

The galvanometers used by Messrs. Siemens with these bridges are either Dubois' sine multipliers or Weber's reflecting galvanometers. Professor Thompson's reflecting galvanometer is well adapted for such work; better, perhaps, than either of the others, as its sensibility is greater than that of the sine instrument, and it is less unwieldy than Weber's.

With a very sensitive galvanometer, and a given battery power, it is sometimes found that the needle is deflected beyond the range of observation. In such an event the operator inserts a shunt by completing the circuit of the upper branch $r\ r$, making it, instead of infinite, equal to some resistance which will take as much of the current from the galvanometer as is necessary. The current goes then (Fig. 141) from the key to c; here it is split into two parts; one goes through ρ, b, U_2, and galvanometer to a, and the other through r to a. At a these parts combine again, and the whole current goes over L' L into the cable. The resistances $r\ r'$ consist of four coils of 10^1, 10^2, 10^3, and 10^4 units, which can be introduced separately or combined, and take off the $\frac{g}{g+r}$ part of the current from the galvanometer (g being the galvanometer resistance). With very rare exceptions these powers of 10 will be found sufficiently comprehensive for supplying the required shunt, and the function of the deflection ϕ of the needle will have to be multiplied with $\frac{g+r}{r}$ in order to arrive at the value

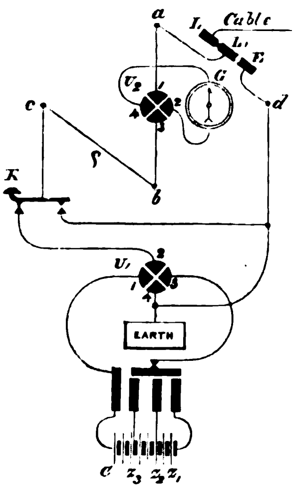


Fig. 141.

which would be obtained were no shunt used and the range of the instrument wider.

47. *Charge.*—This is a method which has two objects: the first is to ascertain the inductive capacity of the cable, and to obtain data for judging of the concentricity of the conductor in the insulating medium; the second is by observing the loss of static charge by recombination of the electricities through the dielectric, in a given time, to conclude upon the degree of its insulation.

The connections of the board for measuring charge are precisely the same as those for insulation by deflection. When the cables are long, it is requisite to employ the shunt resistance *r r′* in order to keep the needle within readable bounds. The plug *g g′* is left out when the throw of the needle is to be observed, and the key pressed down. At the moment of completing the circuit the electro-static charge passes through the galvanometer and enters the cable; the needle is impelled from its position of rest with a sudden jerk to one side, and afterwards continues to oscillate over the zero point until it comes again to rest. The first throw or swing is noted. If the discharge is also to be observed, in order to compare it with the charge, before letting go the key the operator removes the plug from between L′ and L, by which the cable end is insulated from the board.

48. *Discharge.*—As the coils of the galvanometer are seldom entirely free from magnetism, and the needle seldom so exactly centered that the same strength of current gives an equal deflection on each side of the zero line, it is preferable to obtain the first swing of the needle due to the discharge current on the same side as that which was observed for charge. To this end it is necessary only to alter the position of the contact plugs of the galvanometer commutator U_2 before the discharge current passes through, by which the galvanometer coils are reversed in relation to the points *a* and *b*; and, as the discharge is in the contrary direction to the charge, the deflection of the needle will be, for both, on the same side of zero.

After the cable has been left insulated at both ends during one minute, or whatever time may be fixed upon since the removal of the plug L L′, and the plugs of U_2 rearranged, the plug L L′ is suddenly replaced, and the throw of the needle observed. If the time which has elapsed is only a few seconds, and the cable is well insulated, the deflection of the discharge current is almost equal to that due to the charge; but when the interval is long, or the cable indifferently insulated, the greater part of the charge is recombined through the dielectric.

The methods of comparing these two indications was suggested by Dr. Siemens, and may be considered one of the most important test methods in cable work.

Dr. Siemens assumes the strength of the instantaneous current which produces the swing to be proportional to the sine of half the angle of deflection, or

$$i = C \sin. \frac{\phi^\circ}{2}$$

C being a constant of sensibility of the instrument, and i the current producing the deflection ϕ°. For discharging, therefore, i_1 being the returning current and ψ° the swing which it produces, we have

$$i_1 = C \sin. \frac{\psi}{2}$$

The difference of the two: $i = i_1$, expresses the loss during the interval between the two observations, or that portion which has recombined through the insulating coating. The charge being taken as unit, the loss, L, is, therefore,

$$L = \frac{i - i_1}{i} = \frac{\sin. \frac{\phi^\circ}{2} - \sin. \frac{\psi^\circ}{2}}{\sin. \frac{\phi^\circ}{2}} = 1 - \frac{\sin. \frac{\psi^\circ}{2}}{\sin. \frac{\phi^\circ}{2}}$$

Observations of two following charge currents may also be taken as data for calculating the loss, instead of those of a charge and a discharge. The plug L L′ is removed from its place and the key held down; the plug is then replaced for an instant, and again removed. On completing the circuit the needle is observed to swing through an angle of ϕ degrees. After a lapse of one minute, or other given interval, the stopper L L′ is replaced again, and the swing ϕ_1^o due to this second charge current observed.

The quantity of electricity which is measured by the second observation is obviously not that which remains in, but that which has escaped from the cable; in other words, we make good the loss which the charge has sustained in the time between the observations, and this loss, L, is in terms of the whole charge,

$$L = \frac{\sin. \frac{\phi^o_1}{2}}{\sin. \frac{\phi^o}{2}}$$

49. *Constant of Sensibility of the Galvanometer.*—Galvanometers with single magnets do not vary their constants of sensibility considerably unless it is very soon after the magnetising of the needle, but those with astatic systems are very inconstant, altering sometimes during an observation.

For all calculations from measurements by deflection the constant of sensibility must be known. This constant is the deflection produced when an unit of electro-motive force is in circuit with an unit of resistance. The unit of resistance used in measuring insulation of cables is one million, or 10^6 times the small unit used in measuring metallic resistances. This small unit is the resistance of a column of mercury a meter long and a square millimeter transverse section; the great multiple of it is not called an unit, but simply a "million," and the insulation of a cable is expressed as having so-and-so many millions, meaning so-and-so many million times the little column of mercury.

A million metres of mercury, or its equivalent resistance in any other metal, would be very difficult to employ, and we are happily prevented the necessity of employing it to obtain the same deflection of sensibility by using a shunt and a smaller resistance.

In the circuit represented in Fig. 142 the current of the element E has to pass through a resistance, r', and through the parallel circuit g (galvanometer) and R (shunt). The whole resistance is

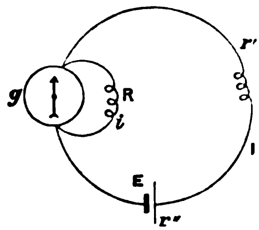


Fig. 142.

$$r' + r'' + \frac{Rg}{R + g}$$

The intensity, I, of the current in r' is the sum of the intensity i in the shunt, and that indicated by the deflection a°. Let the latter intensity be F (a°), then

$$I = F(a^\circ) + i = F a^\circ \left(\frac{g}{R} + 1\right) = \frac{E}{r' + r'' + \frac{Rg}{R + g}} \quad . \quad . \quad (1$$

and the current F (a^0) in the galvanometer is

$$F(a^\circ) = E \frac{R}{(r' + r'')(R + g) + Rg} \quad . \quad . \quad . \quad (2$$

Now, with a given value of R, ρ, and g, to make

$$\frac{R}{r' + r'')(R + g) + Rg} = \frac{1}{1,000,000}$$

we must put

$$R = \frac{g(r' + r'')}{1,000,000 - r' - (g + r'')} \quad . \quad . \quad (3$$

It is sometimes convenient to make

$$\frac{g}{R} + 1 = 100$$

by which

$$R = \frac{g}{99}$$

or the intensity of the current in the galvanometer branch has to be multiplied by 100 to give the current in the main circuit, and with this value inserted in the above formula, the resistance, r', becomes

$$r' = 10,000 - \left(r'' + \frac{g}{100}\right)$$

of which r'' and $\frac{g}{100}$ may often be neglected.

For this measurement by Messrs. Siemens' testing-board, the key K (Fig. 143) reposes upon the back-contact, by which the battery is kept out of the circuit, the plug of the triangular commutator U_3 is put into the hole I-III, introducing the unit element into the branch *a c*, the holes of *r* and ρ are stoppered, and r'(= 10,000) left open, the stoppers L L′ and L′ E, are put in, and lastly the adjustable resistance in the side *b d* is made according to (3, equal to

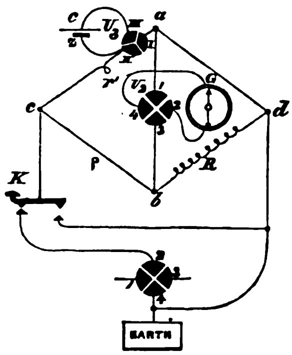


Fig. 143.

$$R = \frac{g\,(10{,}000 + r'')}{990{,}000 - (r'' + g)}$$

The deflection of the needle is obtained on the same side of zero as in the measurement which this constant is to be used for reducing, by means of the commutator U_2. It is the expression of the current due to the unit of electro-motive force and unit of resistance.

50. *Measurement of Electro-motive Force.*—The method of measuring how many times the electro-motive force of the unit cell is contained in the electro-motive force of the battery employed, is the compensation system of Professor Poggendorff, of Berlin. The side *a d*, Fig. 144, is opened by removing the plugs L L′ and L′ E, and *a c* is completed with the unit element. Three circuits parallel to each other are, therefore, formed, combining in the points *c* and *b*, viz.: 1) *c* ρ *b*, 2) *c a* G *b*, and 3) *c* K R *b*. U_1 is stoppered so that the currents of the battery and constant cell oppose each other in the galvanometer circuit; the key is kept down; of the resistance scales, $r = 0$, $\rho = 10$, or 100,

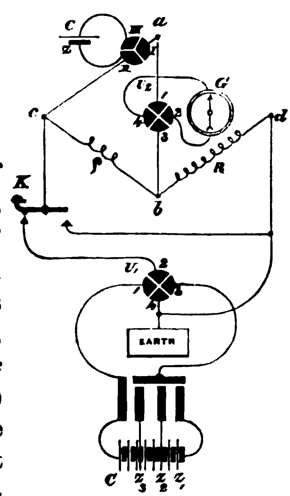


Fig. 144.

or 1,000, according to the strength of the battery, and R is varied until the needle of the galvanometer rests upon the zero-line. When the balance is obtained with, say $\rho = 100$, we alter this side to 110 and get another reading for $R = R_1$. The relation of the electro-motive forces $\frac{E}{E^1}$ is expressed by the equation

$$\frac{E}{E'} = \frac{(R_1 - R) + (110 - 100)}{(110 - 100)}$$

as will be explained afterwards.

These are the principal applications of the beautifully arranged testing apparatus invented by Messrs. Siemens. With some trifling modifications it is equally applicable for measurements by other methods.

51. *British Association Bridge.*—An ingenious electrical balance has been arranged by the sub-committee appointed by the British Association in 1861. The purpose of this balance is for copying standard resistances with great exactness.

Instead of employing proportion resistances of some unalterable value, the ends of the two branches A and C, Fig. 145, enclose a wire, W X, of sensible resistance, contact being made with it by means of a travelling point, *u*. According as *u* is moved to the one side or the other, therefore, resistance is added to one and subtracted from the other branch; and the resistance of W X being small, a balance of great exactness may be obtained between the proportion resistances A and C, which is otherwise liable to be temporarily deranged by inequality in the temperature of these coils.

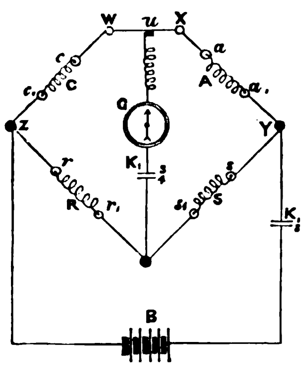


Fig. 145.

Fig. 146 shows a special plan of the board. The two branch coils A and C, of equal, or nearly equal, resistances, are wound upon a wooden reel, C A ; their ends terminate in thick copper connections, which dip into the mercury cups a a_1, c and c_1. The standard resistance S is wound upon a similar reel, and its ends connected to the amalgamated copper wires, which terminate in mercury cups s s_1. R is the resistance whose length is to be adjusted. D is a commutator consisting of two parallel arms of copper connecting the mercury cups d with d_1, and f with f_1, or d with f, and d_1 with f_1. E is a gra-

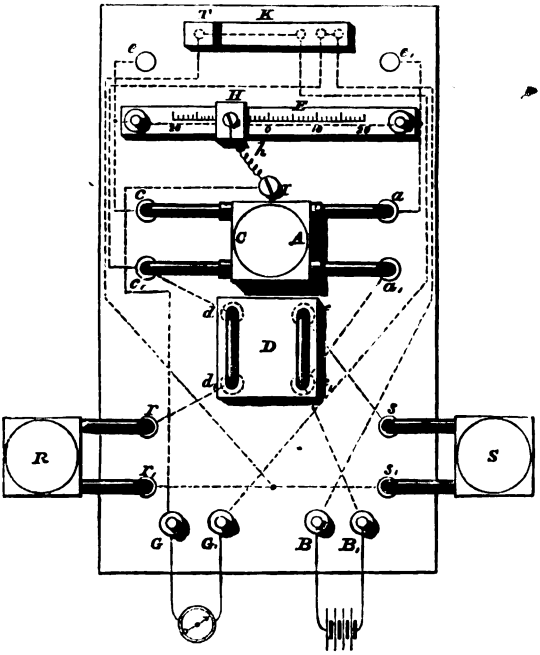


Fig. 146.

duated scale, underneath which the adjusting-wire W X is stretched, and with which the sliding brass piece H is in contact. The contact-key is of original construction; its duties are to close the battery circuit first and then the galvanometer circuit. It is made of three brass springs, 1, 2, and 3, Fig. 147, each insulated from the other at K, and connected by screws with the opposite corners of the bridge; 1 and 2 being in the battery-circuit, 3 at a bottom contact-point, 4 in the circuit of the galvanometer. T is an ebonite button, on which the finger is placed to depress it, and Q a piece of ebonite intended to prevent 2 and 3 making contact with each other, and to push 3 down upon 4.

The resistance-wire R being approximately adjusted is placed opposite to the standard in the bridge, and the point

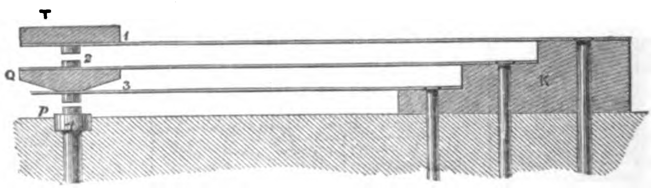


Fig. 147.

U moved along the wire W X until, on depressing the key, the galvanometer indicates no current. The commutator D is then reversed, by which R and S exchange places, and the contact-point U moved again until the balance is obtained as before. If the balance is obtained without moving U, it is evident that R and S are equal to each other, and that the resistances A + X *u* and C + W *u* are also equal, indicating, at the same time, a small inequality between the values of A and C. If the balance is only obtained by moving *u*, the direction in which this movement takes place shows whether the wire R is too long or too short, and if R is a known length of the same wire as W X, the distance through which the contact is moved gives a measure of the excess or deficiency of the length of R. When the length of R has been adjusted till the balance is attained, the proportion coils, A and C, are removed and replaced by others, A′ and C′, whose resistances are ten times as great. A second adjustment is made with these coils, which are afterwards substituted by two others of still greater resistance; and in this way any required degree of accuracy may be attained.

The connections (shown by dotted lines) between the mercury-cups, &c., are made with stout copper wires. The bridge may be used for other than copying purposes, by inserting proportion resistances between *a a′* and *c c′*, the comparison resistance or set of adjustable coils between *s* and *s′* and the resistance to be measured between *r* and *r′*. As the resistance of the wire, W X, might be embarrassing in the general employment of the bridge, it may be short-circuited by a wire between the mercury cups, *e* and *e′*.

52. *Balance formed by a Bisected Wire.*—Balances, the two proportion resistances of which are made variable by moving the point of bisection of a wire, are the most delicate and best adapted for measuring very small resistances; they are, of course, of more use in the physical laboratory than in the testing-room.

Fig. 148 represents a perspective view of the wire bridge constructed by Dr. Siemens for use in his laboratory at Berlin, and with which the mercury unit of resistance was determined, and most of the elegant experiments made by that able physicist carried out.

Upon three thick slabs of vulcanite, *a a*, *a′ a′*, and *a″ a″*, which rest upon a table, is supported the brass guide, A A, on the top of which is a rack, D D, whose teeth engage with those of a horizontal pinion underneath the carriage B B, with which it travels when the milled head C is turned to the right or left. The same slabs of vulcanite support a brass scale, *m m*, a metre long, graduated in millimetres; in front of the scale is stretched, between insulated metal clamps, a fine platinum wire, *w w*, of exactly a metre in length between the clamps, passing between two platinum contact rollers, G, carried by B B. The clamps, between which the ends of the wire are held, are in metallic connection with the bolts and couplings, E E, and from these through thick copper bars to the opposite corners, 1 and 2, of a commutator, S. The other corners, 3 and 4, of S are connected by similar bars with the clamps K K in front. In the clamps K K are sliding connecting rods, L L, between which and the front contact H of a key, J, the standard resistance W, and the resistance X, which is to be measured, are connected.

The wire, bisected by the contact rollers G, therefore forms

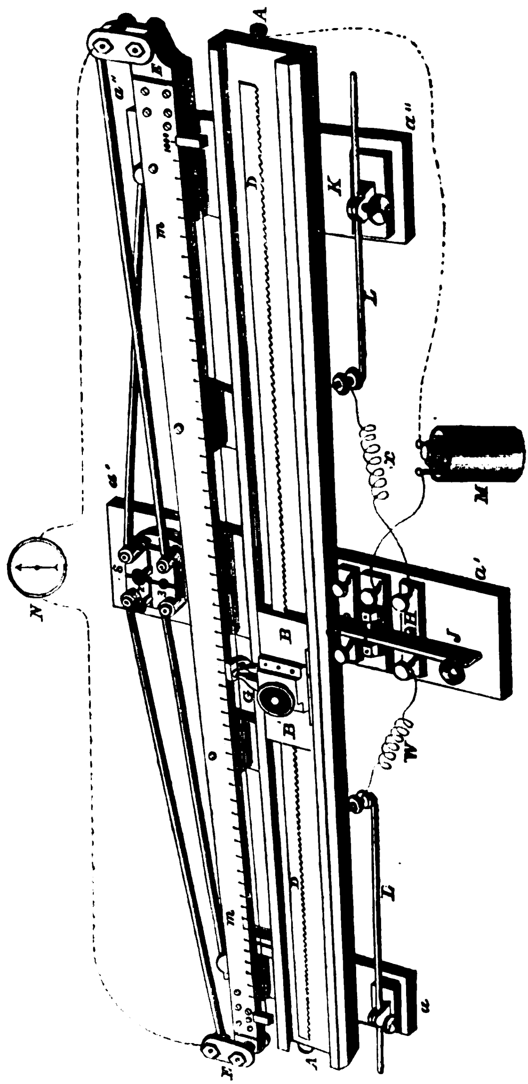


Fig. 148.

two sides of the bridge, and between its ends the galvanometer N is inserted. A Daniell's element is inserted between the lever of the key and the brass stage A.

The galvanometer used with this bridge is one of Weber's construction, with a polished steel mirror. With a single Daniell's element, when the currents of the system are balanced, if the contact rollers be moved 0,1 millimetre out of their place, the galvanometer mirror shows a deflection, represented by five divisions of the reflected scale passing before the fibre of the telescope.

The resistance of the platinum wire is about twenty units. It is seldom procurable absolutely cylindrical, although drawn with great care through stone; the conicalness, however, rarely exceeds an amount which throws the resistance middle-point above 0,2 millimetre from the middle-point of the length.

The resistance of passage from the wire to the clamps E E is a source of some little annoyance in using this really beautiful apparatus, and renders it inapplicable, with the same degree of accuracy, when the contact rollers are far from the middle.

The position of the roller is read off by a nonims carried by the waggon, B, along the metre scale, *m m*. One reading only is necessary for giving the value of x:—

$$x = W \frac{a}{1{,}000 - a}$$

a being the length read off by means of the nonims from the index to one end of the bridge. A second reading is, however, usually made, by inverting the wire by means of the commutator S, and reading the length a' with the rollers on the other side of the middle point of the wire, by which we get

$$x = W \frac{1{,}000 - a'}{a'}$$

If no appreciable resistance exists in the junction of the wire with its clamps, and the electrical and geometrical middle points of the wire coincide, $a + a' = 1000$; but as this is rarely the case, the value of x is given with the nearest approximation to the truth by the formula—

$$x = W \frac{1,000 + a - a'}{1,000 + a' - a}$$

When double readings are made—that is, when in each experiment the comparison and measured resistances are inverted—there is no need for having the bisected wire so rigidly in contact at both ends, provided the contact at the end from which the lengths are measured is without sensible resistance, and the resistance of the other end does not change during the double observation. On this principle we have constructed a bridge-balance of this kind, in which the bisected wire is soldered between good contact clamps at one end, and at the other is held by a metallic block running upon an adjusting screw, by which the wire can be strained or slackened at pleasure, the total length not appearing, the resistance x being given by

$$x = W \frac{a}{a'}$$

A method of increasing very materially the sensibility of the system was used by us in Dr. Siemens' laboratory in 1861. It consisted in inserting between the ends of the platinum wire and the points branching to the galvanometer and resistances W and x, an equal resistance coil, r, which amounts, in fact, simply to lengthening the bridge-wire. With this arrangement, the contact rollers can be moved considerably farther from the middle point with less error. The resistance x by a single reading, in this way, therefore, is—

$$x = W \frac{a + r}{1,000 - a + r}$$

This method of testing with continuations was not practised to any great extent, however, and was, we believe, never published until Dr. Matthiessen constructed a similar arrangement with his apparatus, in connection with the Unit

Committee, which probably suggested the idea of the adjusting wire in the British Association balance.

53. *Determination of the Constants of Galvanic Elements.*—We have already seen that, according to Ohm's law, the intensity of the current in any galvanic circuit is a function of the electro-motive force, and resistance in that circuit; or that

$$I = \frac{E}{R}$$

R being the sum of all the resistances, and E the sum of all the electromotive forces in the circuit; and have considered the value of R as the sum of resistances interior and exterior to the battery, by which the same value of I is expressed by

$$I = \frac{E}{r + r_1}$$

r being the resistance due to the passage of the current from the plates of the elements to the fluids, and *vice versâ*; and r_1 that which is exterior to the element—interposed resistance.

Resistances we can compare directly, or calculate from given dimensions and conducting powers of materials; intensities we can also compare directly with each other, or with some given amount of work done in the decomposition of water or salt solutions, or in the deflection of a magnetic needle, or in heat developed; and electro-motive forces we can compare with each other by their known relations to these two combined.

54. *Determination of the Resistances of Galvanic Elements.*—There are different ways in which this may be done. The readiest is with the aid of a tangent galvanometer. The element whose resistance is to be measured, is put alone in the circuit of the galvanometer, the deflection of whose needle is observed; a resistance is then inserted in the circuit, which lessens the intensity of the current and diminishes the deflection of the needle to ϕ' degrees. The two intensities are—

$$C. \tan. \phi = \frac{E}{x + r^1}$$

and

$$C. \tan. \phi' = \frac{E}{x + r' + r''}$$

of which x is the resistance of the element, r' that of the galvanometer and connections, and r'' that added to reduce the deflection.

By combining these two equations, C and E are eliminated, and the resistance x of the element obtained in the same measure as that in which r' and r'' are expressed in

$$x = \frac{r' \tan. \phi - (r' + r'') \tan. \phi'}{\tan. \phi' - \tan. \phi}$$

If we use the galvanometer as a sine instrument, instead of reading off the angles of deflection ϕ and ϕ', the coils being turned through the angles a and a', the formula becomes

$$x = \frac{r' \sin. a - (r' + r'') \sin. a'}{\sin. a' - \sin. a}$$

When neither a sine nor tangent galvanometer, but only a galvanoscope, the functions of whose needle-deflections are unknown, is at the command of the operator, he can determine exactly the resistance of the element in the following way:—

The element to be measured is connected in the circuit of a rheostat or other wire, whose length is adjustable, and that of the coil of the galvanoscope.

If the resistance of the galvanoscope coil be g, that of the rheostat wire r, and that of the element x, the needle being deflected, say a degrees from the magnetic meridian, the intensity, according to Ohm, is

$$F(a^\circ) = \frac{E}{r + g + x},$$

E being the electro-motive force, as before, F the unknown function of the angle, and therefore $F(a^\circ)$ the intensity. A resistance equal to $r + g$ being connected between the poles of the element, the current will be split into two equal parts, one part going through the galvanometer and rheostat, the other through the shunt resistance, which is equal to their sum. The consequence is that the intensity of the current in the galvanometer branch is decreased, while the intensity in the whole circuit is increased to

$$2 \text{ F } (\beta^{\circ}) = \frac{\text{E}}{\frac{r+g}{2} + x} = \frac{2 \text{ E}}{r + g + 2x} \quad . \quad . \quad . \text{ (I.}$$

β° being the new deflection due to this altered state of things. The shunt is taken away, the needle returns again to a° and the current has its original intensity, F (a°). The resistance r of the rheostat is then increased by r', until the needle descends from a° to β°, with the corresponding intensity.

$$\text{F } (\beta^{\circ}) = \frac{\text{E}}{r + r' + g + x} \quad . \quad . \quad . \quad . \quad . \text{ (II.}$$

Dividing (I by (II, the value of x is obtained.

$$x = r'.$$

55. *Determination of the Electro-motive Forces of Galvanic Elements.*—In calculating the insulation resistances, and other electrical conditions of submarine cables from the deflections of a needle, it is indispensably necessary to know the electro-motive force of the battery used in the measurement. The methods of comparing the electro-motive force of a battery with that of some constant element, taken as unit, are very various. Sometimes the electro-motive forces of elements are referred to the amount of work which, with an unit of resistance in the circuit, they are capable of performing in an unit of time; as, for instance, the measurement by the voltameter.

The intensity I of the current in any closed circuit is directly proportional to the volume of water which it decomposes in a given time, and when the resistance R is constant, the volume decomposed is also proportional to the electro-motive force, for when the unit of resistance is determined upon, or R = 1 is set in the expression of Ohm's fundamental equation, $\text{I} = \frac{\text{E}}{\text{R}}$, we get the equation I = E, that is to say, if the whole resistance of the circuit be = 1, the electro-motive force will be equal to the intensity, which is also equal to the number of cubic centimeters of gas developed in a minute. The unit of resistance in this case has been taken as that of a prism of copper, 1$^{\square}$ millimeter section, and 1 meter long.

According to this method of determination, the electro-motive forces of the following elements are:

Zinc—Carbon element		—Deleuil	= 839
Ditto	ditto	Stohrer	= 777
Zinc—Platinum ditto		Grove	= 829
Zinc—Copper	ditto	Daniell	= 470

Or, were the resistance of the circuit that of a copper prism of the above dimensions, each of these elements would decompose so many cubic centimetres of gas in one minute, as is indicated by the number set opposite to it in the list.

56. Another method of measuring the electro-motive force is by means of the unit adopted by Regnault, namely, the electro-motive force of a thermo-electric pair of copper-bismuth wires, whose soldered ends are kept at the constant temperatures of 0° C., and 100° C. To measure the electro-motive force of any element, Regnault combines a number of these copper-bismuth elements together, until, when the currents of the two batteries are opposed, they exactly compensate each other. The number of thermo-elements required to do this is, therefore, the measure of the force of the element under inquiry; and, as the force of each individual thermo-element is very small, the number brought to balance a galvanic element is great enough to allow of very nice adjustment, and would give very good results if the electro-motive forces of the individual thermo-elements were practically equal, which unhappily is not the case.

The electro-motive force of a Daniell's element, whose copper-plate is immersed in a concentrated solution of sulphate of copper, and whose zinc is immersed in dilute sulphuric acid of the strength of 1 part, by weight, of acid, to 4 parts of water, is now usually adopted as the unit of electro-motive force.

57. Fechner's method of comparing the electro-motive forces of two elements consists in measuring the intensities of the two currents, when the resistances are equal. He prefers to employ a galvanometer with a long thin wire, making many turns round the needle, besides a considerable resistance in order to be able to neglect the resistance of the element itself.

58. Another and preferable method is mentioned by Wiedemann. The two elements are connected up in the same circuit with a tangent galvanometer, or other apparatus for measuring intensity; first, so that their currents go in the same direction, and secondly, in contrary directions.

Let

The electro-motive forces be.............. = E and E',
the resistances of the elements........... = R and R',
the interposed resistance .... = r, and
the intensities of the sum and difference = I_s and I_d

then

$$I_s = \frac{E + E'}{R + R' + r}$$

$$I_d = \frac{E - E'}{R + R' + r}$$

whence

$$E' = E \cdot \frac{I_s - I_d}{I_s + I_d}$$

59. Another method, requiring, like the last, two observations for obtaining the necessary data for comparison, is that commonly resorted to when no galvanometer is at hand; a galvanoscope will then fulfil all that is required, in conjunction with a sufficiently well arranged adjustable resistance scale or rheostat.

One of the elements, E, whose resistance is r, is first connected in the circuit of the galvanoscope (resistance g) and of the adjustable resistance R. A deflection of, say ϕ degrees, is obtained and noted. The other element, E', whose resistance is r', is then put into the circuit, in the place of E, and the resistance altered to R_1, until the needle is again deflected ϕ degrees.

The intensity with the first element is

$$\frac{E}{R + g + r}$$

and that when the second element is used,

$$\frac{E'}{R_1 + g + r'}$$

These expressions equalled give the value of E_1, the electro-motive force of the second element in terms of that of the first,

$$E' = E. \frac{R + g + r}{R_1 + g + r'}$$

The resistances, $R + g$ and $R_1 + g_1$ may be made so great in comparison with r and r_1, that the latter may be neglected, and the calculation simplified by the disappearance of these magnitudes from the numerator and denominator of the fraction, or

$$E' = E. \frac{R + g}{R_1 + g}$$

It sometimes happens that a large electro-motive force has to be measured by a comparatively small one, as in measuring the battery used for testing the insulation resistances of telegraph cables by the force of a Daniell's cell. In this case it is better to use a shunt for obtaining the common deflection, ϕ degrees. If both the batteries are large, a shunt may be used in both measurements with advantage.

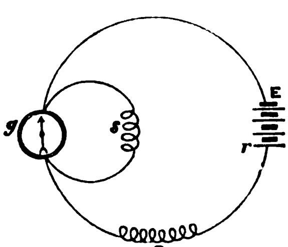


Fig. 149.

The battery E (Fig. 149) has a resistance r units, the galvanometer g units, the shunt s units, and the interposed resistance R units; we get a deflection of the needle through ϕ degrees. The battery is substituted by E^1 with r^1 resistance, the shunt being changed to s^1 till the needle is again deflected ϕ degrees, while R and g remain unaltered.

The equal intensities in the galvanometer circuits are—

$$f(\phi) = \frac{E}{(R + r)\left(1 + \frac{g}{s}\right) + g}$$

and

$$f(\phi) = \frac{E'}{(R + r')\left(1 + \frac{g}{s'}\right) + g}$$

from which

$$E' = E\,\frac{(R + r)\left(1 + \frac{g}{s}\right) + g}{(R + r')\left(1 + \frac{g}{s'}\right) + g}$$

A large battery, E^1, being compared with a small one, E, the shunt is only used in the case of the large one, and $s = \infty$ may be inserted in the above formula, by which

$$E' = E\,\frac{R + r + g}{(R + r')\left(1 + \frac{g}{s'}\right) + g}$$

60. Professor Wheatstone's method is as follows:—he connects the element, E, to be measured, in circuit with a galvanometer, while the whole resistance of the circuit is R. The resulting deflection is $\phi°$. He then adds r units to the circuit until the deflection is reduced to $\phi°_1$. These deflections being noted, he puts the constant element E_1 in the place of E, adjusts the new resistance R_1 of the circuit until the needle is deflected ϕ degrees, and adds to this r_1 units, until this deflection falls to ϕ_1 degrees as before.

From these observations he has four expressions—

$$F(\phi°) = \frac{E}{R} \qquad F(\phi°) = \frac{E_1}{R_1}$$

$$F(\phi_1°) = \frac{E}{R + r} \qquad F(\phi_1°) = \frac{E_1}{R_1 + r_1}$$

$F(\phi^{\circ})$, $F(\phi_1{}^{\circ})$, R, and R_1 eliminated,

$$E = E_1 \frac{r}{r_1}$$

61. Ohm's method, although it has rendered good service to the science in being the means of measurements of great value by Professor Poggendorff, is less to be recommended, as it depends upon the correctness of the functions of the galvanometer deflections; whereas all those methods from which these functions are eliminated are to be preferred. By the method invented by Professor Ohm, a galvanometer and set of resistance coils are connected in circuit with the elements to be measured, and the intensities observed with two different values of the interposed resistance. E being the electro-motive force, R_1 the resistance of the element, r_1 and $r_{\prime\prime}$ the two interposed resistances, and $I_{\prime}$ and $I_{\prime\prime}$ the observed intensities,

$$I_{\prime} = \frac{E}{R + r_{\prime}} \quad \text{and} \quad I_{\prime\prime} = \frac{E}{R + r_{\prime\prime}}$$

whence

$$E = \frac{(r_{\prime} - r_{\prime\prime})\, I_{\prime}\, I_{\prime\prime}}{I_{\prime\prime} - I_{\prime\prime}}$$

Thus E, which is expressed in arbitrary units of resistance and intensity, may be compared with the E measured in the same way, of some constant or unit element, or $I_{\prime}$ and $I_{\prime\prime}$ may be expressed in cubic centimetres of water decomposed in a minute, and $r_{\prime}$ and $r_{\prime\prime}$ in the units of copper prism mentioned before.

62. *Compensation Method of Poggendorff.*—This is the most elegant of all the methods yet introduced. It has, in addition to the advantage of comparing the electro-motive forces of two elements or batteries by a single observation, that of being independent of any detrimental polarisation. This is one of the few null-methods which are applicable in electricity; that is to say, one of those methods of measurement in which we balance the currents either of two batteries or of two circuits, so that we have a circuit whose electrical conditions are such that, if we insert a galvanometer, no traces of current can be perceived.

Two batteries, E and E_1 (Fig. 150), are connected parallel between the points *b* and *c*, so that their currents are opposed to each other, and between the same points a conductor whose resistance is R_1 is inserted. Let the resistance of the circuit *c* E *b* be R, that of *c* E_1 *b* be R_2, and let the intensities of these circuits be i, i_1, and i_2, as in the figure, then

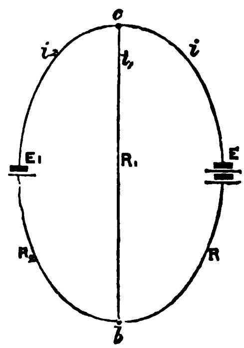


Fig. 150.

$$1) \quad . \quad . \; i - i_1 + i_2 = 0$$
$$2) \quad . \quad . \; R\,i + R_1\,i_1 = E$$
$$3) \quad . \quad . \; R_2\,i_2 + R_1\,i_1 = E_1$$

Dividing 2) by 3),

$$\frac{R\,i + R_1\,i_1}{R_2\,i_2 + R_1\,i_1} = \frac{E}{E_1} \quad . \quad . \quad . \quad (4$$

For the determination of which it would be needful, in addition to the values of R, R_1, and R_2, to know the values of i, i_1, and i_2. The same is done, however, by reducing the intensity in one of these circuits to nothing, by which the remaining two become equal to each other. By adjusting one of the resistances, R or R_1, we arrive at a point where the intensity i_2 in the circuit *c* E_1 *b* is reduced to nothing, by the currents of its proper battery E_1 and of E being balanced.

Where this is the case,

$$i_2 = 0$$

and equation 1) becomes

$$i - i_1 = 0$$

or $i = i_1$.

These values set in (4, we obtain the relation of the two electro-motive forces—

$$\frac{R_1 + R}{R_1} = \frac{E}{E_1} = \frac{R}{R_1} + 1$$

from which we see that with this method it is impossible to compare the electro-motive forces of two batteries when they are equal, and R_1 a measurable quantity; because if

$E = E_1$, it follows, from the above equation, that $R = R_1 + R$, which could only occur if either R, the resistance of the element and circuit *c* E *b*, were nothing, which is impossible, although it may be made comparatively small; or if the resistance R_1 were infinite, in which case $\frac{R}{R_1} = 0$, and the above expression would become $\frac{E}{E_1} = 1$, that which is equivalent to setting the batteries in a single circuit in opposite direction through the galvanometer.

In practice, it is necessary to consider the resistance of the battery E, and the resistance inserted in the same circuit between the points *c b*, as separate magnitudes; because it is not always that we can make the resistance exterior to the battery so great as to be able to neglect entirely the internal resistance without error.

The circuit as arranged for comparing the electro-motive force of a battery with that of a single cell is as follows:—

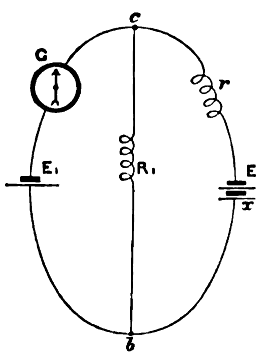


Fig. 151.

The battery is inserted in the part circuit *c* E *b* (Fig. 151), with a coil of wire of known resistance, *r*; in the opposite part-circuit, *c* E_1 *b*, a galvanoscope, G, is inserted, with the constant cell E_1; and, from the points of junction, *c b*, of the two part-circuits, is the adjustable resistance scale R_1.

If the resistance of the battery is *x*, the resistance of *c* E *b* is

$$R = r + x$$

and the currents being balanced, the relation of $\frac{E}{E_1}$ is

$$\frac{E}{E_1} = \frac{r + x + R_1}{R_1}$$

The resistance of an element is generally known approximately, and if the battery is composed of *n* similar elements, of which each has ρ units resistance, it is near enough to set $x = n\rho$, in the above formula; but it is better, where great exactness is desired, to make two observations with the same batteries, E and E′, with other resistances, r_1 and R'_1, in order to eliminate x altogether.

Thus, by the first measurement with R_1 and r, we have

$$\frac{E}{E_1} = \frac{r + x + R_1}{R_1}$$

and by another measurement, with R'_1 and r_1,

$$\frac{E}{E_1} = \frac{r_1 + x + R'_1}{R'_1}$$

which, being combined* and x eliminated, give

$$\frac{E}{E_1} = \frac{(r - r_1)(R_1 - R'_1)}{(R_1 - R'_1)}$$

a formula in which differences of resistances only appear. The measurement may be made without knowing the values of either r or R_1; as it is only necessary to note the difference, Δ, the addition to or subtraction from the side c E b, which compensates a difference, Δ', in the same sense, in the circuit c R_1 b, and we have

$$\frac{E}{E'} = \frac{\Delta + \Delta'}{\Delta'} = \frac{\Delta}{\Delta'} + 1.$$

Mr. Varley has pointed out to us that which he considers a source of objection to this method. It is that the tension of the constant cell is different in the circuit in which its current is 0, to that which it would be if the circuit were closed without this condition, while we measure the force of the battery E, whose elements have only a tension due to an ordinary closed circuit. This objection does not, however, interfere with the correctness of the system; for as the unit cell

* These two measurements enable the operator to ascertain the resistance of the battery E. If, instead of eliminating x, we eliminate $\frac{E}{E'}$, and seek the value of x, we get

$$x = \frac{R_1(r' + R'_1) - R'_1(r + R_1)}{R'_1 + R_1}$$

And by dividing this expression by n, the number of elements in the battery E, we get the average resistance of each of the elements composing it.

is always in the same condition at the moment the observation is made, it follows that we need only alter our phraseology and term the unit of electro-motive force, that of a certain element in those precise conditions of tension, and as the difference between the tensions of the poles of the same kind of element under two given conditions must be always the same, it is easy to deduce from experiment the constant with which the values found must be multiplied, in order to give the first comparison.

In measuring the electro-motive force of a battery of *n* similar elements, in series, it will always be found that the observed value is less than *n* times the observed electro-motive force of each single element. This is explained by the fact that the decompositions and recompositions which take place in the single element are due only to the formation of its current; whereas, in each of the *n* elements under consideration, these decompositions and recompositions are due to two causes—first, to the formation of its proper current; secondly, to the conduction of $n - 1$ times this current — that of the remaining elements. This action gives rise to an impoverished solution in the compartment of the negative metal and to a contrary polarisation.

There are other excellent methods; but the foregoing are the most important, and the last of them can be recommended as the best.

63. The following comparisons between the electro-motive forces of pairs of metal plates in a single fluid medium were made by Professor Poggendorff with his method of compensation.

The alternate relations of three metals were always measured at the same time, all three being placed in the same fluid. It has been explained that the electro-motive force of a pair of metal plates is the difference between the electro-positiveness of the two metals, when immersed in the same fluid. If three different metals are taken in the order of this electro-positiveness, and the difference of the first and second be measured, and then the difference between the second and third, it is evident that the difference between the first and third must be equal to the sum of the other two differences. Imagine a scale on which the distances from a common point, *o* (Fig. 152), to certain heights, *a b c*, represent the electro-positive polarisations of three metals, A, B, C, when plunged into water; then the distance *a b*, which is the difference between their electric conditions, will be the expression of the electro-motive force of a galvanic pair composed of the metals A and B, and the distance *b c* will be similarly the electro-motive force of a pair of B and C. A pair of plates of the metals A and C will evidently have an electro-motive force, *a c*, equal to the sum of the two electro-motive forces *a b* and *b c*.

Fig. 152.

This will also be observed in the following table; the sum of the two first values being very nearly equal to the third of the same series.

A. Two metals and one fluid.
(The unit in which the electro-motive forces are expressed is that of a Daniell's Element.)

I. In sulphuric acid (sp. gr. = 1·838) 1 part, water 49 parts.

1. Zinc—Tin	0·409
Tin—Copper	0·410
Zinc—Copper	0·824
2. Zinc—Copper	0·837
Copper—Silver	0·214
Zinc—Silver	1·053
3. Copper—Mercury	0·356
Mercury—Platinum	0·231
Copper—Platinum	0·604

II. In nitric acid (sp. gr. = 1·222) 1 part, water 9 parts.

4. Zinc (amalgamated)– Copper	0·882
Copper—Platinum	0·616
Zinc (amalgamated)—Platinum	1·495

III. In muriatic acid (sp. gr. = 1·113) 1 part, water 9 parts.

5. Zinc (amalgamated)—Copper	0·788
Copper—platinum	0·743
Zinc (amalgamated)—platinum	1·537

6. Copper—Silver	0·152
Silver—Platinum	0·620
Copper—Platinum	0·771

IV. In caustic potash 1 part, water 6 parts.

7. Zinc—Iron	1·003
Iron—Silver	0·201
Zinc—Silver	1·198
8. Zinc—Antimony	0·541
Antimony—Platinum	0·709
Zinc—Platinum	1·257

V. In carbonate of soda—water—concentrated solution.

9. Zinc—Iron	0·832
Iron—Copper	0·072
Zinc—Copper	0·909
10. Zinc—Tin	0·235
Tin—Platinum	0·842
Zinc—Platinum	1·078

VI. In chloride of soda—water—concentrated solution.

11. Zinc (amalgamated)—Iron	0·476
Iron—Copper	0·260
Zinc (amalgamated)—Copper	0·743
12. Zinc—Copper	0·672
Copper—Platinum	0·673
Zinc—Platinum	1·346

VII. In bromide of potassium 1 part, water 6 parts.

13. Zinc—Copper	0·650
Copper—Platinum	0·452
Zinc—Platinum	1·102
14. Zinc—Iron	0·280
Iron—Silver	0·439
Zinc—Silver	0·726

VIII. In iodide of potassium 1 part, water 4 parts.

15. Zinc—Iron	0·447
Iron—Platinum	0·427
Zinc—Platinum	0·864
16. Zinc—Tin	0·439
Tin—Copper	0·051
Zinc—Copper	0·499

IX. In cyanide of potassium 1 part, water 6 parts.

17. Zinc—Silver	0·545
Silver—Iron	0·420
Zinc—Iron	0·967
18. Zinc—Copper	0·052
Copper—Bismuth	0·818
Zinc—Bismuth	0·874

B. Two metals and two fluids.

a) Iron in diluted sulphuric acid—1 part acid, and 49 parts water; Copper in concentrated solution of sulphate of copper	0·461
b) Copper in concentrated solution of sulphate of copper; Platinum in nitric acid (sp. gr. 1·34)	0·711
c) Iron in sulphuric acid; Platinum in nitric acid	1·177

The following determinations were made by the same physicist with Ohm's method:—

I. Grove's Element.

Zinc in diluted Sulphuric acid	(1 : 4);	Platinum in nitric acid	(fuming)	=1·812
Ditto	(1 : 4);	Ditto	(sp. gr. 1·33)	=1·678
Ditto	(1 : 12);	Ditto	(ditto 1·33)	=1·603
Ditto	(1 : 4);	Ditto	(ditto 1·19)	=1·558
Ditto	(1 : 12);	Ditto	(ditto 1·19)	=1·512
Zinc in sulphate of zinc solution;		Ditto	(ditto 1·33)	=1·550
Zinc in solution of common salt;		Ditto	(ditto 1·33)	=1·765

II. Daniell's Element.

Zinc in sulphuric acid, diluted	(1 : 4);	Copper in sulphate copper solution	1·000
Ditto	(1 : 12);	Ditto	0·906
Ditto	(1 : 12);	Copper in nitrate of copper solution	0·926

The foregoing are a few of the numerous valuable comparisons with which Professor Poggendorff has enriched the science of galvanic electricity. Others of equal value have been made by Joule, Wheatstone, Svanberg, and various other physicists. They all agree pretty well amongst each other, considering that different methods were employed in the comparisons. As an instance, the electro-motive force of Grove's element, measured by one of Daniell's, is, according to

Poggendorff	1·812 to 1·670
Joule	1·870
Buff	1·787
Levy and Saweljew	1·920
Beetz	1·708
Regnault	1·732

The differences are so slight as to be amply accounted for by small inequalities in the degree of concentration of the fluids employed.

V.—Units of Resistance.

64. *Siemens' Mercury Unit.*—The best of all the arbitrary units of electrical resistance is that of a prism of mercury defined and determined by Dr. Werner Siemens.* The want of agreement between the resistance *étalons* distributed by Jacobi, induced Dr. Siemens to direct his attention to the introduction of some method of constructing an unit whose reproduction, with small chance of error, would be a matter of comparative facility.

The metal, mercury, adapts itself best to this purpose; its conducting power, as we have already said, is less than those of the other pure metals, while its molecular structure at the same temperature is always the same.

The difficulty first experienced was to get a vessel in which the mercury could be contained, and glass tubes were selected as giving an unalterable form to the body.

The unit of resistance which Dr. Siemens defined is that of a prism of pure mercury 1 $^{\square}$ millimetre section and 1 metre long, at 0° C. Glass tubes are generally irregularly conical, very seldom, for any length, cylindrical, so that, in the selection of uniformly conical tubes consisted the principal difficulty. From a great number of glass tubes of different calibres, cut to the length of a meter, a few were selected as being most uniform, and the amount of their conicalness

* Pogg. Ann., Bd. cx., Seite 1.

quantitively determined with the aid of a drop of mercury sucked into one end, and its length measured at intervals along the whole length. The effect which conicalness has upon the resistance was calculated as follows:—The tube is regarded as a truncated cone, A, B, C, D (Fig. 153), whose parallel bottom and top have the radii R and r, and whose length is l. At the distance, x, from the top, suppose a disc, M N, of the thickness $d\,x$, and radius z, to be drawn; then if W is the resistance of the cone, in the direction of its axis, and d W the resistance of the disc M N, in the same direction,

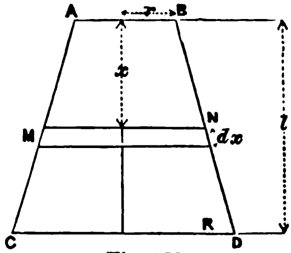


Fig. 153.

$$d\,W = \frac{d\,x}{z^2\,\pi}$$

and

$$z = \frac{(R - r)x}{l} + r$$

This value of z differentiated gives

$$\frac{d\,z}{d\,x} = \frac{R - r}{l}$$

$$d\,x = \frac{l}{R - r} \,.\, d\,z$$

which we must insert in the first equation to obtain the resistance of the differential disc.

$$d\,W = \frac{l}{(R - r)\,\pi} \cdot \frac{d\,z}{z^2}$$

And this integrated gives W, the resistance of the cone.

$$W = \int_r^R \frac{l}{(R - r)\,\pi} \cdot \frac{d\,z}{z^2} = \frac{l}{(R - r)\,\pi} \cdot \left(\frac{1}{r} - \frac{1}{R}\right)$$

or

$$W = \frac{l}{R\,r\,\pi} \quad . \quad . \quad . \quad . \quad . \quad (I.$$

To ascertain the values of the radii, R and r, for each tube to be used as a measure, the only way is to fill the tube with pure mercury at a known temperature and weigh it, and to accept the reciprocal-lengths of the mercury drop, with which the tube is calibrated, as the relations of its sectional area, at different points.

The weight, G, of the mercury is arrived at by repeatedly filling and weighing, making the necessary reductions for temperature and atmospheric pressure, and taking the mean of several observations. If σ is the specific gravity of mercury at 0° C, the volume V is

$$V = \frac{g}{\sigma}$$

For the value of V we have also the geometrical expression for the contents of a truncated cone.

$$V = (R^2 + R\,r + r^2)\frac{l\,\pi}{3}$$

which, divided by R r, becomes

$$\frac{V}{R\,r} = \left(\frac{R}{r} + 1 + \frac{r}{R}\right)\frac{l\,\pi}{3}$$

And if we make

$$\frac{R^2}{r^2} = a,$$

$$\frac{V}{R\,r} = \left(\sqrt{a} + 1 + \frac{1}{\sqrt{a}}\right)\frac{l\,\pi}{3}$$

Whence

$$R\,r = \frac{V}{l\,\pi} \cdot \frac{3}{1 + \sqrt{a} + \frac{1}{\sqrt{a}}}$$

Or, with the value $V = \frac{g}{\sigma}$ inserted,

$$R\,r = \frac{g}{l\,\pi\,\sigma}\,\frac{3}{1 + \sqrt{a} + \frac{1}{\sqrt{a}}}$$

which is now substituted for R r in equation I., and gives for the whole resistance of the cone

$$W = \frac{l^2\,\sigma}{g}\,\frac{1 + \sqrt{a} + \frac{1}{\sqrt{a}}}{3}$$

The value of a, representing a ratio $\left(\frac{R^2}{r^2}\right)$, and not a number, is given by the mercury thread, measured in calibrating the tube. The thread is longest where the section is smallest, and *vice versa*, or

$$L : l = r^2\,\pi : R^2\,\pi.$$

$$\frac{R^2}{r^2} = \frac{l}{L} = a.$$

When great care is taken in the manipulation, a corresponding degree of precision may, unquestionably, be attained.

When a tube is very slightly conical, the coefficient* $\frac{1 + \sqrt{a} + \frac{1}{\sqrt{a}}}{3}$ approaches so very nearly to the value, one, that it may be neglected, and the resistance of the tube calculated by the formula—

$$W = \frac{l^2\,\sigma}{g}$$

in which the only measurements necessary are the length of the tube and the weight of its contents of mercury.

A still nearer approximation to the true resistance, when the tube consists of a number of small obtuse cones of various lengths and proportions, is to calculate the resistance of each separate little cone, and the sum of all these several subordinate resistances will be found to give very nearly the same

* In his reproduction of the mercury unit Dr. Matthiessen has used, instead of the one given above, the coefficient $\frac{n^2}{\Sigma(\lambda)\,\Sigma\left(\frac{1}{\lambda}\right)}$ in which n is the number of measurements, and λ the length of the column of mercury in any position. This coefficient, however, is not more exact, as the tubes are taken into account as being series of different cylinders instead of cones.

result as the foregoing, which regards the tube as a single truncated cone, whose top and bottom are to each other as the least and greatest sections, wherever these may occur in the tube: but the difference, however slight, is in the right direction towards the truth. Before the tubes are used, they are furnished at the ends with glass angular pieces, made to fit tightly by india-rubber packing or cement, and are filled with mercury for receiving the thick terminals of the measuring apparatus. These terminals are either of copper amalgamated or of copper electro-nickeled and the nickel amalgamated.*

A correction for resistance which the current meets with in passing between the ends of the tube and the mercury cup, is made as follows:—

It is accepted that this resistance is equal to the resistance of a hemispherical shell, whose inner radius is *r*—the radius of the bore of the tube—and whose outer radius is very great, and, therefore, to be regarded as infinite in comparison with *r*. The resistance, $d\,y$, of a shell of the thickness $d\,x$, and radius x, is expressed by

$$d\,y = \frac{d\,x}{2\,x^2\,\pi}$$

* In using mercury resistances it is very necessary to amalgamate the ends of the leading wires. If this precaution is disregarded, a condensed layer of gas remains adhering to the ends, immersed in the mercury, although they may be perfectly clean, and occasions a considerable resistance. The high conducting power of copper recommends it for connections of this kind, but it is doubtful whether the copper will not after a time dissolve in the mercury, and the amalgam entering the tube lessen its resistance. The best way to avoid this is to cover the surface of the copper first, in the galvanic way, with a thick coating of metallic nickel, and then to amalgamate the nickel. Nickel, although, like platinum and iron, it is not easily amalgamated by the methods which Gmelin and others give, may be readily amalgamated on its surface by galvanic deposit. For this purpose a small quantity of a solution of nitrate of mercury in a porous pot, is placed in a glass of acidulated water in which a zinc plate is immersed. A wire from the zinc is attached to one end of the terminal to be amalgamated, the other end of it being dipped into the mercury solution. In the course of a few minutes a thick coating of mercury is obtained on the end, which should be stirred in a vessel containing metallic mercury, and then washed.

whence, by integration—

$$y = \frac{1}{2\,r\,\pi} = \frac{r}{2\,r^2\,\pi}$$

But $\frac{r}{2\,r^2\,\pi}$ is the resistance of a tube, whose length is equal to its radius. The resistance to the current spreading at the ends, therefore, in the case under consideration, amounts to the addition of its radius to its length, by which the corrected resistance, W, becomes

$$W_1 = W + 2y = W\left(1 + \frac{r}{l}\right)$$

65. *The absolute Units.*—Professor Weber first proposed, defined, and determined units of resistance and electro-motive force referred to units of mass, space, and time; and Professors Thomson and Helmholz have since determined similar units, with reference further to work performed, on strictly mechanical principles.

The so-called absolute units hold the same relation to the arbitrary ones which the expression of mechanical effect in foot-pounds does to the same expressed in horse-power. In the latter case, we refer the capability of an engine to the average capabilities of so many strong horses; in the former we refer to an unit of work, based on fixed standards—in other words, to the number of pounds which the engine could lift one foot high from the ground, in one second of time.

In determining the absolute units of electrical force and resistance, it is only necessary to follow the natural relations between the various electrical magnitudes and the relations between these and the common units of time, mass, and space. Each of these magnitudes is capable of direct experimental comparison with others of the same nature, while their dependence upon each other is expressed by mathematical formulæ, the truth of which has been proved by experimental research.

These magnitudes are, (1) intensity or mechanical effect, (2) quantity, (3) electro-motive force, and (4) resistance.

The mathematical expressions of the laws governing these are as follows :—

First, the fundamental law of Ohm expresses the invariable relation of three of these magnitudes.

$$I = \frac{E}{R}. \quad . \quad . \quad . \quad (1.$$

I being intensity, E electro-motive force, and R resistance; of which, if any two are units, the third must also be an unit.

The second law, experimentally verified by Faraday, is that the quantity, Q, of electricity conveyed by a current, is in proportion to the intensity of that current, and to the time, t, during which it circulates; the equation is

$$Q = I\,t \quad . \quad . \quad . \quad . \quad (2.$$

The next law is that of mechanical effect performed by the current. Whenever and wherever a current circulates, it works; it performs either mechanical effect or its equivalent. Thus, if the current pass in the neighbourhood of a freely-suspended magnet, it deflects it; if it traverse in its circuit a fluid conductor, it decomposes it, it separates its atoms into their components, perhaps it dissolves one of the electrodes; and all this time it warms the whole circuit. And the energy of this heat, of this decomposition, of this deflection, if it could be directed favourably for the experiment, would be found able to lift so and so many pounds weight from the ground, to the height of one foot, in one second of time.

Dr. Joule has proved that this mechanical effect is proportional to the resistance of the circuit to the time, and to the square of the intensity. Algebraically expressed, W being the work—

$$W = I^2\,R\,t \quad . \quad . \quad . \quad (3.$$

These three equations would, obviously, be sufficient to determine the units of all the electrical magnitudes in question, if one of these were chosen arbitrarily; but this is to be avoided, as the object of the system is to refer all of them to natural units, or at least to units of universal application.

The equation wanting is that of force—an expression for the relation of the deflecting power of a circular current on the poles of a magnet needle, the conductor being at all points equidistant from the same. If the current form a circle whose radius is r, round the magnetic pole as its centre, the deflecting force will be directly proportional to the length, L, of the conductor, to the magnetic intensity, m, of the pole, and to the intensity, I, of the current, and inversely to the square of the distance of the pole from the conductor. Hence the force is

$$F = \frac{I\,L\,m}{r^2} \quad . \quad . \quad . \quad . \quad (4.$$

Defining each of the electrical magnitudes as certain units determined by existing units of time, mass, and space, we have, according to the foregoing, the following expressions of their mutual relations :—

The unit of intensity will be produced in the circuit of unit resistance, by the unit of electro-motive force.

This unit of intensity will convey the unit quantity through the same circuit in the unit of time.

The same unit of intensity will produce the equivalent effect of the unit of work in the unit of time.

Lastly, the unit of intensity circulating in a conductor of unit length, will exert the unit force upon the unit pole at an unit distance.

So far the elements of the theory. To put all this into practice, and determine these units, is a work of much patience and expense.

The unit of intensity is the easiest to determine. The circular conductor, and short magnet needle suspended in its centre, which are conditions considered in (4, forms a simple tangent galvanometer.

When a current, I, moves in the circuit L, and deflects the needle through an angle ϕ degrees from the plane of the magnetic meridian, we know that the force with which one of its poles is deflected (supposing, for the moment, all the magnetism to be collected in the poles) bears a certain relation to the horizontal component M of the earth's magnetism, and thus, in the form of equation (4, is

$$F = M \tan.\phi^\circ = \frac{I\ L}{r_2}$$

whence the intensity

$$I = M \tan.\ \phi^\circ \frac{r^2}{L}$$

an expression for which we only want to know the value of M, at the moment of the observation, to give us the intensity, I, in electro-magnetic absolute units.

With this one electrical magnitude known in absolute measure, we want only one more to enable us to express the third dependent magnitude contained in Ohm's law, and the whole system is in our hands. The magnitude next to I in rank of facility, to be determined, is R.

To do this for us—to find the absolute value of R, has lately been the task of a very diligent committee, composed of some of the most expert physicists in England, appointed by the British Association; and they have fulfilled their commission with much credit to themselves, and benefit to the scientific world. Their results, published in a series of reports on standards of electrical resistance, for which we are principally indebted for our knowledge of the subject, are very comprehensive and valuable. The results, in detail, would be out of place here; but it is necessary to give a glance at the *modus operandi,* in order to get a clear notion of how the absolute measure of R has been arrived at.

The simplest way to do this was that followed by Professor Thomson, who determined the absolute resistance of a wire by means of Dr. Joule's experimental measurement of the heat developed in it by the passage of a current. But a more indirect method was followed by the committee with better results,—that of measuring the magneto-electric current induced in a wire of known length, moving in a magnetic field of known intensity.

If a current of the intensity I circulate in a straight conductor of the length L, placed at right angles to the lines of force of a magnetic field whose intensity is s, the force F in operation will be the same as if the conducting wire were circular, of unit radius, and the magnetic lines radiated from a pole of the intensity s, in its centre.

By equation (4, this force is equal to $s\,L\,I$.

Going back to the straight conductor, let us suppose it to move with a velocity = V, perpendicularly to its own length, and to the lines of magnetic force; a magneto-electric current would be induced in it, which would have the effect of offering a resistance to its motion, and this resistance would be that expressed by the force $s\,L\,I$.

To overcome the resistance due to this retarding influence of the current, work has to be performed; its amount being proportional to the force, and to the velocity with which the conductor passes across; or, if W represents the work,

$$W = V\,(s\,L\,I) \quad . \quad . \quad . \quad . \quad (5,$$

which is equivalent to the work done by the current.

According to (3, however,

$$W = I^2\,R\,t,$$

whence the resistance,

$$R = \frac{V\,s\,L}{I\,t}. \quad . \quad . \quad . \quad . \quad (6.$$

s and I can be obtained in absolute measure; the second member, therefore, contains no unknown magnitude, and we have R in absolute electro-magnetic units.

With R and I in absolute units, with aid of Ohm's law, we find the electro-motive force E,

$$E = V\,s\,L,$$

that is to say, the electro-motive force produced in a straight conductor, moving perpendicularly to its length and to the magnetic lines, is equal to the product of the intensity of the field, the length of the conductor, and its velocity.

The way this is put into practice is by the employment of a circular conductor instead of a straight one, which would be impracticable. A small magnet is suspended in its centre, the deflection of which is observed during the time the conductor is rotated on a vertical axis.

The recent determinations of this really beautiful system of units by those members of the committee who have so praiseworthily worked at it, agree with each other sufficiently well to have induced the committee to adopt the result, and resistances expressed in the unit have accordingly been distributed. Of course, in practice, a multiple of the unit, which is exceedingly small, must be called for convenience the practical unit. The resistance accepted as the practical unit, or the so-called B. A. unit, is 10^7 times the $\frac{\text{meter}}{\text{second}}$ unit, nearly. This B. A. unit is a little larger than the mercury unit issued by Dr. Siemens, in the proportion of 1·0456 to 1. An error has crept into the mercury unit, however, by a wrong value having been assigned to the specific gravity of mercury in the calculated resistances of the normal tubes, so that, allowing for this, one B. A. unit is equivalent to 1·0484 mercury units according to the definition.

A system has been proposed for reproduction of normal resistances, by Dr. Matthiessen, which consists in making an alloy of gold and silver of certain proportions (two parts of gold, and one of silver), and drawing it into wires. The conducting power of an alloy of these metals, in whatever proportions the metals are taken, is less than that corresponding to the volumes of its constituents. When a series of such alloys is made, beginning with pure gold, and gradually increasing the percentage of silver until pure silver is reached, it is found that, as the percentage of silver increases to a certain point, the conducting power decreases, after which it increases again until it approaches that of the pure metal. From the point where the curve reaches its minimum, it rises only very gradually, so gradually indeed, that for a difference of some few per cent. on each side, the conducting powers of the alloys are almost identically the same. In the reproduction of measures by this system, this fact is of the utmost importance, inasmuch as a trifling error made in the proportions of the constituent metals does not materially affect the conducting power of the alloy. The necessity of procuring absolutely pure metals is also, in some measure, obviated by taking an alloy whose conducting power would probably be very little altered by small impurities, which would very considerably modify the conducting power of a pure metal. There are, unquestionably, difficulties in the way of reproduction by means of solid metals, amongst which the principal are, annealing the specimens to the same degree of hardness, drawing the metal into wires of uniform thickness, and, perhaps the greatest of all, the difficulty of soldering the ends of the wire to thick connections without altering its resistance; and to all these difficulties, therefore, the system proposed by Dr. Matthiessen is subject. Indeed, it is difficult to find any system which is not burdened with very many difficulties and sources of error.

The Committee of the British Association have proved undeniably that at this date resistances can be copied with much greater accuracy than they can by any system yet proposed be reproduced. The reproduction of an unit, when once the unit has been fixed upon, is therefore to be avoided as much as possible. To reproduce any standard measure, other measures are indispensable; and unless these measures agree with each other strictly whenever and wherever the unit is wanted to be reproduced, it can never give twice the same result, however much care and conscience are employed in manipulation. This has been amply proved by the different values of the mercury unit, which Matthiessen arrived at in London, and the writer in Berlin, and those which Weber arrived at in Göttingen, and Thomson in Glasgow, in determining the absolute unit.

For this reason the Committee of the British Association have done well in principle in fixing upon a material measure as an unit, and in distributing copies of it; but in doing this they have lost sight of the dignified position which they held as an impartial jury at starting in their duties, and have attached themselves exclusively to the cause of the so-called "absolute system," and issued an unit whose agreement with the defined "absolute unit" is by no means certain—a proceeding which has had for its consequence not only that they have shut their eyes to many points of great merit in other systems, but have also attacked them, in certain instances, with so much apparent animus, that, if we did not know better, we might almost suspect some of them of having some little personal feeling in the matter.

The B. A. unit is, however, in all probability a very near approximation to the value $10^7 \frac{\text{meter}}{\text{second}}$ units. It may be as near an approximation to its original as the mercury units which have been determined are to be the defined unit, or as any of the alloys of gold and silver are to be defined alloy. All these are of course only approximations; but we are certain that with the two last systems these approximations may be brought with certainty infinitely nearer to their true values, because the manipulations and the sources of error are less than those which profess to represent the absolute system; and therefore these systems are better adapted to supply the unit of resistance.

In a practical sense, it is of importance to have the unit of resistance that of some geometrical body of the material taken as unit of conducting power. Beyond this we do not see that it matters much what expresses the unit so long as one system only is adopted, which is capable of reproduction if this should become necessary, and correct resistance-scales constructed to it.

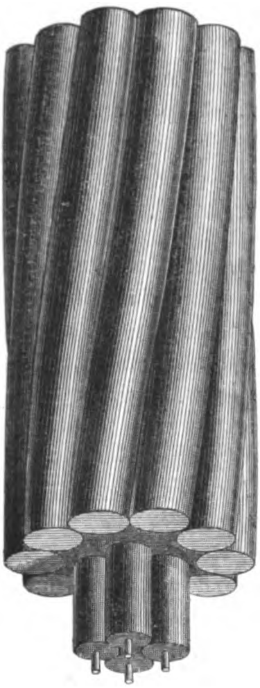
But while the electric permanency of solid metals is still an open question, whatever objections may be tenable against reproductions we must nevertheless return to them, from time to time, to control our resistances. For this purpose, then, the exactest and simplest method of reproduction must be available. Weber's system for this would be scarcely suitable; first, because it lacks the certainty of the condition of exactness, and, secondly, because it has no pretensions whatever to simplicity. One of the two systems—the mercury or the alloy—must therefore be chosen, or both, for security. Indeed, why it should be necessary at all to exclude a single method by which truth may with great probability be attained or truth controlled, is to us incomprehensible.

VI. Submarine Telegraph Lines.

66. The greatest achievement of the electric telegraph is unquestionably the instantaneous transmission of intelligence across the seas. To whom the credit of the first idea of a submarine cable is due, is matter of secondary importance. It has been claimed for several, with, perhaps, equal justice.

The first cable, however, which was intended to be of any real use, was the gutta-percha covered copper wire paid out in 1850, between Dover and Calais, by Mr. Brett, but which, unhappily, lived only a single day—just sufficient to save the concession.

The next cable made consisted of four copper wires—No. 10, B.W.G., each twenty-seven miles long, separately insulated with gutta-percha to a thickness of 0,284″ diameter, and the whole spun up in the form of a rope with tarred hemp, with an outer protection of ten No. 1 galvanised iron wires, as shown in natural size in Fig. 154. This cable weighed, when completed, seven tons per mile. It was laid successfully in the year 1851, and is still at work. The partial success of the first wire, and the brilliant success of the second, decided the practicability of submarine telegraphy, and, after a little line of three miles had been laid down between Keyhaven and Hurst Castle, and one of eighteen miles across the Belt, both of which succeeded, and are still in working order, faith expanded, and the length of the ropes grew proportionally. In 1853, Messrs. Newall made a line, which they laid down between Dover and Ostend, seventy miles long, weighing seven tons per mile. In this cable the number of conducting wires was increased to six; they were of copper, No. 16, B.W.G., each covered to a thickness corresponding with No. 2, B.W.G., with gutta-percha. The six lines were spun up into a rope with hemp, and protected externally by ten iron wires. A section of this cable is shown in Fig. 155.



67. The success attending most of the short lines gave rise to schemes of greater dimensions, and suggested the idea of joining the Old and New Worlds by a similar connecting link. In 1856, Mr. Brett, in conjunction with Sir (then Mr.) Charles Bright, Mr. Whitehouse, and Mr. Field, formed a company for laying a cable between St. John's, Newfoundland, and Valencia, on the south-west coast of Ireland. The form of cable selected was calculated to bear a strain of three tons, while a length of one English mile of it weighed only one ton, in air. The conductor consisted of a strand of seven copper wires, of No. 22½ gauge, weighing 93 lbs. per mile, covered with three coatings of gutta-percha, weighing 227 lbs. per mile. The core was served with jute-yarn, saturated with a composition of tar and other materials, and protected by a sheathing of eighteen strands of iron wire, each strand containing seven wires of No. 22 gauge, as in Fig. 156. This was for deep sea line. For shore end, a length of thirty miles of the same

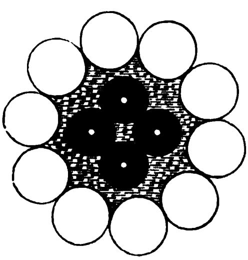


Fig. 154.

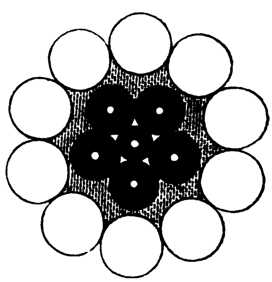


Fig. 155.

core was covered with hemp, and protected by twelve thick iron wires (Fig. 157). The deep-sea cable, over two thousand miles long, was manufactured in five months—half by Messrs. Newall, of Gateshead, and the other half by Messrs. Glass, Elliott, and Co., of Greenwich. On the 5th August, 1858, the cable was successfully submerged, and congratulatory messages exchanged between the two countries. It was faulty when laid, and broke down entirely in three weeks after its submersion.

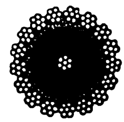


Fig. 156.

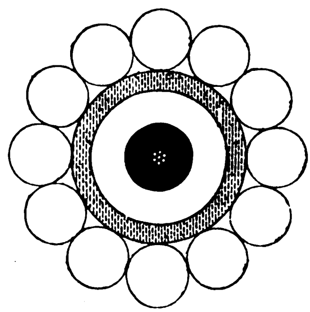


Fig. 157.

This experiment was a very costly one, but served to enlighten the electricians and caution the manufacturers.

68. The next cable of magnitude was that manufactured for the Red Sea and Indian Telegraph Company. The core was manufactured by the Gutta-percha Company, and the sheathing done by Messrs. Newall. The core consisted of a strand of seven copper wires, weighing 180 pounds per nautical mile, covered with two coatings of gutta-percha, alternated with two coatings of compound, weighing 212 pounds per knot. The core was served with hemp saturated in tar. For the deep-sea portion the rope was protected with eighteen (No. 16) iron wires (Fig. 158); the shore end with nine iron wires of a larger gauge, as in Fig. 159.

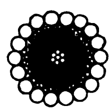


Fig. 158.

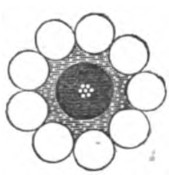


Fig. 159.

The first portion of this cable—Suez to Aden—was laid in three sections. The first between Suez and Cassire, 255 knots; the second between Cassire and Suakin, 474 knots; and the third between Suakin and Aden, a distance of 629 knots. The second portion of the cable—Aden to Kurrachee—was divided also into three sections, of which the first, that from Aden to Hallain, was 718 knots; the second, from Hallain to Muscat, 486 knots; and the third, between Muscat and Kurrachee, 481 knots.

Notwithstanding the able staff of electricians and engineers present at the submersion, numerous faults were paid out. Every section of this line, one after the other, became faulty; and after repeated attempts to repair it, the cable had to be regarded as a failure. A marked progress was, however, to be observed in the manufacture and submersion of this cable; and, although the pecuniary loss was great, a corresponding amount of information was gained, which the next cable, of equal magnitude, was destined to reap the benefit of.

69. Passing over the shorter cables laid in the interval, some of which struggled through the difficulties that beset them, we come to the Malta-Alexandria cable. At this date (1860) begins the scrupulous supervision of cables, both of their electrical and mechanical conditions, during the different stages of the manufacture. This progress we owe to the late lamented Mr. Lionel Gisborne, and to Messrs. Siemens, who were appointed by the Government to superintend the engineering and electrical departments. The cable was originally designed to join Falmouth with Gibraltar in telegraphic circuit.

The core consists of a strand of seven copper wires, weighing 400 pounds per knot, covered with three coatings of gutta-percha, alternating with three coatings of compound, also weighing 400 pounds per knot. The core was served at the sheathing works at Greenwich with hemp saturated in tar, and covered with eighteen No. 11 iron wires for the deep-sea portion, of which Fig. 160 gives a perspective view and section; the shore-end was made of two sizes, lengths of the same core being covered with iron wires of two thicknesses for thick shore-end and intermediate shore-end.

When the Gibraltar-Falmouth line was abandoned in March, 1860, it was determined to lay the cable between Rangoon and Singapoor; and in December of the same year the steam-ship *Queen Victoria* was laden with the first portion of the cable. Stress of weather compelled the ship to put into Plymouth, on her way round the channel, and while there the electrical conditions of the cable appearing to justify a delay, and this delay preventing the possibility of the ship, which wanted some repairs after her passage, reaching the Malay coast in time to save the fine season, the expedition was decided to be put off. In January, 1861, the destination of the line was again altered, and the authorities determined that it should finally be laid in three sections between Malta, Tripoli, Bengazhi, and Alexandria. The submersion was carried out in the summer of 1861 with signal success, by the engineers of Messrs. Glass, Elliott, and Co.

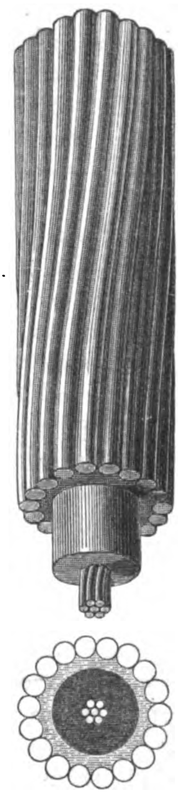


Fig. 160.

The length laid between Malta and Tripoli is 230 knots, that between Tripoli and Bengazhi 507 knots, and that between Bengazhi and Alexandria 597 knots.

The cable has not worked uninterruptedly since that time, but the faults which have occurred in it have been, happily, of minor importance, and a few days have always sufficed to enable the engineers in charge to effect its reparation. It is sincerely to be hoped that this cable may continue long in working order to re-establish the confidence which the failures of the previous long cables has shaken, and to reward its manufacturers for the conscientious care with which they carried out their share of the work.

70. The Persian Gulf cable, laid in 1864 by Sir Charles Bright and staff, had, during its manufacture and submersion, the advantage of all the experience accumulated in dealing with the previous cables. The result will prove if this experience has been made good use of. The conductor is a compound copper wire consisting of five pieces, four segments forming a cylinder, and a tube in which they are contained.

This conductor was made by placing the four segmental pieces in a tube and drawing the whole down as a solid wire. The diameter of the wire so drawn is 0,111 inch; its weight 225 lbs. per knot. The conductor is insulated with four coatings of gutta-percha and compound to the thickness of 0,380 inches, weighing 275 lbs. per knot. The core was served with the best Russian hemp, saturated in salt water. The outer covering consists of twelve No. 7, B.W.G., galvanised iron wires, covered with two coatings of hemp and a bituminous compound consisting of 34 parts of mineral pitch, 56 of silica, and 10 of tar. The cable was covered with this mixture by means of an elevator driven by the closing machine, so arranged that whenever the machine stopped the elevator was also stopped, and no compound was poured over the cable until the machine started again. In this way the core was guarded against exposure to heat for any length of time at one spot.

The total length of cable laid down is a little over 1,150 knots in the following four sections: Kurrachee to Gwader, 246 knots; Gwader to Mussendom, 357·3 knots; Mussendom to Bushire, 392·7 knots; and Bushire to Fao, 154·2 knots.

The electrical conditions of the cable are good: its insulation resistance, at 75° Fahr., being about three times as great as the standard contracted for by the Gutta-percha Company.

71. Of more recent date still is the little cable laid in 1864, between Carthagena and Oran, by Messrs. Siemens; in point of length comparatively insignificant; but embracing a totally novel construction, and many points which entitle it to a place here.

The core was manufactured by the Gutta-percha Company, and did them infinite credit for excellent workmanship and materials. It consisted of a strand of three copper wires, weighing 72 lbs. per knot, covered with three coats of gutta-percha, alternated with as many coats of compound, weighing 144 lbs. per knot. Each separate knot was tested, at a temperature of 24° C., under a pressure of 300 atmospheres, by Reid's method, and had at that temperature and pressure an average resistance of insulation of over 600 millions per knot.

The core was covered at the cable factory of Messrs. Siemens Brothers, at Charlton, with a laminous sheating, patented by Mr. C. W. Siemens. It was passed through a series of three machines in close succession. In going through the hollow spindle of the first machine, a close spiral covering of fine hemp strings was applied in such a way that the strain upon each of the strings was nearly equal. This strain was adjusted by friction springs at the sides of the bobbins containing the hemp. The second machine, similar in construction to the first, supplied a second covering of hemp, wound in the opposite direction to the first. Finally, the third machine covered the rope, spirally, with four strips of sheet copper, under a moderate pressure. By an ingeniously constructed covering tool, these strips were made to overlap each other nearly half their breadth, by which the copper covering became about twice the thickness of the sheet. Fig. 161 shows a perspective view and section of a piece of this cable.

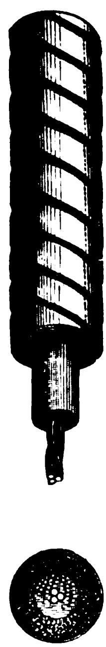


Fig. 161.

The cable was laid completely from the *Douane* at Ain-el-Turck, on the north coast of Africa, to the harbour of Carthagena, on the south coast of Spain, but broke about ten miles from the Spanish coast, soon after its submersion. During the time it lasted the resistance of its insulation was over a thousand millions per knot, and the speed with which it could be worked quite equal to that which the telegraphists had attained. The rupture occurred over the sudden fall which runs east and west along the Mediterranean, and on which the Toulon-Algiers cable parted some years before. This experiment will probably be the last to lay down a cable over this dangerous bottom.

A cable of the same construction was subsequently submerged with success between Bona and Bizerta, and worked very satisfactorily.

At the date of the first Atlantic cable the mechanical department was far ahead of the electrical. The cable was successfully laid—mechanically good, but electrically bad. At the present day the electrical department has made great progress towards perfection. A striking proof of this is that cables now rarely or never break down through electrical faults. To remedy the rapid oxidation of the iron-wires in sea-water, experiments have been made, although on no very extended scale, to tar the cable as it passed out of the ship. Subsequently Messrs. Bright and Clark patented their method of covering the finished cable with a bituminous compound, which should preserve the iron by excluding entirely the sea-water. In the development of the same idea, Messrs. Siemens have made a cable based on more scientific principles. It consists in covering the iron wires with hemp, and the hemp with zinc, in such a way as to form a large iron-zinc element. Zinc is electro-positive in regard to iron, and is, therefore, dissolved, while the iron, forming the negative element, is left undisturbed. So long as the zinc lasts the iron must remain intact; but the zinc in oxidising forms upon itself an insoluble crust, which preserves it for an indefinite time, so that a cable so constructed must last for years.

72. The most recent and unconditionally the most important cables at present are those which have been laid over the route of the old Atlantic line. This great undertaking comes at the right moment, in every respect, to realisation, when both the electrical and mechanical departments have arrived at comparative perfection.

The cable was manufactured by the Telegraph Construction and Maintenance Company—an incorporation of the firms of Messrs. Glass, Elliott, and Co., of Greenwich, and the Gutta-percha Company, of Wharf Road. The core was made by the Wharf Road branch. It consists of seven No. 18 gauge copper wires, twisted into a spiral, weighing 300 lbs. per knot, covered with four coats of gutta-percha, between which are intervening thin layers of Chatterton's compound, weighing 400lbs per knot. The diameter of each wire is 0,048″; that of the strand, 0,146″; and that of the gutta-percha, 0,464″. The core was manufactured in knot lengths, and tested, before it left the factory, under a pressure of 600 lbs. per square inch at a temperature of 75° Fahrenheit. At Greenwich, the core was served with hemp, saturated with salt water. The outer covering of the deep-sea portion is formed by ten wires (No. 13, B.W.G.) drawn from Webster and Horsfall's homogeneous iron, each surrounded by five yarns of Manilla yarn, laid on spirally with a preservative compound. A section of this portion is shown in Fig. 162. Its total diameter is 1·127″. The shore end portion, a length of 50 miles, of the deep-sea cable is served with an extra thickness of hemp, around which is an outer protection of wire strands. The weight of the deep-sea cable, per knot, in air, is thirty-six hundred-weights, and its breaking strain eight tons.

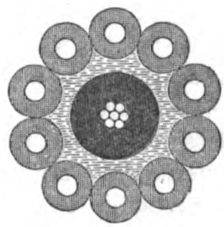


Fig. 162.

The finished cable was subjected to careful tests of its electrical conditions under the superintendence of the electrician to the contractors. As the cable left the closing machines it was coiled into tanks of water, and, when the lengths became sufficiently great, was transported to the steam-ship *Great Eastern*, which was destined to pay it out across the Atlantic.

The electrical conditions of the cables are unexceptionable, and the complete manner in which every stage of the manufacture was carried out entitles the hope that, as they have reached the bottom in safety, these lines will last an indefinitely long time in thoroughly good condition. The employment of so large a vessel as the *Great Eastern* for cable laying was a courageous experiment, and the result is the most brilliant success of the present century.

At the present moment there are upwards of 10,000 miles of insulated wire submerged in the form of submarine cables, in daily work, transmitting intelligence across different seas;

and at least an equal length has been lost in the same form, partly by failure in the submersion, principally by the development of faults after the lapse of time.

73. *Tests of the Finished Core at the Gutta-percha Works.*— The insulated conductor, for some days after it has left the last covering machine, has a lower insulation than when the material has become consolidated by age. A peculiarity of gutta-percha, which it is necessary to take into account in measuring the insulation resistance of a cable at different temperatures, is that the conducting power of this material does not immediately alter with the temperature, but follows it leisurely. Mr. Varley observed this to be the case with the Atlantic cable at Greenwich; and we have repeatedly observed also that, in changing the temperature of the water in which cable-core is immersed, the altered resistance of the copper conductor will indicate the change to a nicety some time before the gutta-percha is in the least affected by it. For this reason the core which is made at the Wharf Road Gutta-percha Works, is kept in a bath at an uniform temperature of 24° C., for a period of twenty-four hours before it is submitted to the electrical tests. Were it allowed to be in at varying temperatures, the numbers obtained for insulation resistance at any moment might easily express the resistance due to a temperature which the cable had had hours before, and be quite wrong for its observed temperature.

The core is submerged either in hanks or coiled upon iron drums, according to its size, and is allowed to remain in the water for the prescribed twenty-four hours, during which time the water is frequently stirred to equalise its temperature. The lengths of the hanks or coils tested are between one and two knots, in which lengths the electricians have to measure its conducting power of copper and insulating capacity.

74. When a cable is submerged in the sea, it is evident that it becomes subject, in every point, to the presence of a superincumbent column of water. In order to produce during the testing, as nearly as possible, the conditions under which a cable is placed when submerged, Mr. Reid conceived

the idea of testing the single knots of his cable, destined for submersion between England and Holland, under the pressure of a column of water about equal to that which would press upon it after being paid out. He feared especially to submerge a cable without this provisional test, as, in case of the existence of air-bubbles or small fissures in the dielectric, the weak places might otherwise remain undiscovered until the water, under the greater pressure, forcing its way in, would develop them, when too late to remedy the evil. For the accomplishment of his design, he took his core in coils in a vessel to sea off Sunderland, and there, retaining one end of each coil on board, having insulated the other, sunk them to the bottom, and tested their insulation while there by means of a galvanometer and battery.

This method of testing under high pressure entailed, however, considerable expense and trouble, which, combined with the disinclination of some of the coils to sink, induced Mr. Reid to construct cylinders in which he could place them, and, by means of a system of force-pumps, subject them to a considerable pressure. Another advantage accruing from the employment of tanks, instead of sinking the coils in the sea, was the opportunity it gave of subjecting the insulated wire to a vacuum before the application of the pressure. This the inventor believed to be essential, as air-bubbles—which, like elastic balls, might not be broken by any pressure, however great, uniformly surrounding them—would be burst by the internal pressure when put into a chamber from which the air was exhausted; and, further, that, should fissures occur in the envelope, the air would be expelled from them, and the water afterwards compelled to enter.

The first pressure tanks of any importance were those erected on the premises of the Wharf Road Gutta-percha Works, and employed in testing the cores of the Toulon-Algiers and Malta-Alexandrian cables. These cores were subjected to a partial vacuum, and to a pressure of 600 pounds per square inch.

Subsequently Mr. Reid constructed another tank, put up at the same place, capable of resisting an internal pressure of over 10,000 pounds on the square inch, or that of a column of sea-water nearly four nautical miles high.

The core to be tested in the tank is coiled regularly upon an iron drum of such dimensions as permit it to enter comfortably into the tank, and to hold as great a length of cable as is possible. With this tank the core of the Mediterranean cable, made in 1863-64 for Messrs. Siemens, was tested, under a pressure of nearly 4,500 pounds per square inch, equal to the pressure which the cable would be exposed to at the greatest depth.

The engineers of the Atlantic cable tested by this method the core of the new cable, under only 600 pounds pressure per square inch, although when laid it has to resist a pressure of at least ten times this. The economy of time and of joints was probably the principal reasons which induced the scientific committee to insist on no higher pressure tests, combined with a conviction that the perfect manner in which the core was made, and some weak points in the system of high-pressure testing itself, render at the present day the testing of core in this manner almost superfluous.

If the gutta-percha coating were put on to the conductor at one operation, it would be always possible, even probable, that bubbles would occur which could be broken open by the vacuum test, and completely filled with water when under the water-pressure; but when the gutta-percha is put on the wire in two, three, or four concentric coatings, as is done with all cable cores, the probabilities of such an occurrence are infinitely reduced; and it may be almost regarded as an impossibility for a bubble to extend beyond a single coating, especially as, between each coat of gutta-percha, an intervening layer of compound* is put, which, in the process of its application to the wire, fills up any cavities left in the gutta percha.

The weak point of the system is, that the bubbles which

* Its ingredients are, by weight, 1 part of Stockholm tar, 1 part of resin, and 3 parts of gutta-percha. Its conducting power is higher than that of the best gutta-percha; its specific gravity about the same.

do occur in the single coatings are small, and for the most part well surrounded by gutta-percha, which is able to resist the internal pressure of the air contained in them, under the partial vacuum, and, being in an elastic medium, the external pressure is only able to contract them for the moment.

In all the knot lengths—some hundreds in number—which we have tested under pressure, not a single fault has been developed by this method. This will by no means speak against the system, but in favour of the core tested. Mr. Reid's argument, that if, in ten thousand lengths tested, only one be found faulty by this method, which resists detection by the ordinary process, the discovery will save infinitely more than the cost of testing the whole, is perfectly just; but then the probability may be less than one in ten thousand.

There are two conditions, therefore, under which a cable is generally operated upon electrically: first, under atmospheric pressure; and, secondly, under an augmented pressure: both at an uniform temperature.

There are two ways in which the core may become faulty: the first is by injury sustained by the gutta-percha, or by the thin places which would occur on one side if the wire, by any mischance, became eccentric in the gutta-percha; the other kind of fault is of very rare occurrence in cables which are not submerged, but has happened sometimes in the process of sheathing: it is the rupture of the copper conductor where it is joined, or where it is too brittle to accommodate itself to some strain or sudden small elongation which the cable can otherwise sustain.

75. *Electrical Measurement of the Copper Conductor of a Cable.*—This may be done in two ways:—

(1.) By means of a differential galvanometer.

(2.) By means of a Wheatstone's bridge.

The first system is the simpler of the two. Differential galvanometers are usually made with two coils of insulated wire of equal and opposite magnetical effects upon the needle suspended in their centre; so that, on joining up the coils, parallel to each other, and inserting them in the circuit of a galvanic battery, although the whole current passes through the instrument, no deflection of the needle is produced; but when one of the parallel circuits is interrupted, the needle is deflected ϕ° to the right, and when the other is interrupted instead, ϕ° to the left of zero.

Such a galvanometer, G (Fig. 163), has the ends of its coils, a and b, on one side, connected together, in the point c, to the pole z of the battery E. The opposite end of the coil a is connected to the cable conductor, or resistance to be measured; the opposite end of coil b to an adjustable resistance or set of coils, R; and the further ends of these, in a point, d, are connected with the pole c.

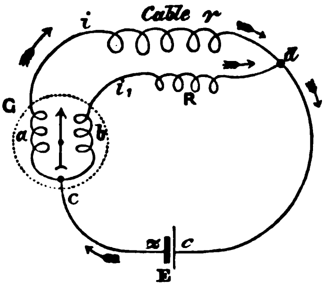


Fig. 163.

The current of E is therefore divided into two circuits: the one, a and cable; the other, b and R.

The intensity in the upper circuit being $= i$, and that in the lower one $= i_1$, while the resistance of the cable conductor is c, Kirchhoff's equation gives us the general expression,

$$i\,(a + r) - i_1\,(b + \text{R}) = 0$$

Whence the resistance of the conductor

$$r = \frac{i_1}{i}\,(b + \text{R}) - a$$

When the resistance R is adjusted so that the needle rests upon the zero line,

$$i = i_1$$

and if, at the same time, the resistance of the galvanometer coils are also equal $(a = b)$, the value of r is

$$r = \text{R}$$

or the resistance of the conductor is observed directly from the adjustable resistance in the opposite circuit.

Wheatstone's bridge method is more generally used for this measurement. The arrangements of this system have been already explained.

Having found the copper resistance, r, for the whole conductor of the length l, in knots, at a temperature of t° Cels., it remains still to find the resistance per knot, at some fixed degree of temperature, from these data. The resistance r_t of the conductor, per knot, at the temperature at which the measurement was made, is found by simply dividing the resistance, r, by the length, l,

$$r_t = \frac{r}{l}$$

When r_t has to be reduced to some other temperature, say τ° Cels., in order to compare it with the resistance of some standard knot of wire at that temperature, the quotient is multiplied by $1+0,0003765\ (\tau^\circ - t^\circ)$, and the reduced value, r_τ, becomes

$$r_\tau = \frac{r}{l}\left\{1 + 0,0003765\ (\tau - t)\right\}$$

This comparison contains, however, an element which may lead to error; for, although r, l, and t may be known exactly, yet the copper may be of different sectional area to that of the standard, and its resistance appear too great or too little, when, in reality, its different dimensions are in fault, and its conducting power unexceptionable.

To avoid this, it is preferred to reduce the conducting power of the material from the data already obtained, and the weight, W, of the l knots of copper strand.

Having the value of W in lbs., l in knots, and r_0 in units, the conducting power c, compared with that of pure mercury at 0°C., is, by the formula given before,

$$c = \frac{\alpha}{\beta} \cdot \frac{l^2\,\sigma}{W\,r_0}$$

in which α, β, and σ are constants:

α is the length of a knot in centimetres $=185200$,
β is the weight of a lb. in grammes $=453,6$.
σ is the specific gravity of drawn copper$=8,899$.

The highest value, probably, yet found for the conducting power of pure copper is sixty times that of pure mercury. Commercial copper may be considered of good quality when its conducting power is over fifty.

Dr. Matthiessen's results on this subject are valuable. He has found the conducting powers of annealed wires of the following sorts of commercial coppers, when the conducting power of pure copper at 15·5°C. is taken as 100, to be:—

1.	Lake Superior, native, not fused	98·8, at 15·5
2.	Ditto, fused, as it comes in commerce	92·6, at 15·0
3.	Burra Burra	88·7, at 14·0
4.	Best selected	81·3, at 14·2
5.	Bright copper wire	72·2, at 15·7
6.	Tough Copper	71·0, at 17·3
7.	Demidoff	59·3, at 12·7
8.	Rio Tinto	14·2, at 14·8

76. *Measuring the Insulation Resistance of the Core.*—The first measurements of the electrical conditions of submarine wires were made with a simple galvanometer, inserted between one end of the cable to be measured and one of the poles of a galvanic battery, the other pole of which was to earth. When the farther end of the cable was put in connection with the earth the current of the battery passed through both cable and galvanometer, deflecting the needle of the latter to a greater or less degree as the cable was shorter or longer, or the section of the conductor greater or smaller, than that of some piece of cable taken as a standard. This test served to show at the same time that the conductor of the cable was entire, and gave a remote idea of its length. When the end of the cable was insulated, however, or dry and free in air, the current of the battery passed through the galvanometer as before, but, having to traverse the insulating medium surrounding the conductor, its intensity was materially lessened, depending upon the degree of insulation of the cable. If no deflection was observed, it was presumed that the cable was good; and if the current was strong enough to deflect the needle, the magnitude of its deflection gave an

idea of the magnitude of the fault through which the current found a complete circuit.

The instruments used for this purpose were of a rough nature, badly insulated, and insensible to currents of small intensity. But notwithstanding the obvious insufficiency of this method of testing, it did not entirely give place to a more scientific way until the date when the Malta-Alexandria cable was begun. The Government tests applied to this core began, however, the work of civilisation; the insulation resistances and the copper resistances were expressed in one and the same unit, and were thus made directly comparable with each other; the dependence of the resistance of the conductor upon the conducting power of the metal used and upon its dimensions, and the dependence of the resistance of the insulating covering upon the specific resistance of the material and its dimensions being known, these resistances were calculated and the results compared with those found by actual experiment; and thus the electrical conditions of the cable were judged by the agreement of the results found with those expected.

Dr. Werner Siemens was the pioneer who began this very serviceable work, and carried it through; and, after the first prejudice at innovation had been got over, electricians, one after the other, fell into the same way of thinking and of measuring.

In manufacturing the core of a submarine cable, as much care is devoted to the selection of gutta-percha of high specific insulation as of copper of high conducting power. Both are only to be attained by freeing the commercial materials from impurities.

The Gutta-percha Company, of Wharf Road, have succeeded signally in the production of first-rate insulation. The way they secure this is by selecting the best gum, and, after the process of cutting the imported blocks into small shavings and masticating it at the temperature of boiling water, of straining the plastic material through sieves of fine wire gauze. By this operation, almost all the natural impurities of the gum are removed, and the substance rendered homogeneous and of low conducting power.

An idea of the gradual perfection to which the covering of submarine wires with gutta-percha has attained, may be gleaned from the relative insulations of the principal cables which have been made.

The core of the Atlantic cable, made in 1856, had an insulation resistance of 12 millions per knot, at a temperature of 24°Cels.; the Red Sea and Indian cable, made in 1859, had 30 millions per knot; the Toulon-Algiers cable, made in 1860, 60 millions per knot; the Malta-Alexandria cable, made the same year, 100 millions; the Oran-Carthagena cable, made in 1863, 350 millions; the Persian Gulf cable the same; and, lastly, the Atlantic cable, nearly 500 millions per knot.

The insulation resistance of a cable is measured by one of the following methods:—

(1.) Wheatstone's bridge.
(2.) Differential method.
(3.) Deflection.

77. The method of measuring a cable by means of Wheatstone's bridge was given when treating of Messrs. Siemens' testing-board. With the customary arrangements, this method is limited to the measurement of resistances of 10 millions. When greater resistances are sought to be measured, it would be necessary, if this method were to be used, to increase the proportion of the two branches of the bridge, or the value of the adjustable side, but which would proportionably reduce the sensibility of the galvanometer.

78. To avoid this, the system has been introduced of measuring the resistance by mean of a differential galvanometer, the magnetic effects of whose coils upon its needle are very different. When this is done, and a single battery used, the intensity in the smaller circuit is obliged to be so great in order to balance the needle, that it endangers warming the coil and increasing its resistance. To remedy this inconvenience, Messrs. Siemens, in their measurements, have sometimes employed separate batteries in the two circuits of the galvanometer.

Such an arrangement is shown in Fig. 164, in which x is the cable resistance ; *a*, one of the coils of the galvanometer, whose resistance is r; B, the battery, whose electro-motive force is E, the intensity in the circuit on the right hand being I; R is the resistance inserted; *b*, the galvanometer coil; B′, the battery, whose electro-motive force is E′, and I′ the current in the left-hand circuit. Let m and m' be the opposite magnetic effects of the coils *a* and *b* upon the needle suspended between them, when the intensities in the circuits are equal.

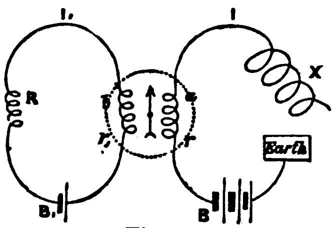


Fig. 164.

The relation $\frac{m}{m'}$ is first ascertained by direct experiment, by inserting in x a known resistance, and by measuring also the relation $\frac{e}{e'}$, when e and e' are the electro-motive forces of the batteries. This is called determining the constant of the apparatus. A known resistance, W, is inserted, instead of x, in the circuit of a battery, B; on the other side the amount of the adjustable resistance with a single element, e', is varied to R′, until the needle rests over zero.

Then the intensities in the two currents are—

$$I = \frac{e}{W + r} \quad . \quad . \quad (1 \quad \text{and} \quad I' = \frac{e'}{R' + r'} . \quad . \quad . \quad (2$$

That the needle may take up this position, however, it is necessary that the currents in the circuits be inversely proportional to the magnetic effects of the coils.

$$\frac{m}{m'} = \frac{I'}{I} \quad . \quad . \quad . \quad . \quad . \quad (3$$

Inserting the values of I and I′, given by (1 and (2 in this equation,

$$\frac{m}{m'} = \frac{e'}{e} \cdot \frac{W + r}{R' + r_1}$$

And if $e = e'$—that is to say, a similar electro-motive force be taken on each side, in measuring the constant,

$$\frac{m}{m'} = \frac{W + r}{R' + r'} = K \quad . \quad . \quad . \quad (4$$

Sometimes the proportion between m and m^1 is so great that it would be inconvenient to obtain the resistance W large enough to establish the balance in measuring the constant of the apparatus.

In this case the operator employs a shunt across the ends of the larger coil of the galvanometer, and introduces its value into the calculation by the constant K. This shunt, $r_{\prime\prime}$, Fig. 165, does not exert any deflecting force upon the needle, its duty being simply to take off part of the current from r, that the needle may not be acted upon by the full intensity, I. The currents in r and $r_{\prime\prime}$ being i and $i_{\prime\prime}$, respectively, by Kirchhoff's laws,

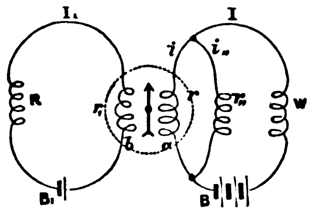


Fig. 165.

$$I - i - i_{\prime\prime} = 0$$

and

$$i\,r - i_{\prime\prime}\,r_{\prime} = 0$$

whence

$$i = \frac{I}{\frac{r}{r''} + 1}$$

And since

$$\frac{I'}{i} = \frac{m}{m'}$$

$$i = \frac{I'\,m'}{m}$$

$$\frac{I'\,m'}{m} = \frac{I}{\frac{r}{r''} + 1}$$

$$\frac{I'}{I} = \frac{m}{m'}\;\frac{r''}{r + r''} \quad . \quad . \quad . \quad . \quad (5$$

By Ohm's law, however,

$$I = \frac{e}{W + \frac{r\,r''}{r_{\prime} + r''}}$$

and

$$I' = \frac{e'}{R' + r'}$$

which, divided by each other, give

$$\frac{I'}{I} = \frac{e'}{e} \quad \frac{W + \dfrac{r\,r''}{r + r''}}{R' + r'} \quad . \quad . \quad . \quad . \quad (6$$

(5 and (6 combined

$$\frac{m}{m_1} = \frac{e'}{e} \quad \frac{W\,(r + r'') + rr''}{(R' + r')\,r''} = K \quad . \quad . \quad (7$$

The cable is now inserted in its place, as in Fig. 164; R is adjusted to obtain a balance between the active magnetic effects of the currents. I and I' being the currents,

$$I = \frac{E^*}{x} . \quad . \quad . \quad (8 \qquad I' = \frac{E'}{R + r'} \quad . \quad . \quad . \quad (9$$

And their relation to each other is

$$\frac{I'}{I} = \frac{m}{m'} = K$$

therefore

$$\frac{E' x}{E\,(R + r')} = K$$

and

$$x = K\,\frac{E}{E'} . \,(R + r')$$

The resistance of the cable, according to this, is equal to the product of the resistance of the circuit $R + r'$, the relation of the electro-motive forces $\frac{E}{E'}$, and the constant K of the initial magnetic forces of the coils of the galvanometer.

Fig. 166 represents a plan of a convenient method of arranging a board by which not only this, but also the foregoing systems may be introduced, by simply changing the positions of a few contact plugs.

* In this equation, as in some of those which precede it, the resistance x is regarded as the whole resistance of the circuit. The galvanometer resistance is neglected, as the value of x is very great in comparison with it.

A similar arrangement, with the exception of the form of commutator U, which we have altered, is used by Messrs. Siemens on board ship while paying out submarine cables, and also at the land stations. The key acts between the lever 3 and back contact 2, as a short circuit across the galvanometer coil α, the longer of the two, and between the lever and front contact 1, as contact key in the circuit of the galvanometer coil β. This application of the key is useful in insulation tests, when the current is allowed to run, for a certain time, into the cable before the observation is made, and the battery circuit on the other side closed, at the same instant that the insulation current is allowed to go through the galvanometer. The other connections and pieces are obvious.

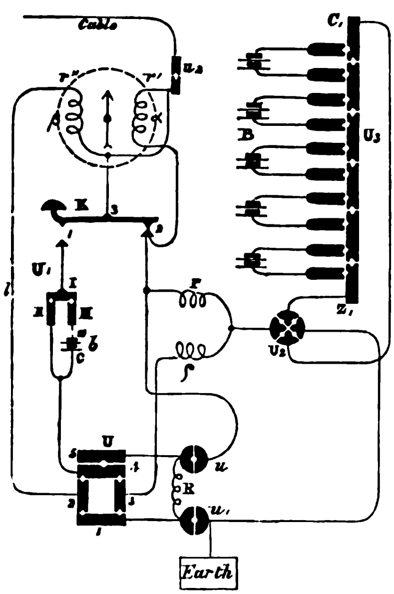


Fig. 166.

The constant of the instrument is measured by allowing the current of the smaller battery b to go, at the same time, parallel through both the coils α and β. This is done by means of contact plugs in the holes I—III of U_1, in the holes 1—3, 2—4, and 4—5 of U, and in all the holes of the proportion resistance coils r and ρ; all other stoppers are left out. The current of b goes through the circuit b, z, I, III of U_1, K (1, 3) (the key being pressed down) divides into

$$\left\{\begin{matrix} \beta,\ l,\ U\ (2,\ 4)\ c\ .\ .\ .\ . \\ \alpha,\ r,\ \rho,\ U\ (3,\ 1),\ R,\ U\ (5,\ 4),\ c \end{matrix}\right\} \text{ of battery } b.$$

The resistance of the coil β and its circuit remains unaltered; R is adjusted until the deflecting forces of the currents in α and β are balanced, in which case

$$K = \frac{R + r'}{r''}$$

R being the amount of unstoppered resistance in the set of coils between u and u_1, r' the resistance of α, and r'' that of β. An advantage is derived from the measurement of the magnetic constant of the coils by the galvanometer with a single battery, as no error can occur from inequality in the electro-motive forces.

For the measurement of insulation resistance, the cable is connected with the terminal u_2, in which the contact plug is inserted, so that the cable end is, in fact, connected with the beam K 3 of the key, or that which is the same thing, with the upper end of the coil α. Contact plugs are inserted in all the holes of r and ρ; diagonally in U_2, so as to put the copper pole or the zinc pole of the battery B to earth as occasion may require; in U_3, so as to introduce a sufficiently great battery power to make the observation sensible, when 1 per cent. of the electro-motive force is added or subtracted; in U, in holes 1—2 and 4—5; in U_1 in hole I—III; in the hole of u_2, when the moment arrives for sending the current of B into the cable; and lastly, after the expiration of a certain time, the key is pressed down, by which the short circuit is broken (letting the insulation current go through α, and the opposite current of b through β), and R is closed at the same instant. In the changed position of the stoppers of U, the resistance coils R, which were in the circuit of α, in measuring the constant, are now shifted into the circuit opposite. The current of B goes through earth, U_2, U_3, U_2, r, α, u_2, cable, dielectric, earth. The current of b goes through the circuit, U_1 (III, I), key (1, 3), β, l, U (2, 1), R, U (5, 4), b, &c.

The resistance of R is adjusted until the needle is not deflected to either side of zero. The resistance of the cable is then expressed by

$$x = K\frac{B}{b}(R + r'') - r'$$

r'—the resistance of α—is so small, in comparison with x, that it may, without sensible error, be neglected, and the resistance of the cable be called

$$x = K \cdot \frac{B}{b} (R + r'')$$

One of the fundamental laws of magnetism is that the magnetic force decreases as the square of the distance between the points acting upon each other increases. The galvanometer coils, in which currents are circulating, being magnets, are subject to the same law. It, therefore, becomes convenient to so arrange the coil β that its distance from the needle may be varied, by which the constant relation K may be obtained of any value most convenient in the calculation of x, as, for example, some power of 10, or the resistance x may be calculated by the distance; which is, in that case, varied by means of a michrometer screw, and observed with a nonius. The latter method, where time and trouble are not of importance, is less to be recommended, however, as any error occurring in the observation of the distance, obviously comes into x in the square. Nothing is easier than to make $\frac{K B}{b} = 10^6$, and then the resistance of the cable is

$$x = (R + r') \text{ millions.}$$

The apparent complication of the board is caused by the arrangements of the pieces for measuring by the other methods as well as by this one.

79. Beyond the limits within which the differential method just explained may be employed, we use the method of deflection. For this purpose Professor Thomson's reflecting galvanometer, and the sine-multipliers, are the best measuring instruments. One end of the cable, *a b*, Fig. 167, is connected with the galvanometer coil, the other end of the coil being in connection with a contact key, K, and, through this, with one pole of a battery, B, whose other pole is to earth. When in this position the key is pressed down, the charge current passes through the galvanometer. This is avoided by a short circuit or shunt of no appreciable resist-

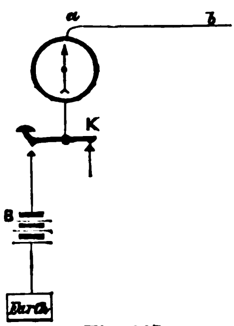


Fig. 167.

ance between K and *a*, which is removed when the steady deflection due to leakage, or conduction of the insulator, is to be observed. The details of these arrangements were given in the description of Messrs. Siemens' testing-board.

80. *Resistance of Insulating Materials under Pressure.*—The arrangements made by Mr. Reid at the gutta-percha works enabled Mr. C. W. Siemens to have the core of his cable tested under a hydraulic pressure of 280 atmospheres. He took advantage of this to make some interesting experiments on the electrical behaviour of gutta-percha, india-rubber, and a combination of both, under high pressure. The results of these experiments, which the writer carried out under Mr. Siemens' direction, were read before the British Association at their recent meeting at Newcastle. The core of the Malta-Alexandria cable was tested under a pressure of 600 lbs. per square inch, and from these tests it was observed that the resistance of insulation increased, under this pressure, to the amount of 14 per cent.; or, more generally, that the resistance, R_p, of a coil of this cable, under the pressure of p lbs. per square inch, whose resistance under atmospheric pressure at the same temperature, was R, could be very nearly calculated by the formula.

$$R_p = R\,(1 + 0{,}00023\,p)$$

The stronger tank since erected by Mr. Reid enabled the tests of part of the Carthagena-Oran core to be carried to 300 atmospheres. The resistance of the insulation was observed at different stages of the pressure, between vacuum and 300 atmospheres, advancing each time 75 atmospheres. The results of the tests with gutta-percha covered wire showed that the resistance increases with the pressure, and that the curve is not approximately a straight line, as the above formula expresses it, but that it is slightly convex to the axis of x, when the ordinates of a graphic system (Fig. 168) represent the resistances, and the abscissæ the pressures, in atmospheres. Wires insulated with india-rubber gave quite opposite results, the resistance decreasing as the pressure was increased, and the curve being somewhat concave to the base line. A wire insulated first with india-rubber and then, over this, with a coat of gutta-percha, gave mean results between those found with the two materials separately.

From all the observations made in carrying out these ex-

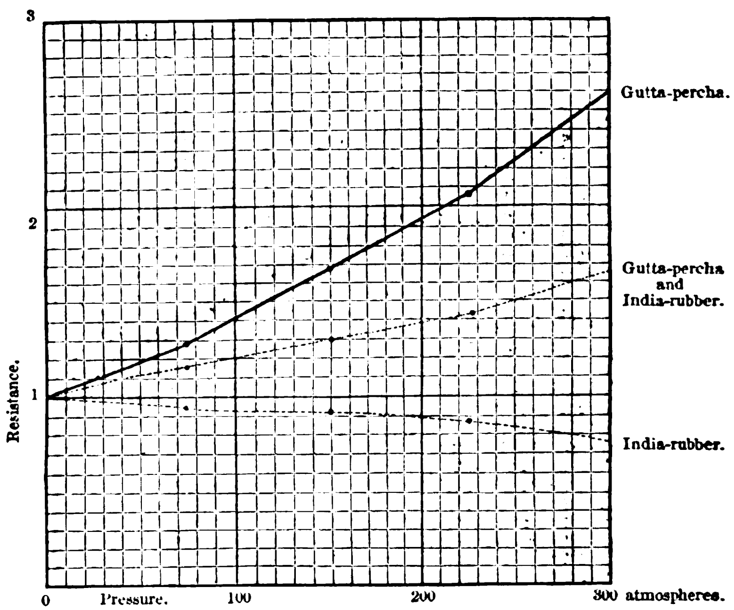


Fig. 168.

periments the means of the co-efficient a, from these three modes of insulation, are for

Gutta-percha........................	+ 0,0041
India-rubber	— 0,0009
Combined	+ 0,0016

to be inserted in the formula

$$R_p = R\,(1 + a\,p)$$

by which as good an approximation to the true resistance is obtained, as the expressions of the curves as straight lines allow; and the observations were too rough and too few to make it worth while to calculate the formula with more members.

The values obtained for the Carthagena-Oran core agree sufficiently well with the corresponding observations with the core of the Malta-Alexandria cable, to render it highly probable that the per-centage improvement in the resistance under pressure is independent of the thickness of the insulator, as well as of improvement in the quality of the material.

81. *Electrification.*—In the earliest days of cable-making attention was called to the fact that, when a current is kept on an insulated wire, the insulation resistance increases with the time, but not proportionably to it.

The late Dr. Esselbach made some elaborate experimental investigations to determine empirically the nature of the curve, during the time he officiated as government electrician to the Malta-Alexandria cable, and had prepared himself to prosecute his researches on this subject with the Persian Gulf line, of which he held the position of general-superintendent. It is much to be regretted, however, that his untimely death has deprived the science of the most valuable part of that which he had already accomplished in illustration and explanation of the phenomenon.

If we take a wire, insulated with gutta-percha, and connect the pole of a battery to one end of it, we find that the observations of the current, after stated periods of time, will give us a curve represented by the line *a b*, Fig. 169, in which the strengths of current are the ordinates, and the times the abscissæ. It is evident that the decreasing current observed is due to two causes—the one to leakage through the material, and which is the proper insulation current, and the other to electrification. A glance at the line which we obtain will suffice to make it evident that the curve is assymptotical, nearing the axes of the system in both directions. From this it is obvious that the current which we measure is never the true insulation-current 1, but always 1 plus some function of the time, although the curve after an hour or so approaches very near to the line of the true insulation-current.

There is but one conclusion to be drawn from this phenomenon: it is, that a cable takes an infinitely long time to become completely charged, and that the quantity of electricity which goes into it, to contribute to the charge, at any moment, after closing the circuit, is represented by the difference between the true insulation and the measured current.

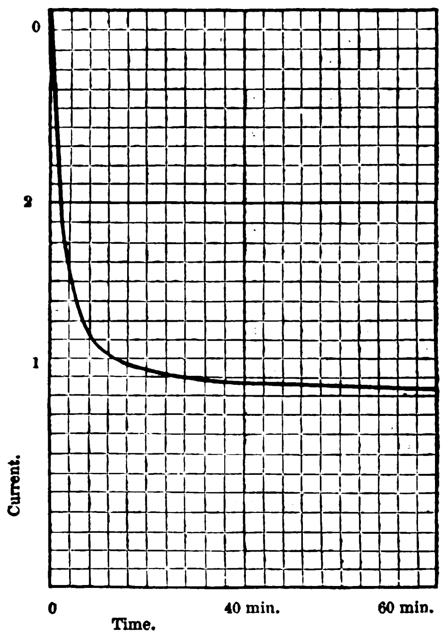


Fig. 169.

This difference is found experimentally to be inversely proportional to the time, or nearly so.

82. *Joints in the Core.*—After the tests of the single knots of core, these are joined up in lengths of six knots, more or less, to be transferred to the machines in the sheathing works. Joining the core is an operation requiring manual skill, and, above all, scrupulous cleanliness. No joint is admitted into a submarine line unless made by a workman who has had a considerable practice. This is a branch brought to perfection by the Gutta-percha Company. The jointer commences by cutting off the two ends of the core, so that the gutta-percha and copper-wire are "flush;" he then

warms the percha, for a distance of about three inches from each of the ends, with a spirit-flame, and, when sufficiently soft, pushes it back until it forms an enlargement as at A and A_1, Fig. 170. The wires of the copper strand are then cut off at different distances between the bulbs and the ends.

There are two ways in which joints are made in the conductors of cables. The first is called the "scarf-joint." It

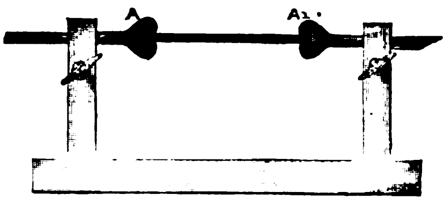


Fig. 170.

is made by filing off the two ends of the strand at a corresponding angle; fitting and soldering the slanting faces. When this is done, the whole is wrapped round with two coats of fine copper wire, the first wrappering being soldered all the way, the second only on each side of the joint; by which, should the conductor part at this point, the outer wrapper-wire will preserve electric continuity. Such an accident might easily occur; and, in that case, the outer wire would only be extended like a spiral spring. The other method, which is sometimes used, is less convenient for strands of seven than for those of three wires. The wires of the opposite ends of the strand are opened out, and each are joined separately. Each separate joint is made with slanting faces, soldered like the scarf-joint, but not wrappered, and a distance of at least half an inch left between each separate soldering. When the soldering is finished, the workman endeavours to bring the same spiral twist into the soldered wires as in the rest of the conductor. This is best done by having previously coiled a length upon the floor, and put a couple of reverse twists in it, which are afterwards concentrated in the soldered place, to give it the right spiral.

The soldering completed, the operator washes his soldered wire with naphtha, warms it with his spirit-flame, and smears it with some of the compound of resin, tar, and gutta-percha, invented by Willoughby Smith. The joint is then screwed into a holder (Fig. 170), where one of the knobs of gutta-percha, A A_1, is gently warmed until the gum is soft. It is then drawn carefully up to the other knob, leaving, on its way, a perfect tube of gutta-percha upon the wire. The superfluous percha is removed, the other knob warmed and drawn in the same way over the tube already formed, which is at the same time heated sufficiently to make the two adhere. A thin coating of Chatterton's compound is put over this; and, finally, after kneading the plastic tubes well together between the finger and thumb, an oblong piece of sheet gutta-percha is warmed in the lamp, and the whole joint clothed with it. When he has kneaded the whole into a homogeneous mass, warming it gently from time to time as it gets consolidated, the operator works the joint as cylindrical as possible with his hands, and finishes it off on the outside by burnishing or ironing with a small polished steel tool, heated to a degree sufficiently high to smooth the percha.

The Gutta-percha Company do not make two tubes of the knobs A A_1, but simply draw them together over the joint so as to form a single tube, which they cover up in a piece of sheet gutta-percha. The methods are, perhaps, equally good. Sometimes also joints are made with alternate coverings of gutta-percha and compound, so as to resemble exactly the insulator.

83. *Testing the Joints.*—Joints are the weak points of submarine cables. It is therefore essential to test those which occur between the lengths of core with the utmost precision. The old method of testing joints was to get a steady deflection by the insulation current after the battery had been on the core or cable some time, during which the joint was held in the air, dry; it was then suddenly plunged into water in electrical connection with the earth; and any movement of the galvanometer needle, however slight, was taken as an indication of an inferior joint.

Mr. Whitehouse first sought to refine this crude process by measuring only the current which actually went through the joint, and expressing it in terms of the insulation resistance of lengths by the cable. The joint between the lengths α and β (Fig. 171) was immersed in acidulated water contained in an insulated vessel, v; a plate of metal, also immersed in the water, was connected to one pole of a powerful, well-insulated battery, B, the other pole being in connection with one end of a galvanometer coil; the other end of the galvanometer coil, and both ends of the conductor of the cable, were to earth. Whatever current was indicated by the deflection of the galvanometer needle must necessarily pass through the water in the insulated vessel, and through the joint.

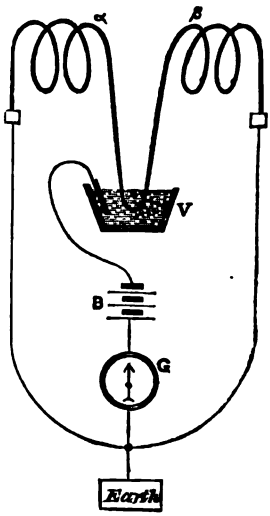


Fig. 171.

This method was employed for some time, but has been succeeded by a modification of it, introduced by Messrs. Bright and Clark, which consists in accumulating the electricity which goes through the joint upon the plates of a condenser, and sending the discharge suddenly through the galvanometer, instead of letting the current go gradually through, as Whitehouse did.

This modification is decidedly superior to its original. The two parts, A and B (Fig. 172), of the cable are placed conveniently, that the joint between them may be immersed in water contained in the insulated vessel, v, from which a connection, *l*, leads to the plate, 2, of the condenser, C. The other side of the condenser is connected with the lever, 1, of a switch, S, the two anvils, 2, 3, of which are respectively in the circuits of a battery, E, and of a galvanometer, G. The other end of the galvanometer coil is connected to side 2 of the condenser, and the other pole of the battery with the conductor of the cable. When all is ready for the test, the lever of the switch is turned upon the contact 2, closing the circuit of the battery from one pole through E, *t*, B, joint, water in V, P, *l*, and plate 2 of condenser; andfromthe other pole, through s, 2, 1, l', and plate 1 of the condenser. Whatever leakage occurs through the joint carries with it an equivalent quantity of electricity, which is accumulated upon the plates 1 and 2 of C. After the lapse of a certain time, the lever of the switch is taken from the anvil, 2, and put upon 3, completing the circuit between the plates of the condenser with the galvanometer (C, 2, G, 3, s, 1, l', C, 1). The discharge from the condenser plates passes thereupon through the galvanometer whose magnet needle is deflected, the deflection depending of course upon the leakage of the joint, the length of time during which the condensation continues, the degree of insulation of the condenser itself, and the force of the battery.

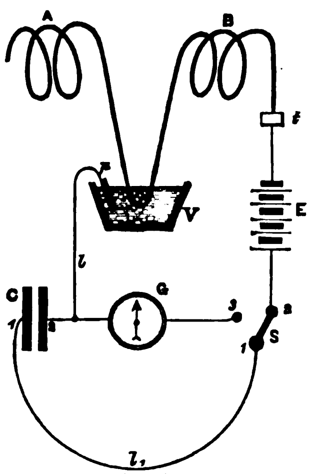


Fig. 172.

In the Gutta-percha Works, Mr. Smith uses a length of cable instead of an ordinary condenser. In this case the conductor of the condenser cable is connected with *l*, instead of C, 2; and as the outside (which represents C,) is to earth, the lever s_1 of the switch must also be put to earth.

Mr. Varley prefers the use of condensers made of alternate leaves of tinfoil and paper saturated with paraffin.

At first sight, it might seem doubtful that any satisfactory result could be obtained with this method, in which the condenser conducts, perhaps, ten thousand times as well as the joint which is tested, The objection, however, is easily satisfied. The proportion between the current which goes through the condenser and the static quantity which is retained as charge at the moment of discharging, remains unchanged, whatever the current may be. If the current is small, as it must be if the joint is good, the charge will be proportionally small; and it will increase as the current increases. In shifting the condenser by an instantaneous movement from the battery and joint to the galvanometer, no time is given for any material part of the charge, at the moment in the condenser, to neutralise itself through the dielectric; and, therefore, whatever is present shows itself upon the instrument.

The core, when joined up in convenient lengths, is coiled carefully upon the drums and transported to the sheathing works. Arrived there, if not wanted immediately to be sheathed, it is stored away in water-tanks, and tested at intervals, to ascertain if it has become injured, and to accumulate data for subsequent calculations.

84. *Self-heating of Cables.*—During the manufacture of the cable, also, its electrical conditions are ascertained at regular intervals—usually twice a day—to make sure that no injury has happened to the insulator; or, in the event of the cable being coiled in a dry tank, that it has not heated spontaneously, and increased the temperature of the core. This is seen by the increased copper resistance and lower resistance of insulation.

The cable destined in 1860 for submersion between Rangoon and Singapore, and subsequently laid in the Mediterranean, was coiled in tanks in the yard at Morden Wharf, Greenwich. While there, some of the tanks became leaky, the weight of the cable bearing too heavily upon their foundations; and it was decided not to pump water over the cables, because the iron rusted very quickly, and the oxide, being washed off by every new supply of water, would soon have reduced the sections of the wires. After some days' exposure to the air in this half-wet condition, we found that some of the cables showed signs of deterioration and a higher copper resistance than was due to the temperature of the surrounding air. The cable which appeared the most decidedly affected—a length of 162 knots—was cut into three parts, and coiled into a dry tank, where its electrical conditions were from time to time narrowly examined. Its copper resistance had risen to a degree which indicated a temperature of 80° Fah., while the air and water in the neighbourhood were not above 57° Fah.

Considerable anxiety was, of course, manifested on the occasion of this unlooked-for mishap, and Dr. Miller of King's College undertook for the Board of Trade to inquire into and report upon the subject. In his Report he says that, "These heating effects appear to have been due, not to any permanent chemical change, either in the composition of the insulating coating of the gutta-percha, nor in that of the serving of hemp and tow; but were owing simply to the effects of oxidation upon the iron at the ordinary summer temperature of the air, produced by the moistening of the cable with the water of the river, the slightly brackish nature of which increased the effect." In support of this opinion a quantity of iron filings was placed in a wooden box, a foot deep, and water at 40° F. poured over them. In a few hours the temperature of the mass had gone up considerably, and, after a day and a half, reached 100° F. The rate at which this increase of temperature went on was found to depend upon the frequency with which the filings were stirred and watered.

In order to measure the degree of self-heating, and to ascertain at all times the temperature of a cable when coiled in the tanks, both in the yard and on board the ship, Mr. William Siemens constructed a resistance-thermometer.

This "resistance-thermometer" consists of a coil of fine copper or other pure metal wire, whose resistance at 0° Cels. is 100 or 1,000 units. The per-centage variation of the resistance of pure metals between certain limits of temperature being known, by measuring the resistance of the coil at any moment, its temperature can be calculated, and that of the surrounding medium concluded. A more useful and unerring measure of temperature than this resistance-thermometer does not exist. One of the chief advantages which it possesses over the expansion-thermometers is that its indications may be read off at almost any distance; and by a little ingenious contrivance the unknown temperature of the leading wires will not cause the least error. This is attained by connecting one end of the thermometer wire with the outside casing of the instrument (or earth), the other end with one of the leading wires, and the remaining leading wire also with the casing. The leading wires are made of the same metal, of the same length of course, and

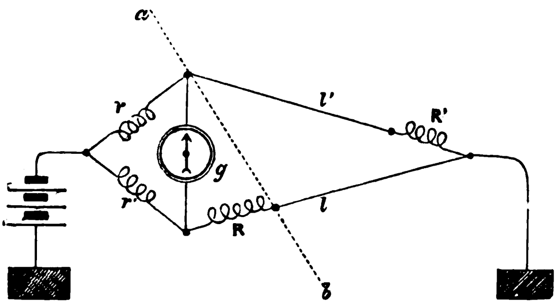


Fig. 173.

are adjusted to be of the same resistance. They are bound up together so that they each must have the same temperature in any point. Thus arranged, the thermometer is put in its place of rest, and the ends of the leading wires connected with the measuring apparatus, which consists of a Wheatstone's balance. The resistances r and r' (Fig. 173) are equal to each other, of the same metal, and coiled together upon a common reel. In the circuit of the leading wire l, connected with the casing of the thermometer, an adjustable resistance, R, is inserted. The whole then forms a balance, giving us in the proportion of equilibrium,

$$\frac{r}{r'} = \frac{l' + R'}{l + R}$$

or, as $r = r'$ and $l = l'$,

$$R = R'$$

Knowing beforehand the resistance of R' at 0° C., its temperature giving any other resistance is easily calculated by means of the coefficients given in the table at p. 267.

A more handy arrangement still is by substituting a resistance, R, equal in every respect to R′, in fact, by a second resistance-thermometer. This is immersed in a vessel of water whose temperature is changed until the electric equilibrium is established; the temperature of the water gives then, without any reduction whatever, by means of a mercury thermometer, the temperature of the distant coil R′. Only that portion of the apparatus on the left-hand side of the dotted line *a b* is in the testing-room, that on the right hand is outside. Such an arrangement might be used with good results for ascertaining the temperature of the sea at different depths. In this case all on the right-hand side of *a b* would be submerged, that on the left on board. With a number of these instruments, placed between the layers of cable on board the ship *Queen Victoria* it was observed, after the cable had been stowed a few days, that the upper part increased in temperature at the rate of about 3° F. daily, until 86° F. was reached, while the lower part retained the temperature of the hold and water.

The obstinate doubts which were urged at the time against the truth of these results were silenced signally when water of 42° F. was pumped upon the cable, and flowed out at the bottom at a temperature of 72° F. This shows the necessity of keeping an iron-covered cable, which has once been under water, always under water, even during the transport, although it may be attended with some inconvenience.

The tests which are made at the sheathing works are of the same kind as those made at the gutta-percha works. Faults sometimes occur; but these are easy to determine, as the operator is in possession of both ends of the cable.

In order to facilitate the discovery and location of faults in sheathed cables, Mr. Willoughby Smith has invented and patented the idea of serving the core with tanned hemp instead of tarred hemp, which he professes to have found has an inclination to temporarily mend small faults which might develop themselves when submerged.

85. *Finding the Place of a Fault in the Insulating Covering when both ends of the cable are at hand.*—The advantage of having both ends occurs before the cable is submerged, and sometimes, but in rare instances, after it is submerged, when the stations at the ends of the line are joined by another wire, whose insulation is good, and which enables the electrician to employ the "loop-method." In this event the ends of the two cables are connected together at the distant station, say at A, Fig. 174, forming a single line, E A *d*.

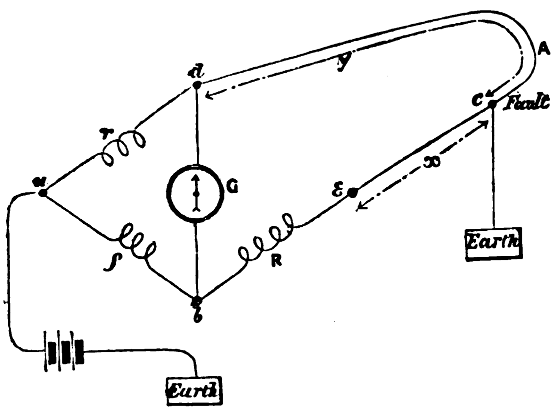


Fig. 174,

Two proportion resistances, *r* and *ρ*, are connected together in a point, *a*, with one pole of a battery whose opposite pole is to earth; their further ends *b* and *d* are severally connected to the end of cable and the end of an adjustable resistance, R, the remaining ends of the cable and resistance-coil meeting in E. The resistance R is inserted in the cable circuit at that end of it towards which the fault lies. A galvanoscope is also inserted between *b* and *d*. The system thus arranged forms the circuits of an ordinary Wheatstone's balance, the sides of which are, respectively, 1) *r*, 2) *ρ*, 3) *y*, 4) $R + x$. The magnitude x is the resistance of the conductor from the fault to E, y the resistance from the fault to d; therefore, the resistance of the whole conductor l is

$$l = x + y$$

and, when the currents of the bridge system are balanced,

$$\frac{r}{\rho} = \frac{y}{R + x}$$

From these two equations the distances are

$$1)\quad x = \frac{l\rho - Rr}{\rho + r} \quad \text{and} \quad 2)\ y = (R + l)\frac{r}{\rho + r}$$

expressed in units of resistance. These values are reducible to units of length by dividing them by the average resistance n of one knot; and they become L_x and L_y knots respectively,

$$L_x = \frac{l\rho - Rr}{(\rho + r)\,n} \qquad \text{and} \qquad L_y = (R + l)\frac{r}{(r + \rho)\,n}$$

Generally, the branch resistances r and ρ may be made equal to each other, facilitating the calculation with the above formulæ, which then become

$$x = \frac{l - R}{2} \qquad \text{and} \qquad y = \frac{l + R}{2}$$

in resistance, or

$$L_x = \frac{l - R}{2\,n} \qquad \text{and} \qquad L_y = \frac{l + R}{2\,n}$$

in knots.

Another way of doing the same thing is by making the resistance between a and b some power of 10, and inserting in the side $a\,d$ a set of resistance-coils, R. The ends of the cable are connected immediately to the points b and d, which are joined also by the ends of the galvanometer-coil G, as before; x and y being the two ends of the cable from the fault in opposite directions, and no current deflecting the needle of G on closing the battery circuit, we have the bridge equation

$$\frac{\rho}{R} = \frac{x}{y} = \frac{x}{l - x} = \frac{l - y}{y}$$

whence

$$x = l\,\frac{\rho}{R + \rho} \qquad \text{and} \qquad y = l.\frac{R}{R + \rho}$$

in resistance, or

$$L_x = l \frac{\rho}{(R+\rho)n} \quad \text{and} \quad L_y = l . \frac{R}{(R+\rho)\,n}$$

in knots.

86. *Rupture of the Conductor while the insulation remains good.*—Another kind of fault, and one of a serious nature, when it occurs, which is happily seldom, is when the copper conductor, from its inability to withstand the elongation to which some point of the cable is exposed, snaps asunder, and the electric continuity is lost. This fault is of more danger while paying out than before. The only way to determine the distance of the rupture, in such a case, is by comparing the static capacity of the cable from the end to the fault with the average capacity of the core, per knot.

There are two very excellent methods of doing this; the one is by Mr. De Sauty, the other by Mr. Varley.

87. *De Sauty's Method of comparing the Capacities of Leyden jars by Bridge System.*—This is one of the most elegant of the

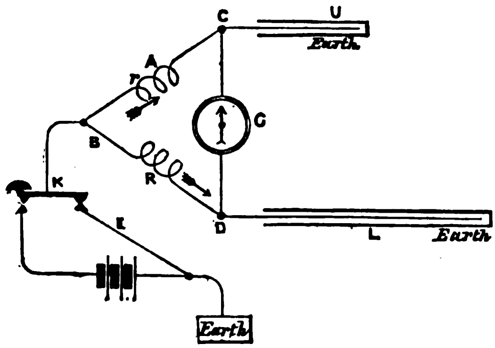


Fig. 175.

many applications of the null-methods, its purpose being to compare the capacity of a cable with that of a jar of unit surface; in determining the distance of a rupture of the conductor it is invaluable.

The method in question depends upon the same principles as Wheatstone's bridge, the only difference being that capacities are dealt with in one half of the bridge instead of resistances. At the point of junction of two resistances, *r* and R (Fig.

175), one of which is adjustable between limits, is connected the beam of a contact key, K, between the point-contact of which and earth a battery, E, is inserted. The farther ends of the resistances r and R are connected respectively to the interiors of the unit jar U, and of the cable L, and to the two ends of the galvanometer coil G. The external coatings of both the jar and cable are to earth. On pressing down the key, the charge current flows in r and R, and into U and L, either directly or partly through G, into one of them.

The charge current or that current which flows into the jars at the instant of closing the circuit is proportional to, and may be taken as expressing, the quantity of electricity conveyed by the currents to commence their charge, and therefore to their capacities for this charge. C and D being the intensities of the currents flowing into the jar and cable at the moment of closing the circuit,

$$C : D = K_U : K_L$$

K_U and K_L being the two capacities, or

$$\frac{C}{D} = \frac{K_U}{K_L} \quad . \quad . \quad . \quad . \quad (I.$$

By Kirchhoff's law of branch circuits,

$$1) \quad . \quad . \quad A\,r - B\,R \pm G\,g = 0,$$
$$2) \quad . \quad . \quad A \pm G - C = 0, \text{ and}$$
$$3) \quad . \quad . \quad B \pm G - D = 0.$$

When the intensity G in the galvanometer circuit = 0, which is the condition upon which the method rests, and which is obtained by adjusting the value of R, these equations become

$$A\,r - B\,R = 0 \quad \text{or} \quad \frac{A}{B} = \frac{R}{r}$$
$$A - C = 0 \quad \text{or} \quad A = C$$
$$\text{and } B - D = 0 \quad \text{or} \quad B = D$$

from which

$$\frac{C}{D} = \frac{A}{B} = \frac{R}{r} \quad . \quad . \quad . \quad . \quad (II.$$

and as according to (I. $\frac{C}{D} = \frac{K_U}{K_L}$,

we have also

$$\frac{K_U}{K_L} = \frac{R}{r}$$

$$K_L = K^U \frac{R}{r} \quad . \quad . \quad . \quad . \quad \text{(III.}$$

The jar U may be formed by a length l_U of the same cable as L, in which case the capacities K_U and K_L of the two lengths are to each other as the lengths.

$$\frac{K_U}{K^L} = \frac{l_U}{l_L}$$

which, being substituted in III.,

$$l_L = l_U \frac{R}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(IV.}$$

when the length l_U is some unit used to express the length of the cable as a knot, 2026 yards, for instance, the distance l_U of the rupture will be $\frac{R}{r}$ knots from the end.

In arranging a board for this measurement, a condenser made of alternate plates of gutta-percha and metal, having the same capacity as an unit of length of the cable to be tested, is found more convenient than a piece of cable, which is liable to accident.

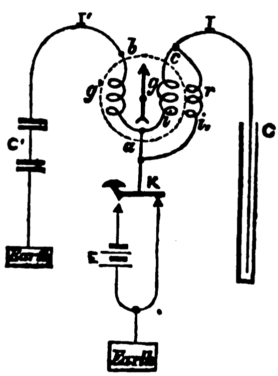


Fig. 176.

88. *Varley's Method of comparing Capacities of Jars.*—An equally good method of comparing the charge of one cable with that of another, or with that of a condenser of known capacity, has been used with good results by Mr. Varley. He employs a differential galvanometer, whose coils have the initial magnetic effects m and m', and the resistances g and g. The ends of these coils, joined up in the

point a (Fig. 176), are connected by means of a contact key, K, with a battery, E. The other end of the coil g', goes to one side of a condenser, c', or to the interior of the standard piece of cable; the other end of g to the interior of the cable whose charge is to be measured. Part of the current of the coil g is shunted by means of an adjustable resistance, r. When the key is pressed down, the current divides itself at a, part I$'$, passing through the coil g', to the unit jar C$'$, and the remainder I, passing through the parallel circuit g and r, whose combined resistance is $\frac{gr}{g+r}$, into the cable C.

Let the intensities in g and r be expressed by i and i_1, and at the moment of closing the circuit, let the needle be unaffected by the currents, then

$$\mathrm{I}' m' = i\, m$$

$$i = \mathrm{I}' \frac{m'}{m}$$

From the law of branch circuits,

$$i = \mathrm{I}\frac{r}{g+r}$$

therefore

$$\frac{\mathrm{I}' m'}{m} = \frac{\mathrm{I}\, r}{g+r} \quad \text{or} \quad \frac{\mathrm{I}}{\mathrm{I}'} = \frac{m'}{m} \cdot \frac{g+r}{r}$$

$$\mathrm{I} = \mathrm{I}' \frac{m'}{m} \cdot \frac{g+r}{r};$$

and since the intensities of the charge currents at the moment of closing the battery circuit are proportional to the capacities of the jars, or

$$\frac{\mathrm{I}}{\mathrm{I}'} = \frac{\mathrm{C}}{\mathrm{C}'}$$

$$\mathrm{C} = \mathrm{C}' \frac{m'}{m}\left(\frac{g}{r} + 1\right)$$

For simplicity, to save measuring the constant $\frac{m'}{m}$ of the galvanometer, Mr. Varley makes the coils g and g' of his galvanometer equal in every respect, by which, therefore, $m = m'$, and

$$C = C'\left(\frac{g + r}{r}\right)$$

To obtain a balance with this arrangement, therefore, it is necessary that the ratio of the capacities of the two jars $\frac{C}{C}$, should be equal to that of the sum of the resistance of the galvanometer coil, and its shunt divided by the resistance of the shunt; and for attaining this it suffices to alter the value of r.

A detailed description of Mr. Varley's apparatus for this method may be found in Mr. Culley's Handbook.

89. *Final Tests of a Complete Cable.*—To ascertain whether the electrical conditions of a finished cable correspond with the known conditions of the separate lengths of which it is composed, the conditions of the whole cable must be calculated from the results of the separate tests, and compared with the final test of the complete cable.

Let the lengths of the coils of the core, tested separately, be l_1, l_2, l_3, ... l_n, and their sum L; the insulation resistance per knot of the same, after the same time and at the same temperature, r_1, r_2, r_3, ... r_n, and the resistance, per knot, of the whole cable x, then we have the equation,

$$\frac{L}{x} = \frac{l_1}{r_1} + \frac{l_2}{r_2} + \frac{l_3}{r_3} + \ldots\ldots + \frac{l_n}{r^n}$$

whence

$$x = \frac{L}{\Sigma \frac{l}{r}}$$

With a cable carefully made and handled, the measured will agree within a trifle with the calculated value of x. Beyond the errors of observation, the leakage of the joints, which is always great in comparison with that of similar lengths of perfect core, should be the only source of difference.

The mean value of the copper resistance, per knot, measured with a finished cable, agrees still better with the calculated value. The respective lengths l_1, l_2, l_3, ... l_n, having been found to have the average resistance ρ_1, ρ_2, ρ_3, ... ρ_n per knot respectively, the mean resistance R, per knot, of the whole cable conductor should be

$$R = \frac{\Sigma \rho l}{L}$$

L being, as before, the total length.

Lastly, the mean inductive capacity C, per knot, from the single reduced average capacities c_1, c_2, c_3, ... c_n, per knot, of the separate lengths l_1, l_2, l_3, ... l_n,

$$C = \frac{\Sigma c l}{L}$$

is compared with the reduced capacity, per knot, of the complete cable as measured, to see that the inductive capacity of the material has remained unaltered in the process of sheathing, and by age, and that the conductor has not, by some accidental application of heat to the cable, become eccentric in its envelope.

90. *Insulating Materials.*—Efforts have repeatedly been made to insulate cables with india-rubber and other materials, with which it was professed that a conductor covered with the same thickness would suffer less loss of current than with gutta-percha; but the fate of the attempt has proved in most cases their real value, and gutta-percha is still employed alone in the insulation of large submarine lines.

Specifically, india-rubber has a greater resistance than gutta-percha, by which the loss of current on a line insulated by the same section of perfect dielectric would certainly be less; secondly, it has, at the same time, a smaller inductive capacity, by which the retardation of the signals would be less, and the speed of speaking through the cable proportionably greater; and, thirdly, it does not become plastic when moderately heated, and allow the conducting wire to fall eccentric, as is the case with gutta-percha.

These are the principal advantages which would be gained, could a line be insulated safely with pure india-rubber. The want of plasticity which would be an advantage to it in one sense, is, however, fatally opposed to its employment in another; for while gutta-percha can, at a moderate temperature, be put upon the wire by means of a die in an unbroken tube; pure or masticated india-rubber must be joined, and the joint must, however the material is applied, reach from end to end. This is a great objection to its use. By the method most commonly employed, the india-rubber is put upon the wire in a spiral, and the joint between the overlaps secured by subjecting it, for a while, to the temperature of boiling water. This joint is very neat but extensive in its dimensions. Mr. Siemens has invented a process by which pure india-rubber is put on cold, under pressure; the joints running longitudinally on opposite sides of the conductor, are formed by the adhesion of freshly-cut surfaces. This is also a pretty joint, and the plan which is followed by the inventor of making the joints in concentric coverings at right angles to each other, adds to its security. But this is no exception to the general rule: joints, however made, are the weak points of a cable. Another drawback against the fortunes of india-rubber as an insulator for submarine lines, is the property it has of turning into a viscid mass when in contact with other bodies.

It was the opinion of Dr. Miller that this phenomenon might be the result of a process of oxidation. Were this the case, however, the decomposition would take place more slowly when oxygen is excluded than when in contact with the air. Experience shows, however, that under exclusion of air, india-rubber turns viscid more rapidly than otherwise. For example, in those wires covered spirally and cemented by means of heat, we have observed that the decomposition commences invariably next to the wire, and seldom or never extends to the outside of the coating; further, when an india-rubber covered wire is coated with some other substance impervious to the air (such as gutta-percha), the process goes on more rapidly than when uncoated. Under water also the process seems to thrive.

91. Another reason against the employment of india-rubber, is its greater absorption of water, first pointed out by Mr. W. Fairbairn. Dr. Siemens had experiments made in his laboratory at Berlin, by which, at the end of three hundred days' immersion, he concluded the relative absorptions of different sorts of india-rubber and gutta-percha to be as follows:—

	In fresh water.	In salt water.
Raw india-rubber	25 per cent.	3 per cent.
Unvulcanised block ditto	23 ,,	3·8 ,,
India-rubber and mica ...	19 ,,	3·9 ,,
Vulcanised india-rubber .	10·14 ,,	2·9 ,,
Gutta-percha	1·5 ,,	1·0 ,,

The details of these measurements are graphically shown in

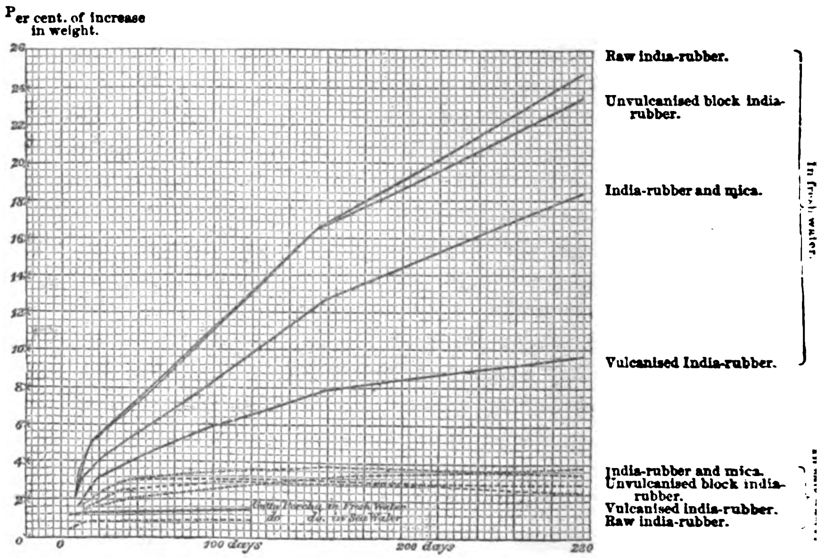


Fig. 177.

the curves, Fig. 177. The ordinates represent the per-centage increase in weight, and the abscissæ the periods after immersion.

The experiments were made with pieces of equal dimensions, 1 millimetre thick, 100 millimetres long, and 50 millimetres broad. One set of such samples was immersed in a bath of distilled water, and another set in a bath of water containing 5 per cent. of sea-salt, both being kept at the mean temperature of the laboratory.

It appears from this, that the absorption goes on more rapidly in fresh than in salt water. On removing the pieces of india-rubber from the baths, previously to weighing them, their surfaces were invariably found to be slimy, an observation which first lead to the belief that india-rubber was soluble, to a certain extent, in water. This fact is corroborated by the curves of this material being depressed toward the ends, as well as by the weights of the specimens, taken after the series of tests was concluded, showing a decrease of from 0.4 per cent. to 1·2 per cent. It became also apparent that unvulcanised india-rubber is likewise subject to solution in water, but in a less degree. The results of experiments instituted with the view of ascertaining the dependence of the absorption from the thickness of the material, only served to express a law, which might have been foreseen, that thicker plates absorb comparatively less than thinner ones. The difficulty of procuring materials physically equal leaves only a remote chance of arriving at satisfactory results in this respect.

92. Mr. Siemens attempted to overcome all these bad qualities of india-rubber and to take advantage of all the good ones by covering it up in a coating of gutta-percha. By this it was anticipated that the absorption of water and the danger of bad joints would be prevented, while a cable so insulated would possess the small inductive capacity and high insulation due to an india-rubber covering. The conductors were usually coated first with Chatterton's compound, then with one or two coats of india-rubber, and lastly with a tube of gutta-percha.

Wires insulated in this way gave splendid results; but it is to be feared that age does not spare them. It would seem, indeed, that covered up in the tube of gutta-percha, india-rubber shows more disposition to decompose than otherwise, and in some instances, bursts the outer tube in expanding.

The properties of this gum have still to be studied.

India-rubber has been applied to wire in a variety of other forms, amongst which that of Mr. Hooper is perhaps the most likely to obtain a place as a mode of insulating long lines. Mr. Hooper's method consists in covering the copper conductor first with a coating of pure india-rubber, then with a coating of india-rubber worked up with oxide of zinc, and lastly with a coating of india-rubber worked up with flowers of sulphur. This triply coated core is then baked for four hours in a temperature of about 250° Fahr., by which the india-rubber jacket becomes vulcanised, and sufficient sulphur penetrates the interior mass to make the whole combine into a compact and possibly a durable insulator. The joints are secured by baking them in a steam-jacket constructed for the purpose.

There is another substance which, a few years ago, was much talked of, and whose merits, perhaps, have been somewhat overlooked: we mean Wray's mixture. Had gutta-percha not obtained itself so secure a position as a cable insulator, it is probable that Wray's compound would have come into extensive use.

Gutta-percha contains a volatile oil which is expelled from it in time by exposure to the air, and more quickly by overheating. In either case, as soon as the oil has left it, the material becomes brittle and cracks. When submerged, however, or enclosed in an air-tight space, this volatile oil, which seems to be essential to its plasticity, cannot escape, and the gum lasts unimpaired for an indefinite time, which is equivalent to saying that cables will never fail through spontaneous deterioration of the gutta-percha after they are in the water.

Gutta-percha still holds its ground, and is likely to do so, because electrically it is all we can wish; and the advent of a successful rival would, in all probability, cause the price of gutta-percha to be so reduced as to recover its position as an insulator.

93. *The Cable in the Ship.*—At present all cables of any importance are sent to sea in water-tanks on board the transport ships. The tanks are circular, with as large a diameter

and as high as the room of the ship will allow between the bottom of the tank and the deck; they are made of plates of iron, riveted together, caulked, and painted with red lead to prevent rusting. There are usually two such tanks, the forehold and afterhold, on board a cable ship. In the centre of each tank a hollow cone of iron is erected (see Fig. 178), and above this a series of rings of 2″ round iron, which are lowered in the tank as the cable is paid out, are suspended

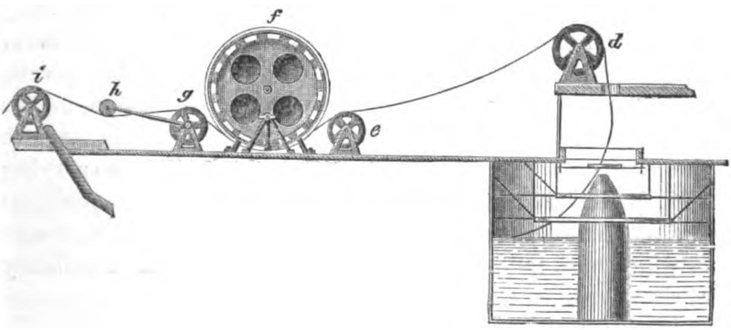


Fig. 178.

for guiding the cable as it leaves the tanks, and preventing it flying out by centrifugal force and going into kinks. On leaving the tanks the cable passes through the rings in the circular space between them and the top of the cone, which it rubs against continually. A V-wheel, *d*, is put upon deck over the middle of the tank, over which the cable is led; it then passes over the V-wheel *e*, before the break, takes three or four turns round the drum, *f*, goes over the V-wheel *g*, under the jockey-wheel *h* of a dynamometer, and finally over the stern-pulley *i* into the sea. When the tank is at a distance from the break it is usual to let the cable run in a wooden trough from *d* over the tank to *e* in front of the drum. The friction which the cable exerts against the sides and bottom of the trough assists the breaks in preventing its too rapid egress from the ship.

A wheel-work with a counter is turned by the axle of the drum *f* for indicating the length paid out, and, by a simple mechanism, a bell is struck at the completion of each unit of length (knot or kilometer).*

No good electrical measurements are possible during the passage out on account of the motion of the ship, and the difficulty of keeping the apparatus dry; the measurements which are made are only of value qualitatively and approximately in the event of a fault occurring. The electrical conditions of the cable are, however, always kept under surveillance.

Messrs. Siemens have constructed a galvanometer purposely for use on board-ship. It consists of an astatic system of magnetic needles on a vertical bar, moving in stone pivots, and surmounted by an aluminium pointer. Each needle turns in the centre of an independent coil of wire. Above the glass cover of the dial-plate is a tall rod of brass carrying a horizontal adjusting magnet, which in different positions and at different distances from the magnet system increases or diminishes its directive force, and with this the sensibility of the instrument.

Professor Thompson has succeeded in eliminating the directive force of the earth's magnetism entirely from his marine galvanometer by surrounding it with a heavy armour of soft iron, which gives it the advantage of retaining its constant of sensibility and zero point in whatever position the ship's head may be put; he also keeps his mirror magnet steady by suspending it to a tightly drawn cocoon fibre.

The measuring apparatus on board does not materially differ from that used on shore, only, where it is possible, it is made simpler. On the sea everything is damp, and with a dampness caused by the particles of salt water carried by the wind; these particles of water are conductors, and provide a

* In picking up a cable, the counter, or tell-tale, sometimes indicates a greater length than that really taken in, the difference being caused by the elasticity of the line, which is taken in under tension. As an instance of this, a hempen rope with a grapnel let out over the drum of a break, appeared by the tell-tale, 3,000 metres, but on being recovered, the index indicated a length of 3,100 metres, notwithstanding the shrinking of the rope in the water. Allowance for this has, therefore, always to be made when drawing in a line.

short circuit for the current to earth from every corner of the apparatus. Therefore, the fewer the pieces used, the fewer the chances are that the "subtle fluid" departs from the way it should go.

94. Before commencing to pay out a cable, and while the ship is quiet in harbour, careful measurements are made of its insulation, copper resistance, and temperature.

In commencing to pay out a cable, one end of the shore-cable is put upon the land and carried into the station. The ship pays this out to the end, when it is joined to the middle-cable, or to the deep-sea cable if no middle cable is employed. At this point the officer of the ship takes the bearings carefully, in his nautical way, and the telegraph engineer takes his bearings in a less scientific and much simpler way. These consist in rough sketches of marked points on the coast. The line which a church makes with a hill, or two hills together, or an inlet with a hill behind should be carefully noted. There are very few coasts which do not present such inequalities as to enable the engineer to find lines between distant objects. Of these lines, two at least should be noted, if possible, making an angle of 90° with each other; and the objects noticed on the land should be, one as near to the water and the other as far from it as the nature of the coast permits. In the long run, this method is the most valuable, and enables the engineer to return at any time to the exact locality of the joint in case he may want to pick it up.

From this point begins the most difficult and risky part of submarine telegraphy. The manufacture requires a constant supervision and care; it has, however, the advantages of *terra-firma* and any accident may be repaired, because the essential element—time, is to be had; but the laying demands untiring courage and caution, and that, because, when once under way, there is no stopping without danger to the cable, notwithstanding the innumerable casualties which invariably attend a sea voyage.

95. In his new book* on telegraphy, M. du Moncel says

* Traité sur le Télégraphie. Paris, 1864.

that, in order to lay a cable successfully the speed of the ship should be precisely that of the outlying cable. Unfortunately for the telegraph engineer, this physicist's ideas of the sea bottom do not correspond with the reality; instead of being level like a street, it is found that as great irregularities occur in the earth under the water as in the earth above it. The sea has its mountains, its valleys, its precipices, as well as the dry land, and over these mountains, and across these valleys, and up and down these precipices, the cable must be laid, and not hung from peak to peak like a tight rope. It must everywhere rest upon the bottom; if not, it must sooner or later break by its own weight between the points of suspension, or abrade against the rocks until it is cut through.

96. The shape of the bottom is ascertained approximately by soundings made with the lead and line. Such soundings

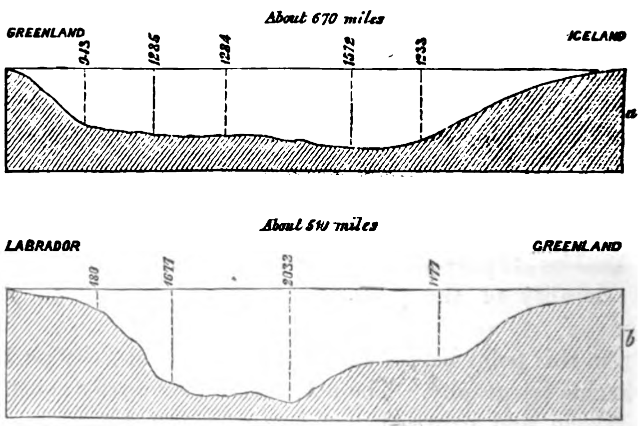


Fig. 179.

have been made in almost all seas, and diagrams of the bottom, from these data, are constructed before the operation of paying out the cable is commenced. Such, for instance, are the sections (Fig. 179) of the bottom of the sea between Iceland and Greenland and Greenland and Labrador, constructed from soundings made for the proposed and highly promising North-Atlantic route. The localities where some of the soundings were made are given by the vertical dotted-lines, and the corresponding depths in fathoms by the figures at the surface. Sudden points may, and no doubt do, occur which the soundings do not discover; but when the soundings are taken at moderate distances all the great irregularities may be considered as being known. Soundings for the English Government were successfully made by Rear-Admiral Sir J. C. Ross in his expedition to the southern Antarctic Sea, in March, 1840, by a method which appears to be the only trustworthy one yet devised—that of sounding by time. A lead is sent down upon a very light line, just strong enough to withstand the friction of the water in descending; its purpose being only to give an indication when the lead reaches the bottom. The times which elapse between the moment when the lead is eased down and each successive mark passes out of the ship, as well as the moment when the lead touches the bottom, are noted and compared with data given by previous measurements or with the calculated velocities. The velocity of a body falling free in water is found to be, after the first few seconds, uniform. When it hangs upon a line, however, the velocity of descent decreases regularly by reason of the friction of the line against the water. The results obtained in this way are more to be depended upon than those obtained by direct measurement of the line, which is liable to make curves in the water by drifting, under-currents, &c., influences which do not alter the times of descent when the resistance of the line is very small. Both line and lead are, of course, lost in this measurement. The French officials use, on the contrary, a strong line, and a lead which they recover always. Their results are therefore less reliable, unless the soundings are taken from a small boat, which is not drifted by the wind so much as the ship, and, even then, not where there are any considerable under-currents.

These diagrams of the bottom give a tolerable notion of the amount of slack which should be expended at each point of the line, and the engineer is able to regulate his break accordingly. As a rule, the more cable thrown away in the form of slack, the more chance there is that the cable will succeed.

97. If the bottom were level, M. du Moncel's idea would be just, and the speed of the ship could be made uniform with the speed of the out-going cable, in which case, the cable from the stern-pulley to the bottom would form, in the water, a straight line. If the speed of the ship were increased the line would bend over and form a curve concave with the bottom; and, if decreased, the cable would have a tendency to form a curve convex towards the bottom. But these curves can occur only after altering the relative speed of ship and cable.

We have heard some engineers question the truth of the assertion that a cable descending in the water from the stern of a ship whose speed is uniform must form a straight line inclined to the bottom. The question admits of an easy solution. From what was said of the descending weight used in sounding, it will be remembered that when a heavy body is thrown into water, after the first instant it descends to the bottom through equal spaces in equal times. Suppose, therefore, from a ship sailing with uniform speed, at distances of every fathom travelled over a pellet were dropped overboard, it is evident that by the time the second pellet touched the water the first would have descended a depth say *n* feet below the surface: when the third was dropped, the second would be *n* feet below the surface, and the first twice *n* feet; when the fourth was dropped, No. 1 would be thrice *n* feet, No. 2 twice *n* feet, and No. 3 only *n* feet down, and so on, forming always a straight line. The same must necessarily apply to a cable paid into the water at an uniform rate and descending uniformly; it can take no other form in the water but that of approximately a straight line.

Messrs. Brook and Longridge* have demonstrated this mathematically in a very able manner.

The results of their developments are of great use in a practical sense, instructing us, as they do, on the important question of how much strain must be put upon the outgoing

* Minutes of Proc. Inst. Civil Eng., 1858.

cable by the break, and indicated by the dynamometer, in order to lay out the line under any desired conditions.

When a cable is being paid out two forces act simultaneously upon it: 1st, gravitation, by which it falls to the bottom—this force acting perpendicularly; secondly, friction of the water, which, by reason of its position, lying upon an inclined plane, gives it a tendency to slide down in a line from the ship to the point where it touches the bottom. The angle formed by the cable in going down depends obviously only upon the relation between the speed of the ship and the velocity with which the cable falls freely in water, and is independent of the tension with which it is laid. The force, however, with which the cable tends to slide down the inclined plane is very nearly equal to the weight of a length of cable reaching from the point where it touches the bottom perpendicularly to the surface of the water. This sliding tendency is of great use in successfully submerging a cable, as it enables the engineer to lay out his line with sufficient sliding, or slack, to cause it to fall into all the irregularities of the bottom without spanning any of them. If the bottom were quite level a cable could without danger be laid out without any slack, in which case it is evident that the engineer would have to oppose just so much resistance or break-power as would *balance the tendency* to slide or to take slack.

This balancing or break power would be exactly the weight of a length of cable in water equal to the depth, if the resistance of the water against the surface of the cable did not retard the inclination to slide in a slight degree, and thus to lessen the force necessary to be applied in retaining it.

The bottom being, however, irregular, the engineer has to be supplied with soundings which instruct him at each point of the course what depth of water he is in. He knows, also, the angle which the cable makes in the water, and therefore he can tell easily under what depth of water the point of the cable is which at any moment touches the bottom, and according to this depth he has to regulate his break-power. Were he to regulate the power according to the plumb-line from the ship to the bottom, at any moment he might fall into the error of giving too little slack just when it is most needed, that is to say, on approaching a bank.

In the late attempt to submerge the Atlantic Cable, the angle at which the cable went to the bottom was 9° 30′. The average depth of the Atlantic is two knots, and, as the cable weighs in sea water 14 cwt. per knot, it follows that in order to lay out this cable on a plane bottom, a retarding force of 28 cwt. would have been required. A very small fraction of this retarding force is found by the cable itself, in the form of friction against the water in sliding. But the strain put upon the cable by the break on board was only 12 cwt., and consequently 15 per cent. of cable slid uniformly down the incline to accommodate accidental irregularities at the bottom, and prevent it hanging suspended between them.

98. *The Break.*—In the early days of submarine telegraphy the breaks were, like many other of the appliances of this art, somewhat crude. The best break which we know of is that fitted up on board the French Government telegraph steamer *Le Dix Decembre.*

The cable, guided on by a plough or knife-edge, is made to pass four or five times round a hollow iron drum, which is turned by the weight of the cable as the ship goes on. On the axle, on each side of this drum, is a break-wheel, of nearly the same diameter, and about 9 inches broad. Around these breaks are straps made of blocks of hard wood, secured at regular distances to iron bands, the ends of which terminate at different distances from the centre in lever bars. This part of the arrangement is known as Appold's break. When insufficiently lubricated, or when the friction becomes great, the wheels have an increased tendency to carry the wooden blocks round with them; this deflects the lever bars from the vertical line, and opens out the iron bands sufficiently to lessen the break power.

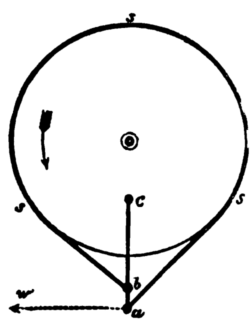


Fig. 180.

Advantage is taken of this to make this break in a measure self-adjusting. This will be better understood by reference to Fig. 180. D is the drum upon which the strap *a, s, s, s, b* presses. It is hinged at the end *a*, on which the greatest strain comes, at a greater distance from the fulcrum *c* of the lever bar *a c* than the other end *b*. The difference between the distance *c b* and *c a*, along the bar, is very little—at most 2 inches. When the lever is deflected towards the left hand by a force, *w*, it is evident that the strain of the strap upon the circumference of the drum will be increased, and that this increase will be exactly proportional to the force exerted, and to the difference of the strains upon *a b*, or to the length $\frac{a\,b}{a\,c}$. Suppose the drum to turn in the direction shown by the arrow at a moment when the force *w* was just sufficient to balance the friction of the break, if by any accidental cause—such as dirt, or want of any lubrication—the coefficient of friction between the surfaces suddenly increased, the strain becoming greater on *a* than on *b*, the lever would be proportionally deflected towards the right; and, owing to the eccentric position of its bearing in turning, would slightly loosen the break-strap and thus reduce the friction. The reverse occurs, of course, when the coefficient of friction is lessened.

The adaptation of hydraulic pressure to the apparatus for supplying the balancing force *w* is novel. On the right side of each of the breaks is a cylinder, connected with a feed-pipe, at top and bottom, attached to a force-pump kept working during the paying-out, for moderately lubricating the break, to prevent it getting too hot by the friction. The connecting rod attached to the piston working in the cylinder is coupled to the point *a* of the bar *a c*. A four-way tap enables the water pressure to be put upon the upper or lower surfaces of the piston in the cylinder, and the blocks on that side are lifted or depressed according to requirement. When the pressure is underneath the piston, the latter is forced up and, with it, the connecting-rod, while the blocks are turned from right to left round the break-wheel, carrying the end of the lever bars with them, and separating the ends of the iron bands sufficiently to loosen the breaks. The pressure being put upon the top of the piston, on the other hand, draws the blocks and lever round in the other direction and tightens the break.

99. *The Dynamometer.*—For the measurement of the tension under which the cable leaves the paying-out apparatus, and also partly to modify the influence of the "pitching" motion of the ship upon the cable, Dr. Siemens' plan of employing a dynamometer is universally adopted.

Half-way between the pulley in front of the break drum and the stern pulley, a weighted jockey-wheel is put upon the cable, bearing it down in proportion to its slackness. This wheel turns freely on an axle carried at the end of a long lever. The relations between the strain upon the cable and the position of the jockey-wheel will be easily understood by

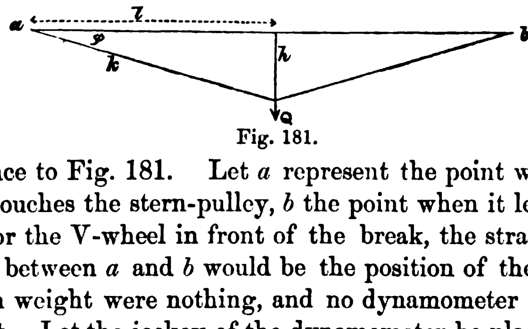


Fig. 181.

reference to Fig. 181. Let a represent the point where the cable touches the stern-pulley, b the point when it leaves the drum or the V-wheel in front of the break, the straight line drawn between a and b would be the position of the cable if its own weight were nothing, and no dynamometer dragged upon it. Let the jockey of the dynamometer be placed upon it in the middle between a and b, the point on which it is put will sink until the cable forms an angle ϕ° with the line $a\,b$; then, Q being the weight of the jockey, &c., and k the tension of the line between a and Q, we have

$$\mathrm{K} \sin. \phi^\circ = \frac{\mathrm{Q}}{2}$$

or,

$$\mathrm{K} = \frac{\mathrm{Q}}{2 \sin. \phi^\circ} \quad . \quad . \quad . \quad . \quad (1$$

Further, if l is equal to half the distance between the points a and b, and h the vertical distance through which the weight Q has bent the cable, we have

$$\sin. \phi^\circ = \frac{h}{\sqrt{l^2 + h^2}} . \quad . \quad . \quad . \quad (2$$

If we set this value of sin. ϕ° in (1 the expression for k becomes

$$K = \frac{Q \sqrt{l^2 + h^2}}{2 h}$$

whence

$$h = \frac{Q \, l}{\sqrt{4 k^2 - Q^2}} \quad . \quad . \quad . \quad . \quad (3$$

In this expression Q and l are constants and known magnitudes; therefore, by setting the values 1, 2, 3, &c., in succession for K in (3, we obtain a series indicating the height h, answering to the load Q, when the cable is under the different tensions 1, 2, 3, &c.

100. The electrical operations during the paying out are of importance. The end of thick cable put ashore is taken into the land-station, and there given in charge of the electrician, whose duty it is to see it insulated, to speak through to the ship or to measure.

Messrs. Siemens, in their expeditions, place a clock at the land station, which puts the end of the cable in position for insulation and continuity tests, and for correspondence, at regular intervals. This arrangement removes the chances of misunderstanding in the event of the insulation becoming bad during the paying out or after it is completed, as the electrician on board the ship knows at what time he may expect to receive currents, and when the farther end is insulated and put to earth.

The commutator constructed for this purpose consists of a small disc of metal, projections upon the periphery of which come into contact at certain moments in each hour with three metal springs, connected severally to earth, telegraph instrument, and measuring board.

The moment each full hour is completed, the end of the cable, represented by the metal disc just mentioned, makes contact with the Morse-instrument of the telegraphing board, and intelligence can be communicated between the ship and shore through the cable. This contact lasts four minutes, then the point of the disc (which makes one revolution per hour) gets beyond the contact-spring, and the disc turns without meeting with another contact for twenty-four minutes, during which time, therefore, the cable end is insulated and the ship measures the dielectric resistance. At twenty-eight minutes past a point of the disc touches a metal spring connected directly with earth, and the ship is enabled to measure copper resistance. This contact is also of only four minutes' duration; and then succeeds an insulation of the cable end, as before, for another space of twenty-four minutes, giving the ship, in all, forty-eight minutes in each hour for insulation measurements. At fifty-six minutes past, the disc or land end of the cable makes contact with a spring, leading to the measuring-board at the station; and, during the succeeding four minutes, the operator there measures insulation resistance, those on board taking care to insulate the ship end in time to let the land-station make the necessary observations, and, at the full hour, to put the end to the Morse apparatus on board, that the land-station can communicate his result in the four minutes during which he is allowed to speak.

Very recently, Mr. Willoughby Smith, Electrician to the Gutta-percha Works, suggested a method by which, during the submersion of a cable, its insulation resistance could be measured on board the ship, and simultaneously an indication of insulation be given at the land end. In addition to this, without entirely disturbing the continuance of these tests, messages can be passed backwards and forwards. In the event of a fault occurring in a cable, it is always of great importance to be able to communicate the results of measurements made on shore, where the instruments are steadier and more delicate, and of necessity the results more to be depended upon, to the electrician on board the ship, who uses the data for calculating the distance of the fault, in order that he may judge what steps are expedient to be taken for recovering it; and such a communication may be delayed for a considerable time, when every moment is precious, when a system of clockwork such as that just described is used.

Mr. Smith proposes to receive signals upon very delicate reflecting galvanometers, constructed for the purpose upon Professor Thomson's principle, by which the currents transmitted may be very weak, and yet sufficient to give sensible deflections. Two such instruments, of different degrees of sensibility, are to be inserted in the line—the less sensitive one on board the ship, the other at the land-station—and are to be employed, at the same time, for the insulation tests. The only battery to be used is that on board. One pole of this is to be put to earth, the other through the ship's galvanometer to the cable end. On shore, the other end of the cable is to be connected with one side of a galvanometer coil, the other side being put to earth; and the earth wire having a very great resistance.

This will be easily understood by Fig. 182. The cable A B is supposed to be partly submerged. The end A is con-

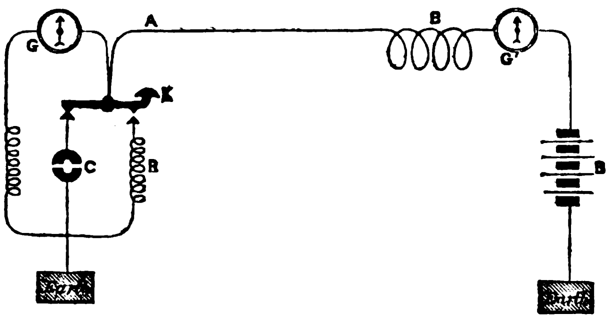


Fig. 182.

nected with the galvanometer G, and with the lever of the key K. Between the galvanometer and earth, resistances, R, equal to about a hundred millions of units, and between the anvil-contact of the key and earth resistances to a much less amount, are inserted. On board ship the cable conductor is connected with the marine-galvanometer G', and the battery B.

As this system was used in submerging the Atlantic line, we may suppose A B to represent the 2,000 knots of cable partly on board the *Great Eastern* and partly in the sea. The resistance of the cable in such a position would be, perhaps, 0,25 millions of units (representing an average of 500 millions per knot length). The current deflecting the needle of the ship's galvanometer G′ with the battery B, due alone to this resistance of the cable insulator, would be 0,000004 B; whilst the current due to the cable and resistance R would be 0,00000401 B, neglecting the resistances of battery and galvanometers. The addition which the introduction of the resistance or shunt R makes, therefore, to the indication of the ship's galvanometer, will only be about 0,25 per cent. of the entire deflection—a difference far too minute to be appreciated. The current from the ship passes from the battery through G′; after which it is divided between the cable leakage and circuit B, A, G, R, and earth. That portion of the current which takes this course—only the 0,0025 of the whole—is nevertheless amply sufficient to give a readable deflection of the needle of the galvanometer G on shore; and this deflection will continue practically unchanged so long as there occurs no alteration in the battery on board and in the cable no fault, the resistance of which is so small as to prevent neglecting the resistances G′ and B in calculation. While it can, however, be said with approximate truth that $G' + B = 0$, a small fault in the cable will not make itself known at the shore end; because it follows from Kirchhoff's laws that when the battery resistance in any circuit is infinitely small, the addition of shunts between the poles makes no difference in the currents circulating in those circuits which were there before. Very different, however, will be the behaviour of the instrument on board ship, which will indicate immediately the magnitude of the fault. The electrician will then determine its distance by means of the method which we shall describe directly. In order to do this, however, he will have to measure the resistance of the copper conductor through the fault, which he can do without sensible error by regarding the end on shore as insulated. He will then have to telegraph to the clerk on shore to put the end of the cable directly to earth; for which purpose a contact, C, will have to be provided. The transmission from ship to shore will be done by simply changing the electro-motive force of the battery—either by increasing or by lessening it—by which the current in the instrument G will be correspondingly altered, and the signals be indicated by the movements of the needle. Each time this occurs, of course, a new charge and discharge will take place which will prevent the rate of speaking ever exceeding that which, with the same receiving apparatus, would be attainable were the resistance R not in circuit.

The shore telegraphs to the ship, by pressing down the key K, substituting thereby the resistance R′ for R, altering therefore the total resistance in the battery circuit. These alterations are responded to by the needle of G′.

A great benefit of this system is that, should a fault occur in the cable even while a correspondence is being carried on, it will become at once evident to the ship; and, if a considerable fault, to both ship and shore. Unfortunately, however, beyond the mere qualitative knowledge that the cable is good and as a means of correspondence, the deflections of the galvanometer on shore are totally useless. As data for calculating the distance of a fault they are valueless, because faults can only be determined by help of the resistance of the copper conductor; and this is so overpowered by the resistance R, which is in the same circuit, that were the fault to occur anywhere at A or at B, or midway between the two, the result, so far as the galvanometer G is concerned, would be absolutely the same.

The method is unquestionably one of the most ingenious that has been suggested, and we hope to see it generally employed. Its great merit consists in enabling the insulation of the cable to be observed continually on board, and at the same time, without diselectrifying the cable, to correspond. We do not, however, believe that a measuring apparatus on shore, where the facilities are so much greater for obtaining exact results, can safely be dispensed with.

In order that the electrician on board might not always be required to keep his eye upon the galvanometer, which in laying long cables is very fatiguing, we proposed to use in the paying out of one of the Mediterranean cables an arrangement by which, if the insulation fell below a certain value, the needle of the galvanometer would be deflected and make contact with a fixed point, closing the circuit of a delicate relay and small battery. The relay was in turn to close the circuit of an alarm, which was to give instant notice of the occurrence of a fault, and prevent such accidents as allowing one to leave the ship for two or three hours before the electrician is aware of it, and when its recovery may be attended with the entire loss of the submerged part of the cable.

101. *Determination of the Position of a Fault in the Insulation.*—When a cable has been sheathed with wet hemp, tested daily during the manufacture under water, and kept wet on board the ship, it is almost an impossibility that a fault can leave the ship before being discovered by the electrical engineer. Formerly, when a cable was made up dry, coiled dry in the hold of the ship, and first wetted in entering the sea on being submerged, it was to be expected that, at this moment,—when too late to repair it with facility,—the first indications should be given of faulty insulation. In this way, many a cable that appeared moderately well insulated when on board the ship, proved to be very bad on leaving it. Although such occurrences are now impossible, faults still occur in cables by abrasion against the bottom, by the line being torn by anchors, and in other ways, after submersion. In such cases, the determination of the exact position of the fault is not an easy matter, on account of its varying resistance and polarisation, and the changing direction of earth currents.

When the cable is laid, and therefore one end only at the disposition of the operator, a fault may be determined by the separate measurements made at both ends, or by those made at either. It is preferable, however, to have measurements made at each end to compare them, where it is possible, by which the chances of errors are reduced.

The cable is represented in Figs. 183, 184, by the line between the points or stations A and B, the fault being at some intermediate point F. From each end two measurements are possible—first, that of insulation, when the opposite end is insulated; and, secondly that of continuity, when the opposite end is put to earth. In Fig. 183 the end B is insulated, and A sends a current from a battery into a cable. With the exception of a very small proportion, which escapes through the insulating covering of the cable between the

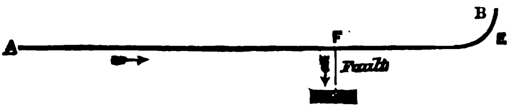


Fig. 183.

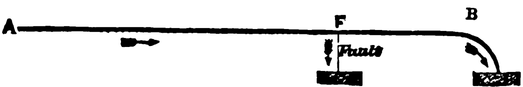


Fig. 184.

station A and the end B, the current goes to earth at F, as is shown by the arrows. Fig. 184 shows the farther end B to earth. The current then divides itself, part going to earth at F, and the remainder at B. Station B can make similar measurements when A insulates, and puts to earth his end of the line.

Let the resistance of the conductor between A and F be x; of that portion between F and B, y; and the resistance of the fault, z; then we have five equations for the calculation of three unknown magnitudes.

$$1) \quad . \quad . \quad R = x + z$$
$$2) \quad . \quad . \quad R' = y + z$$

R being the resistance measured by A, and R′ that measured by B, when the opposite end is insulated,

$$3) \quad . \quad . \quad r = x + \frac{y z}{y + z}$$

$$4) \quad . \quad . \quad r' = y + \frac{x z}{x + z}$$

r being the measurement by A, and r' that by B, when the opposite end is to earth ; and

$$5) \quad . \quad . \quad l = x + y$$

l being the resistance of the copper of the complete cable before the fault occurred.

With the equations 1, 2, and 5, the values of x, y, and z are as follows, in units of resistance:—

$$x = \frac{R - R'}{2} + \frac{l}{2}$$

$$y = \frac{R' - R}{2} + \frac{l}{2}$$

$$z = \frac{R + R'}{2} - \frac{l}{2}$$

or, when a knot length of the conductor has an average resistance of n units, these equations expressed in knots L_x and L_y are

$$L_x = \frac{R - R' + l}{2n}$$

$$L_y = \frac{R' - R + l}{2n}$$

With the aid of equations 3, 4, and 5 we obtain the values of x, y, and z, as follows:—

$$x = \frac{r(l - r')}{r - r'}\left[1 - \sqrt{\frac{r'(l - r)}{r(l - r')}}\right]$$

$$y = \frac{r'(l - r)}{r' - r}\left[1 - \sqrt{\frac{r(l - r')}{r'(l - r)}}\right]$$

$$z = \frac{rr'\{2l - (r + r')\}}{(r' - r)^2}\left[1 - \sqrt{\frac{l(l - r' - r)(r' - r)^2 + rr'(2l - r - r')^2}{rr'(2l - r - r')^2}}\right]$$

and in knots,

$$L_x = \frac{r(l - r)}{n(r - r)}\left[1 - \sqrt{\frac{r'(l - r)}{r(l - r')}}\right]$$

$$L_y = \frac{r'(l - r)}{n(r' - r)}\left[1 - \sqrt{\frac{r(l - r'}{r'(l - r)}}\right]$$

The value of x, divided by y, according to the above, which takes a form, $\frac{x}{y}$, very convenient in application, is

$$\frac{x}{y} = \sqrt{\frac{r}{r'} \cdot \frac{l-r'}{l-r}}$$

Each of these methods depends upon a similar measurement from each end of the cable, and this requires, of course, the communication of the results of the observations from one station to the other. It is, however, possible to calculate the position of the fault with the data given, by the determinations made at either one of the stations alone.

The two determinations made by station A are expressed in the equations 1) and 3), while 5) is an equation which follows from knowing the value of l beforehand.

From these three equations we obtain

$$x = r - \sqrt[2]{(\text{R} - r)(l - r)}$$
$$y = (l - r) + \sqrt[2]{(\text{R} - r)(l - r)}$$

and

$$z = (\text{R} - r) + \sqrt{(\text{R} - r)(l - r)}$$

in units of resistance. In knots they are

$$\text{L}_x = \frac{1}{n}\left[r - \sqrt[2]{(\text{R} - r)(l - r)}\right]$$

and

$$\text{L}_y = \frac{1}{n}\left[(l - r) + \sqrt{(\text{R} - r)(l - r)}\right]$$

From the two measurements made by B—equations 2) and 4)—with the general equation 5), we have in units

$$x = (l - r') + \sqrt{(\text{R}' - r')(l - r')}$$
$$y = r' - \sqrt{(\text{R} - r)(l - r')}$$

and

$$z = (\text{R}' - r') + \sqrt[2]{(\text{R}' - r')(l - r')}$$

The value in knots, L_x and L_y, being, as before, these divided by n, the number of units resistance in a knot at the same temperature.

102. As the ship approaches the shore, where the soundings give a rapidly decreasing depth, the deep-sea cable is cut and the end buoyed. The ship then goes towards the land, and, after sending the end of the thick cable ashore, pays it out from the landing-place to the end of the cut cable, where the shore end is put upon one of the ship's boats, which proceeds to the buoy. The deep-sea cable is hauled up, and the jointer, who is in the boat, makes the permanent connection between the two cables.

Testing joints on the sea is not done with the same precision as on shore. If the joint is made on board the ship, which is sometimes the case in very calm weather, the joint may be tested with the aid of a condenser. Made in the boat, however, it is only possible to test the cable from the shore for insulation, when the gutta-percha joint is dry and when it is wet. The signal of approval being given by hoisting a flag or otherwise, the joint is covered well up in hemp, sheathed, and dropped overboard. Observations of the bearings of the spot are taken, and any striking configurations of the coast noted, in order to be able to return to the spot and fish up the joint if it should become bad.

103. *Sealing up Faults; Hipp's Method.*—A short cable, insulated with gutta percha, laid between Bauen and Fluelen along the Waldstättersee, as part of the line between Lucerne and Altorf, became so faulty as to allow the escape of nearly all the current sent into it at either end. Either through bad manufacture or exposure to the air for a time before submersion, the gutta-percha of this cable was found, on inquiry, to be brittle, and it was therefore probable that the fault was occasioned by cracks in the material, similar to those observed in the short length examined. To take up the cable was found to be impossible, as it had become deeply imbedded in the mud of Lake Lucerne, and had not strength enough to resist the force necessary to extricate it.

Under these circumstances the repair of the faulty cable appeared very doubtful, and it would have been impossible, had not M. Hipp, the ingenious director of the Swiss telegraphs, luckily hit upon a method by which, if not permanently repaired, the cable was at any rate endowed with a new lease of life, and one renewable to a certain limit, from time to time, as its weak condition interfered with its working.

Hipp grounded his operation upon the physical facts that, when the the two poles of a battery are plunged into water, the latter is decomposed—oxygen being developed at the positive, and hydrogen at the negative pole; that when the positive electrode consists of a base metal, it is oxidised by the gas formed on its surface, and that the oxide thus formed is a very bad conductor of electricity. Hipp, therefore, put the positive pole of a battery of seventy-two elements to the Lucerne end of his faulty cable, and insulated the end at Fleuellen; the loss of current expressed by the deflection of his galvanometer needle amounted at the time to 32°, and this lasted during all the first day it was kept on; the next day the deflection fell to 20°; the day following this to 12°; and on the fourth day the loss had decreased to 3°, the battery being kept all the time of the same strength.

After working three weeks with positive currents, and keeping the battery on in the intervals between work, the loss fell to 1°, and the cable was worked through as if no fault existed.

This method, which might be safely followed with a cable laid in fresh water, would be dangerous with one submerged in the sea. The positive current, in this case, finding a way through the insulator, would facilitate the formation of muriate of copper in the fault. This would partly insulate it; but being a soluble salt, it would very soon become dissipated in the surrounding water, and open the wound again greater than before. Besides, the copper of the conductor would be continually wasted, until continuity were entirely interrupted. To avoid this evil Mr. Varley suggested laying a pure platinum wire along the strand, which would not be liable to dissolution by the current, and therefore preserve the continuity. Such a proceeding, with the present high sensibility of the receiving apparatus used upon long lines, would be no doubt of immense value, and we may some day have to regret that it was not employed in the Atlantic cable.

104. *Charge and Distribution along the Wire.*—The measurement of the distribution and charge in an insulated wire is of as much importance as the measurement of its insulating power. The distribution is independent of local faults in the insulating covering, and depends intrinsically upon the geometrical form of the insulator. By measuring the charge of a given length of cable, and comparing the result with the mean charge of the material employed, the electrician has a means of determining, with the greatest certainty, if the insulating material has the same thickness at every point along and around the conductor. A knowledge of the capacity for charge of a cable is also of the greatest importance in the event of a rupture of the conductor while the insulation remains good.

Dr. Werner Siemens first explained the phenomenon of static charge in a cable, having had his attention directed to it by the retardation of signals on a subterranean line between Berlin and Frankfort-on-the-Maine.

He says, in his paper on this subject, that when the resistance of the battery is very small in comparison with the

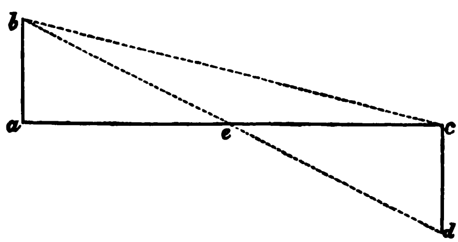


Fig. 185.

resistance of an uniform cylindrical cable, the tension of the pole of the battery connected with one end of it remain unaltered, even when the other end of the line is put to earth, and that the tensions of different points along its length are in proportion to their distances from the end which is to earth. To explain this, let *a c* (Fig. 185) represent the line wire, *a b* the tension of the electricity of the battery inserted between the end *a* and earth, and *c* the end which is put to earth; then a perpendicular raised upon any point of the base *a c* to the point of intersection with the hypothenuse *b c* will express the electric tension or the charge at that point. The superfices of the triangle *a b c* represents, therefore, the whole charge held in the cable under these conditions.

As a second case, suppose a battery of equal force to be connected between the end *c* and earth, so that its current circulates, in the same sense, in the line, as the battery at *a*. The negative ordinate *c d* will then represent the tension of this battery and of the end *c* of the line; and the vertical distances between the straight line joining *b* and *d* and the different points of the base *a c* will represent the tensions in those points. The covered wire is, according to this, from the end *a* to the middle *e* charged with positive electricity, and from the middle to the end *c* with negative. The whole charge of the cable is equal to the sum of the opposite charges in the two equal triangles *b a e* and *c d e*, or null. When the batteries have not equal tensions the sum of the charges is positive or negative, according as the stronger battery is connected with its positive or negative pole to the cable.

A third case of charge is when the end *c* of the cable is insulated. The tension of the electricity in the point *c* will then be the same as *a b*, and the charge of the whole cable will be the contents of the rectangle $a\,b \times a\,c$, which is equal to twice the contents of the triangle *a b c*; in other words, the charge of every point of the cable will be the same.

105. *Inductive Capacity of Materials.*—The amount of this static charge depends, other things being equal, upon the specific induction of the material with which the cylinder is coated.

Faraday says that the inductive action is communicated from one coating of a jar to the other, from atom to atom, through the dielectric. When the jar is a cylinder, therefore, the inductive action must be propagated, from atom to atom, in rings concentric with the conductor.

Dr. Siemens has applied the laws of heat in conductors to electric induction, expressing the capacity K of an insulated wire, with the help of the formula developed for the resistance of cylinders,

$$K = \beta \frac{I\,l}{\log_e \frac{R}{r}}$$

in which I, the inductive capacity of the material, replaces C, the conducting power in the resistance formula, and β a constant factor.

In Mr. de Sauty's method, as well as in that of Mr. Varley, the quantity K is measured by comparison with the capacity of a jar or condenser of unit surface, or of known value in the capacity of an unit of length of some good cable.

Dr. Siemens' experiments were made with a galvanometer, the needle of which was deflected by the charge-current entering a cable. He supposes that when the deflection is caused by a current of very short duration, the quantity of electricity K passing through the galvanometer is proportional to half the sine of the angle of deflection, which is true with the single needles of tangent galvanometers when the angle is not too great; or, a being the angle of the thread, and t half the time of a complete oscillation of the needle under the influence of the earth's magnetism,

$$1) \quad . \quad . \; K = t \sin. \frac{a}{2}$$

To compare the charges K and K_1 of two different wires, having obtained, with the aid of a tangent galvanometer, the angles a and a_1, we have, therefore, the proportion,

$$2) \quad . \quad . \; K : K_1 :: \sin. \frac{a}{2} : \sin. \frac{a_1}{2}$$

while the comparison of the charges by calculation with the dimensions, &c., would give

$$3) \quad . \quad . \; K : K' :: \frac{n\,l}{\log._e \frac{R}{r}} : \frac{n_1\,l_1}{\log._e \frac{R_1}{r_1}}$$

l and l_1 representing the lengths of the wire; R and R_1 the corresponding radii of the insulators; r and r_1 the corresponding radii of the conductors; and n and n_1 the electro-motive forces or numbers of similar elements.

From these three equations some very important consequences are deduced. Supposing that $\frac{R}{r}$ of one cable is equal to $\frac{R_1}{r_1}$ of another, a special instance of which would be if different lengths of the same conductor were covered to the same thickness with different insulating materials,

$$4) \quad . \quad . \quad K : K_1 = n\,l : n_1\,l_1$$

and, further, the same number of elements in action in both cables, that is, $n = n_1$,

$$5) \quad . \quad . \quad K : K_1 = l : l_1$$

If the batteries are not the same, but the lengths are $l = l_1$,

$$6) \quad . \quad . \quad K : K_1 = n : n_1$$

For the relation of the times, t and t_1, which the charge-current takes to appear at the farther ends of the two cables, Professor Thomson and Dr. Siemens have arrived at the proportion—

$$7) \quad . \quad . \quad t : t_1 = \frac{l}{r^2 \log._e \frac{R}{r}} : \frac{l_1^2}{r_1^2 \log._e \frac{R_1}{r_1}}$$

In case

$$\frac{R}{r} = \frac{R_1}{r_1}$$

$$8) \quad . \quad . \quad t : t_1 = \left(\frac{l}{r}\right)^2 : \left(\frac{l_1}{r_1}\right)^2$$

If, besides, $l = l_1$—the lengths are the same—

$$9) \quad . \quad . \quad t : t_1 = r_1^2 : r^2$$

or, if, instead of the lengths being the same, the conductors have the same diameters, $r = r_1$,

$$10) \quad . \quad . \quad t : t_1 = l^2 : l_1^2$$

From the above equations the following important laws are deduced :—

(1.) The charges are in the same proportion as the sines of half the angles of deflection of the needle of a tangent galvanometer.

(2.) When the relations between the diameters of the wires and those of the insulators are respectively equal, the charges only depend upon the lengths of the lines and upon the number of cells, and, according to 4), will be in direct proportion to the products of the lengths of the cables by the number of cells.

(3.) If the proportion between the diameters of the conductors and those of the gutta-percha coverings are the same, and the electro-motive forces of the batteries are also equal, while the lines are of different lengths, the charges, according to formula 5), are directly proportioned to the lengths of the cables.

(4.) If the proportion between the diameters of the conductors and those of the gutta-percha coverings is the same, and the lengths of the lines are also equal, while the electro-motive forces of the batteries are unequal, the charges, according to formula 6), are in the same proportion as the number of cells.

(5.) The times of charge are independent of the batteries. Electro-motive forces do not appear at all in the formulæ 7) to 10).

(6.) When the proportion between the diameters of the conductors and of the gutta-percha coverings is the same, the times of charge only depend upon the lengths of the lines and the diameters of the conductors, and, according to 8), are directly proportional to the squares of the lengths, and inversely proportional to the transverse sectional areas of the conductors.

(7.) If the proportions between the diameters of the conductors and insulators are the same, and the lengths of the cables also equal, the times of charge, according to 9), are in the inverse ratio of the squares of the radii of the conductors.

(8.) The conductors and coverings being equal in both cables, the times of charge, according to 10), are as the squares of the lengths.

With the help of these formulæ it is easy to compare the quantity and time of charge in any submarine line with those of a given line.

When calculating the speed of telegraph signals, another condition, discovered by Faraday, steps in, viz., the formation of electric-charge waves in the cable.

As may be deduced from what has gone before, the charge precedes the current in going to the extremity of the cable. If the communication between the battery and the line be interrupted before the current has reached the end, the electricity diffuses itself and causes a deflection of the galvanometer needle, although the battery at that moment may not be in circuit. By reversing the pole of the battery, instead of cutting it off, that part of the line nearest to the battery will be charged with the opposite electricity, while the electricity already in the more distant part of the line will discharge itself towards both ends of the cable, that is, one part will pass through the instrument and the other combine with, and be neutralised by, the opposite current. An electric wave is therefore formed at the same time, which is neutralised by degrees by the opposite one which follows it, but which, nevertheless, reaches the end. In this manner a succession of signals may be made to pass through a line by rapidly changing the batteries, which will set in motion the receiving instrument at the farther end, if they are of sufficient power on arriving there. If the currents which succeed each other are of the same strength and duration, these waves will all be useful in long lines; but if long and short signals alternate, the latter will be more or less neutralised by the former, and very short signals will be absorbed to an extent which will render them powerless to move the armature of the receiving instrument.

106. *The Wippe or Self-acting Make and Break.*—In order to overcome the inconvenience and difficulty attending the observation of angles by the sudden throw of the needle, Dr.

Siemens constructed an instrument, called, in German, a "Wippe," which is, in fact, a self-acting commutator capable of interrupting or reversing the currents with great rapidity.

If the end *c* of a cable were connected by two parallel circuits, *a* and *b* (Fig. 186), with the two anvils *a′* and *b′*, in the reach of two movable contact springs, *c* and *d*,—*c* being

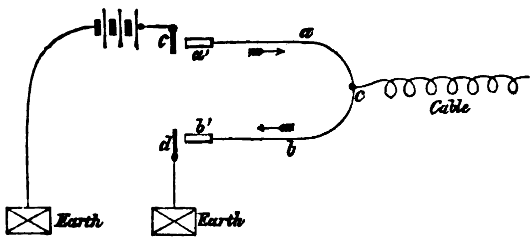


Fig. 186.

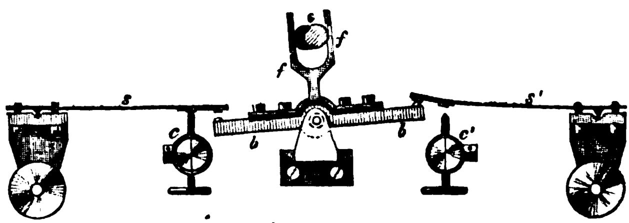


Fig. 187.

connected with one pole of a battery, the other pole of which is to earth, and *d* being connected to earth direct,—then, upon pressing the spring *c* for an instant upon *a*, a charge would flow into the cable from the battery, through *a*, in the direction represented by the arrow; and if, *c* and *a′* being interrupted, the lower spring *d* were pressed upon the contact *b*, a quantity of the electricity held in charge in the cable would rush out and pass through the side *b* as shown by the arrow. Thus, by connecting *a′* and *b′* with *c* and *d* alternately, so that the one contact is always broken when the other is made, a succession of currents will circulate in the arm *a* towards the cable, and in the arm *b* from it.

By inserting a measuring instrument in either of these circuits, therefore, the quantity flowing into the cable or out of it may be measured, if the contacts follow each other with sufficient rapidity, by a constant deflection.

The "Wippe" consists of two permanent steel bar-magnets supported at right angles to each other upon a vertical shaft, turning on points in stone bearings. Around these magnets are two coils of wire at right angles to each other, and whose ends are connected with a commutator, turned by the shaft in such a way that when the magnet system is deflected a certain distance by the current, the latter is then reversed and the deflection continued in the same direction till the magnets have made half a revolution, when the first current direction obtains again, keeping the magnets rotating with an immense velocity. For this a driving battery, separate from the experimental battery, is required.

The shaft carries a small metallic eccentric, *e* (Fig. 187), which, turning between the prongs of a fork, *f f*, rocks the beam *b b*, lifting alternately the springs *s* and *s′* from the contact anvils *c* and *c′*. The springs, anvils, and beam are insulated from each other and connected by leading wires with convenient terminal screws.

The terminals of the Wippe may be connected in various ways to fulfil the same duties. If both the ends of the cable are at hand, they may be connected between the springs *s* and *s′*, as in Fig. 188, the galvanometer G being inserted in the same circuit, while a battery, B, is connected between earth and *c′*; and *c* is put to earth.

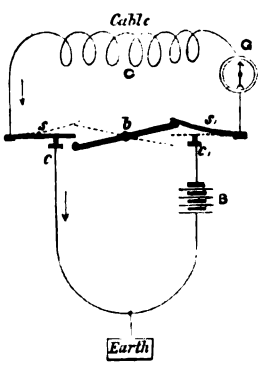


Fig. 188.

When the beam *b* is in the position shown in the figure, whatever electricity is in the cable will be discharged, by way of *s*, *c*, and earth. When the beam places itself in the opposite way, as shown by the dotted lines, the end of the cable which was before on earth will now, in turn, be insulated, and the galvanometer end put, through *s′* and *c′*, in connection with the battery B. The charge will therefore pass through the galvanometer in the direction of the arrow, and deflect the needle.

When only one end of the cable is to be had, it may be connected with the beam b, as in Fig. 189, while the battery circuit is made to include the galvanometer G between s and s'. The spring s is also connected with earth, and the anvils are insulated. In this position successive charge-currents are measured on the galvanometer in the battery circuit—cable, b, s', galvanometer, &c.—and the discharge returns out of the cable, from b, over s, to earth.

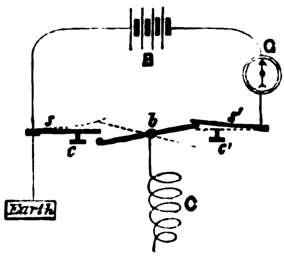


Fig. 189.

The galvanometer, if a sine instrument, is turned after the needle through an angle, a. The charge is then calculated by the formula

$$K = \frac{1}{E} C \sin. a$$

When a mirror galvanometer is used, the reading m of the scale being directly proportional to the intensities,

$$K = \frac{1}{E} C m.$$

C, being the number of charge and discharge contracts in a second of time, and E, the electro-motive force of the battery.

Having a jar of known capacity, K′, which, substituted for the cable in one of the above arrangements, gives, with the same speed of oscillation and electro-motive force requiring the coils of the sine-galvanometer to be turned through an angle, a', or giving a deflection represented by m' divisions of the scale when a mirror galvanometer is used, the capacity of the measured cable is

$$K = K' \frac{\sin. a}{\sin. a'}$$

in the one case, and

$$K = K' \frac{m}{m'}$$

in the other.

Of the cables submitted for experiment with this apparatus, all those insulated with gutta-percha give nearly the same value when K is reduced for dimensions, and this value is entirely independent of the insulating capacity of the specimens examined.

107. *Rate of Working.*—The comparative rates of speaking through two submarine cables of the same materials, and of known dimensions, may be calculated by means of the formula,

$$\frac{S_1}{S} = \frac{r_1^2 \, l^2 \log._e \frac{R_1}{r_1}}{r^2 \, l_1^2 \log._e \frac{R}{r}}$$

whence

$$S_1 = S \, . \, \frac{r_1^2 \, l^2 \log._e \frac{R_1}{r_1}}{r^2 \, l_1^2 \log._e \frac{R}{r}}$$

in which S and S_1 are the speeds attainable, r and r_1, the radii of the copper conductors, R and R_1 the radii of the gutta-percha covering (therefore $R - r$, the thickness of the covering), $\log._e \frac{R}{r}$ and $\log._e \frac{R_1}{r_1}$, the Naperean or natural logarithms of the ratios of the diameters of the gutta-percha to the copper, and l and l_1, the lengths.

Certain conditions of equality in the dimensions of the two cables simplify the above formula. 1. For instance, if two lengths l and l_1 of the same cable be taken, the remaining dimensions are equal, and

$$S_1 = S \left(\frac{l}{l_1}\right)^2$$

or the speeds, in this case, are to each other severally as the squares of the length. 2. If the lengths are the same, and the cables different, then

$$S_1 = S \frac{r_1^2 \log._\epsilon \frac{R}{r}}{r^2 \log._\epsilon \frac{R}{r}}$$

or the speeds are related directly as the transverse sections of the conductors, and as the logarithms of the proportion between the diameters of gutta-percha and copper.

With aid of the formula

$$S = r^2 \log._\epsilon \frac{R}{r}$$

the diameter 2 R, of the gutta-percha being given, the thickness of conductor which would give the greatest speed is found by the ordinary method of maxima and minima, by the differential calculus. The value of r which, set in the above formula, gives the greatest possible value of S is

$$r = \frac{R}{\sqrt{\epsilon}} * \text{ or } \frac{R}{1{\cdot}649 \ldots}$$

When the conductor is a solid or a sectional wire, the value $\frac{R}{r}$ is best deduced from the weights of the conductor and core. The weight w of a knot of the copper conductor, and that of a knot of finished core, W, being known, the weight of the insulating coat (W—w) will be also known. Knowing the specific gravity s of the insulating material, and that of the conductor ρ, we can find the value of $\frac{R}{r}$ from the equations

$$1) \quad \ldots W - w = (R^2 - r^2) l \pi s$$

and

$$2) \quad \ldots w = r^2 l \pi \sigma$$

which, divided by each other, give

$$\frac{R}{r} = \sqrt{\frac{(W - w) \sigma}{w s} + 1}$$

* $\epsilon = 2{\cdot}7183 \ldots$ etc., the base of the Naperean system of logarithms.

From several determinations with specimens of gutta-percha, kindly given us by Mr. Willoughby Smith, we have found the mean value of s, the specific gravity of this material at 4° C. to be 0,9693 . . . . The value of σ, the specific gravity of telegraph copper may be taken at 8,899. . . . .

When the conductor is a strand of seven wires, the value of r, which enters into the formula for calculating the speed, is obtained by taking five per cent. from the value of 1·5 times the diameter of a single wire.

The following table, extracted from a more detailed one by Professor Thomson, who was the first to put it in this form, gives the relative speeds of working in similar lengths of cables, with different values of $\frac{R}{r}$.

$\frac{r}{R}$	$\frac{R}{r}$	S $200\epsilon\left(\frac{r}{R}\right)^2 \log._\epsilon \frac{R}{r}$
0,1	10	12·52
0,2	5	35·00
0,3	3,33 . .	58·91
0,4	2,5	79·71
0,5	2	94·21
0,6	1,66 . . .	99·96
$0,6065 = \frac{1}{\sqrt{\epsilon}}$	$1,649 = \sqrt{\epsilon}$	100·00
0,7	1,429 . .	95·54
0,8	1,25	77·64
0,9	1,111 . .	46·84

"It is easy to understand," says Professor Thomson, "why there should be a particular diameter of copper which will give a maximum rate of signalling with a stated outer diameter of gutta-percha, since if the copper wire is too small there is a loss of speed owing to a too large resistance not compensated by the smallness of the electro-static capacity; while on the other hand, if the diameter of the conductor be too large—as for instance if it fall but little short of the outer diameter of the gutta-percha—the thinness of the gutta-percha coat gives rise to a greater loss of speed by increased capacity than is compensated by the gain, owing to diminished resistance."

According to this, a cable insulated with a coating one-third the thickness of the diameter of its conductor is in the most favourable condition to transmit with speed. Of all the long cables yet made, the new Malta-Alexandria comes nearest to this theoretical proportion; the thickness of the insulating covering of this cable being, within five per cent., equal to the diameter of the conductor. From a mechanical point of view, a cable which has a proportionally thinner covering than this would be too much exposed to faults, therefore no engineer would ever recommend it. It is nevertheless highly interesting to find in practice that the theory is corroborated.

Calculated by the above formula, taking the speed of 4·75 words, actually obtained on 1320 knots of the Malta-Alexandria cable, as data, the speeds with which some other cables might be worked through, are given in the following table:—

No.	Cables and dates of submersion.	Length—Knots.	$\frac{r}{R}$	r	log. $e\frac{R}{r}$	Speed:—Words per minute.
1	Atlantic, 1858	2,500	4·8	1·00	1.570	0·51
2	Red Sea, 1860	1,358	3·4	1·27	1·224	2·15
	Suakin-Aden section	629	,,	,,	,,	12·5
3	Malta-Alexandria, 1861 ..	1,320	2·95	1·95	1·082	4·75
	Malta-Tripoli section	230	,,	,,	,,	156·5
	Tripoli-Bengazi section ..	507	,,	,,	,,	31·8
	Bengazi-Alexandria section	597	,,	,,	,,	23·2
4	Persian Gulf, 1863	1,150	3·48	1·31	1·249	3·20
	Kurrachee-Gwader section .	246	,,	,,	,,	71·3
	Gwader-Mussendom section .	357	,,	,,	,,	33·8
	Mussendom-Bussire section .	393	,,	,,	,,	27·2
	Bussire-Fao section	154	,,	,,	,,	189·0
5	Atlantic, 1865	2,500	3.28	1·73	1·190	1·15

The calculated speed of working through the Suakin-Aden section of the Red Sea cable, 12½ words per minute, agrees with that which was really obtained, viz., 11 words, allowance being made for the great improvements which had been effected in the relays and transmitting apparatus. With regard to the value obtained for the speed of speaking through the new Atlantic cable = 1·15 words per minute, this might seem a direct contradiction to the assertion of Professor William Thomson and Mr. Varley, that they can telegraph through the whole line at a rate of 8 words per minute. The reason of this very augmented rate of working, is due to the employment of a new transmitting apparatus, invented by these two celebrated electricians. This apparatus consists in a key so arranged as to send for each signal a series of five separate waves of different lengths into the cable. The first wave is positive, and lasts long enough to reach the other end of the cable and move the receiving instrument, immediately upon this succeeds a wave of shorter duration from the negative pole, which wipes out the positive charge and leaves it negative; this wave is not intended to reach the other end or give a signal. The third wave is again positive, it is cut off still shorter, and "wipes out" the negative charge, and leaves the cable, towards the home end, positive. The fourth wave is still shorter, negative, and so on. By this means, by the time the complete signal or five decreasing waves are given, each of which, except the first, is absorbed in the next succeeding it, the cable is left in its normal condition, and without the necessity of adopting any of the contrivances explained in the first part, the correspondence can be regularly proceeded with.

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