Pioneers of Electrical Communication - Charles Wheatstone

By Rollo Appleyard

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Sir Charles Wheatstone, F.R.S.

Pioneers of Electrical Communication

CHARLES WHEATSTONE—IV

By ROLLO APPLEYARD

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IF from a list of names of famous men associated with the early development of electrical communication we exclude those immortalised in the designations of the electrical and magnetic units, the best known among the remainder is probably that of Charles Wheatstone; and if the telegraph and telephone engineers of the present generation were asked the reason for that electrician's undiminished popularity, a considerable proportion of them would attribute it, correctly enough, to "Wheatstone's Bridge." Nevertheless, he did not invent that device—on the contrary, he scrupulously assigned it to its true discoverer. Wheatstone's fame rests upon surer foundations; he was a pioneer in practical electrical communication, and a leader in the realms of qualitative and quantitative physical research. The memory of him lives—"not only for his discoveries and for the methods of investigation with which he had endowed science, but also by the recollection of his rare qualities of heart, the uprightness of his character, and the agreeable charm of his personal demeanor."

This last noble tribute from Jean-Baptiste Dumas, then Secretary of the French Academy of Science, uttered on the occasion of Wheatstone's death in Paris, scarcely more than half a century ago, has proved to be true beyond all that could have been imagined by his contemporaries. There are good reasons, therefore, for availing ourselves of any special opportunities that arise to renew or to extend acquaintance with the achievements and career of Charles Wheatstone. By the courtesy of the authorities at King's College, London, it has been possible recently to examine and to photograph some of the relics of his apparatus, and it is proposed here briefly to recall the part such apparatus played in the establishment of the principles of observation and measurement upon which modern electrical research is founded. The "King George III Museum" at King's College contains a collection that consists primarily of apparatus presented to the College in 1841 by Queen Victoria. It was originally brought together by George III at the Royal Observatory, Kew. To it has been added the "Wheatstone Collection" and the "General Collection." A catalogue of the whole exists, dated 1900, but there is no detailed account available of the various pieces of apparatus in the Museum.

Reference to researches to which the relics here illustrated relate, are to be found in innumerable volumes. If with these are included pamphlets of a controversial character, and articles in scientific and biographical works, the publications relating to Wheatstone become somewhat overwhelming. By judicious selection, however, the essential literature can be reduced to a few classic books and papers. So far as the scientific aspects of his achievements are concerned, the commemoration volume published in 1879 by the Physical Society of London, entitled "The Scientific Papers of Sir Charles Wheatstone" supplies all that is required for general knowledge of his discoveries and of his teaching. For an account of his work, and the work of his contemporaries, relating to telegraphy, attention must be directed to two papers read before The Institution of Civil Engineers on March 2, 1852—the first by Mr. Charles Coles Adley, and the second by Mr. Frederick Richard Window. These luminous contributions to the subject are both printed in Volume XI of the Proceedings of that Institution. To them must be added the obituary notice, written by one of his friends, which was printed in the Proceedings of the Royal Society, Volume XXIV, in 1876. In language that is at once appreciative and critical, it conveys a conception of the human side of Wheatstone, and leaves with us the impression of a man of high principle, of fine intelligence, and of invincible determination in research and its applications. What was the secret of his success? His modest early circumstances, and his immersion as a young man in commerce, could easily have made him a thriving

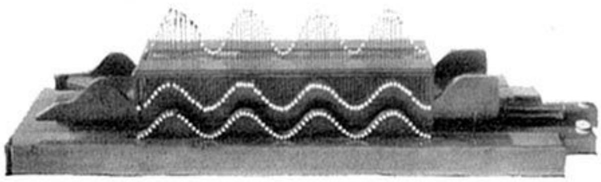

Figure 1—Wheatstone's Sine-wave Model

tradesman. But by what influences was he led along the path of research to the pinnacle cf discovery?

Charles Wheatstone was born in February, 1802, in Gloucestershire. His father, a music-seller in the county-town, removed with his family in 1806 to 128 Pall Mall, London, where he taught the flute, and made and sold musical instruments. Charles, who had received a private-school education, showed early promise of mechanical ingenuity, and as he had clear notions of dynamical principles, he was not long in giving evidence of his capabilities. In 1821 he attracted attention by exhibiting an instrument the name and construction of which prove him to have possessed a sense of humor well calculated to dispel any priggish qualities that might have developed in such a clever youth. It was called "the enchanted lyre," and it was suspended from the ceiling by a "cord of the thickness of a goose-quill." The music appeared to proceed from a combined harp, pianoforte, and dulcimer. Wheatstone himself described it as an application of a general principle for conducting sound. A writer in the "Repository of Arts" of September, 1821, describing this instrument, foreshadowed modern broadcasting in a remarkable phrase, as follows: "Who knows but by this means the music of an opera performed at the King's Theatre may ere long be simultaneously enjoyed at Hanover Square Rooms, the City of London Tavern and even at the Horns Tavern at Kennington, the sound traveling, like gas, through snug conductors, from the main laboratory of harmony in the Haymarket to distant parts of the metropolis . . . perhaps words of speech may be susceptible of the same means of propagation."

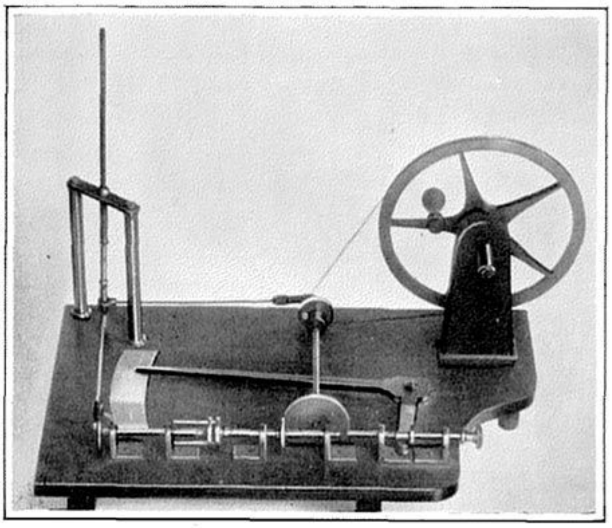

Figure 2—Adjustable Form of Kaleidophone

It is noteworthy that this instrument was exhibited in the Adelaide Gallery, afterwards the scene of his experiments on the velocity of electricity and now part of a restaurant, to the east of St. Martin's Church, London.

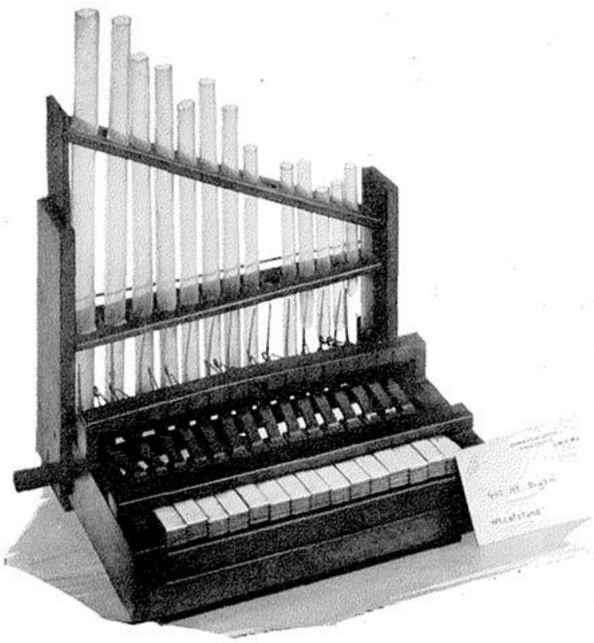

Figure 3—Gas-jet Organ

His early success with this instrument, the special features of which probably were the work of his own hands, must have been a source of great encouragement to him; for the inspirations of the physicist begin at the finger-tips, and the first victory never loses the charm that prompts renewed effort. There is evidence also that direction was given early to his scientific work by his comprehension of the importance of the undulatory theory of light propounded by Thomas Young (1773–1829). This was "the central thread of common sense" upon which the "pearls of analytical research" were strung. His collected papers indicate how firm was his grasp of the meaning of wave-motion, and his researches show with what ease he was able thereby to transfer his ideas from acoustics to optics, and rod—similar to the outlines obtained with a modern cathode-ray oscillograph. Figure 1 shows his model representing wave-motion. It consists of a frame upon which is arranged a series of bent-wire levers terminated by white

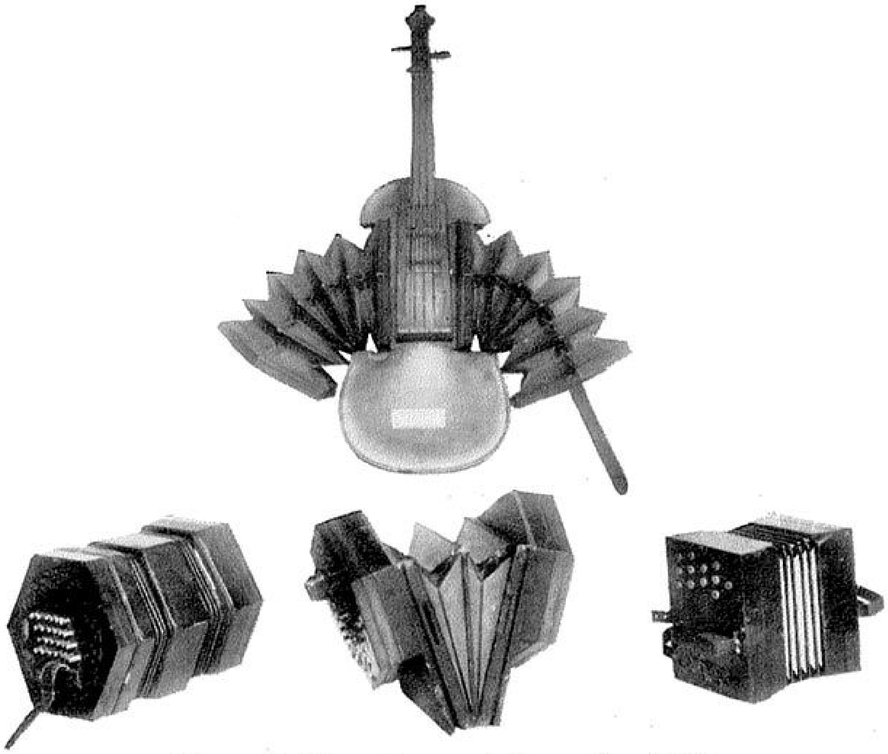

Figure 4—Concertinas and Concertina-fiddle

from optics to electricity. To realise the measure of his early appreciation it should be remembered that his first scientific paper was published in 1823, at a time when, with his brother, he was engaged in the manufacture and sale of musical instruments in London. The reward of his subsequent labours was of a kind that gave him increased facilities for extending his researches. In 1834 he was appointed Professor of Experimental Philosophy at King's College, and in January, 1836, he was elected a Fellow of the Royal Society of London.

As an indication of the general trend of his ideas, there is his memoir on Chladni's figures, and his invention about the year 1828, of the "Kaleidophone"—a simple device for combining two harmonic motions. The Kaleidophone was a steel rod of oblong section, fitted rigidly at its lower end into a heavy base-block, and provided at the top with a white bead. When displaced and suddenly released, the bead traced a curved path—determined by the respective periods and phases of the two motions of the rectangular

beads, and operated by sliding wooden templates cut to the form of waves. The lowest curve is permanently fixed; the upper two curves are modified in phase respectively by the movement of the sliders.

Figure 2 represents his adjustable form of Kaleidophone. It displays Wheatstone's skill in the design of mechanical gearing. The vertical rod is held near its middle point by a ball-and-socket joint. The driving-wheel causes the horizontal transverse shaft to rotate, and motion from this shaft is transferred through a friction-disc to a lateral shaft. The position of the driven-disc on this lateral shaft can be varied by turning a milled-head at the end of that shaft, and the difference in length is taken up by a sliding clutch. Harmonic motion is thus communicated through eccentrics to the lower end of the vertical rod.

In Figure 3 is seen Wheatstone's gas-jet organ, consisting of a group of glass tubes and gas-jets operated by a key-board. The apparatus has deteriorated with age, but there is no doubt that it consisted of a horizontal supply-pipe into which vertical jets were fitted, one to each glass tube, and that the glass tubes were free to move up or down. The keys, probably, were arranged to lift the pipes with respect to the jets to different heights, for "tuning" purposes. It may be supposed that this apparatus was associated with his work in 1828, with reference to resonance in air columns.

The next ten years of his life was a period of transition from research in acoustics to research in optics. Some of his triumphs up to this turning point in his career may be recalled by examining Figures 4 and 5. The English concertina was invented and patented by Charles Wheatstone in 1829. The instruments to the right and left in Figure 4 are marked "By Her Majesty's Letters Patent, Wheatstone & Co., Inventors, 20 Conduit Street, London." As Queen Victoria was not on the throne in 1829, these must not be regarded as Wheatstone's original concertinas. The concertina-fiddle, also shown in Figure 4, is provided with four longitudinal slots, near the bridge, one below each string, which were set into vibration after the manner of an aeolian harp. Figure 5 is an illustration of Wheatstone's original table-concertina, with foot-bellows and keys for finger manipulation. Figure 6 is his famous "Speaking Machine." This consists of hand-operated bellows on the left, and a complex resonator on the right. The right hand is placed over the trumpet shaped orifice or "mouth," with varying degrees of movement or pressure. Above the "mouth" are seen two tubular "nostrils," and below the mouthpiece is a small yielding resonator resembling bellows. It was a modification of De Kempelen's machine (1783). This subject was dealt with by Wheatstone at the British Association in 1835 in his paper "On the Attempts which have been made to imitate Human Speech by Mechanical Means." He wrote also a remarkable article on the history of such devices, in the London and Westminster Review of October, 1837, concluding with the prediction of Sir David Brewster: "We have no doubt that before another century is completed, a talking and a singing machine will be numbered among the conquests of science."

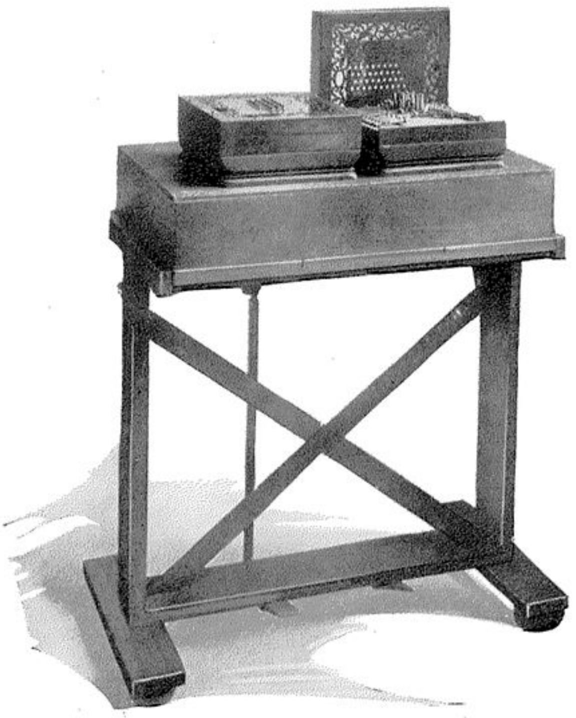

Figure 5—Table Concertina

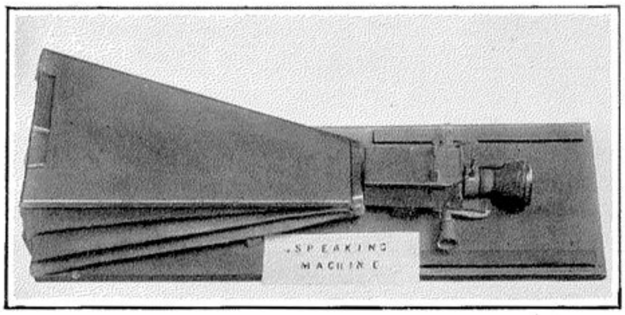

Figure 6—Speaking Machine

If there were no other record of his genius as a research worker than his paper written in 1835 on "The Prismatic Analysis of Electric Light," his fame would have been perpetuated; for he there announced the existence of bright lines in the spectrum emitted by the incandescent vapour of metals volatilised by the heat of an electric discharge—a mode of discriminating metallic bodies more readily than that of chemical examination. Thus he laid the foundations of spectrum analysis and was an early worker at emission phenomena.

Figure 7 is an example of Wheatstone's polar clock. It depends for its operation upon a discovery by Sir David Brewster that the plane of polarisation of the sky is always 90 degrees from the sun. The instrument contains a double-image prism and a thin plate of selenite enclosed in a tube placed parallel to the earth's axis. When the prism—which carries an index traversing a circular arc marked with the hours—is turned round until no colour is perceived, the index points to the time of day.

In 1838 he wrote on binocular vision and produced the reflecting stereoscope, embodying

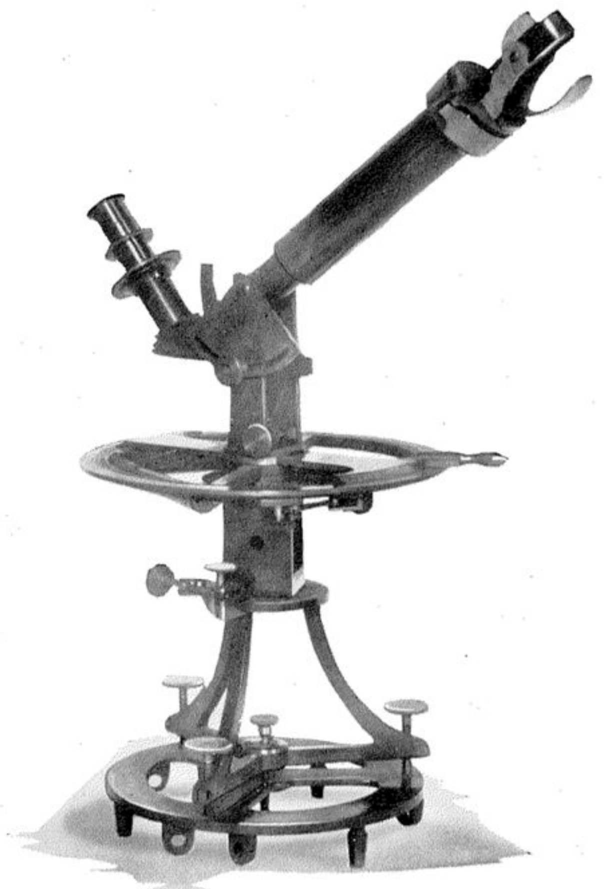

Figure 7—Polar Clock

the principle that the notion of solidity in vision depends upon the mental superposition of two pictures of the same object in dissimilar perspectives. Brewster subsequently used for this purpose the wedge-shaped segments of large lenses, in which the lens and prism arrangement due also to Wheatstone were combined. In 1858 Wheatstone extended this research, and thereby wove the threads of his early achievements in acoustics and optics into the fabric of his later success in telegraphy. Wheatstone was knighted in 1868, following upon the success of his automatic telegraph.

"Wheatstone's Bridge" was invented by Samuel Hunter Christie (1784-1865). In his Bakerian Lecture (1843) Wheatstone described it as "The Differential Resistance Measurer," and he leaves no doubt for posterity to resolve concerning its orgin. He says: "Mr. Christie in his 'Experimental determination of the Laws of Magneto-Electric Induction' printed in the Philosophical Transactions of the Royal Society for 1833, has described a differential arrangement of which the principle is the same as that on which the instruments described in this section have been devised. To Mr. Christie must, therefore, be attributed the first idea of this useful and accurate method of measuring resistances."

Figure 8, which illustrates the original in the King's College Museum, is self-explanatory, except for the small lever attachment fitted to the upper middle terminal. This was used for making a fine adjustment of what we should now call the "variable arm." For this purpose the lever was swung round to left or right until it made contact with one or other of the wires of the two arms shown at the top of the illustration of the bridge, and the rotation was continued until balance was obtained.

In the introduction to his Bakerian Lecture Wheatstone stated that the instruments and processes he was about to describe were all founded on the principles established by Ohm "not yet generally understood and admitted, even by many persons engaged in original research." He proceeded to show the need for a

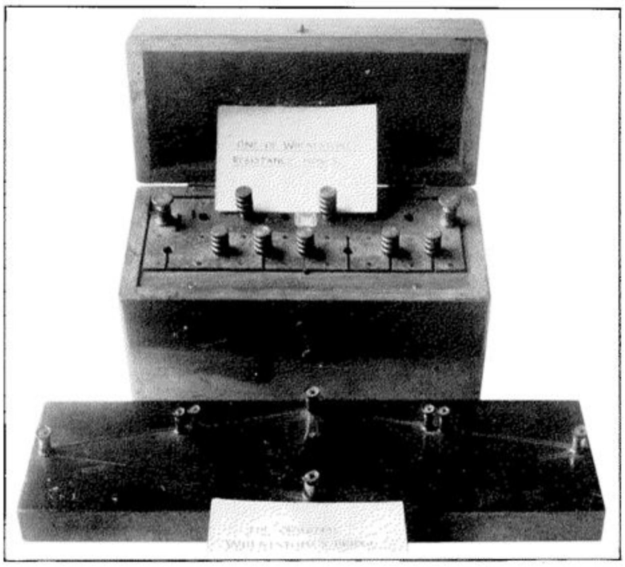

Figure 8—Wheatstone's Bridge and Resistance Box. The box is marked "Miles" near the first plug-hole on the left front.

correct standard of resistance; he adopted for his unit the resistance of a copper wire one foot in length and weighing 100 grains, and he stated the diameter as 0.071 of an inch. One of the original resistance boxes in the King's College Collection (Figure 8) is marked in "Miles"—thus adumbrating the Mile of Standard Cable. At the same time, he gave an account of "the differential galvanometer proposed by M. Becquerel." This, which in a later generation became an instrument of precision, in Wheatstone's day presented constructional difficulties. It is sufficient here to note its comparative antiquity, its supersession in 1843 by the bridge, and the association of the differential-galvanometer principle and the bridge principle as alternatives in the development of duplex telegraphy by Gintl (1853), Stearns, and others.

Wheatstone's generous and unqualified ascription to Christie of what today would be termed the "bridge principle," is more creditable and precious than any self-seeking claim could have been. The relics here illustrated serve to remind us how rapidly Christie's idea, Ohm's law, and Wheatstone's genius, conspired to produce a practical "bridge." To see the matter in true perspective, it is only necessary to turn to the original communication by Christie in the Philosophical Transactions of the Royal Society, Volume 123, 1833. He there describes an investigation to confirm what in modern language would be called the law of change of resistance with length, material, and cross-sectional area of wires, which had been clearly stated by Ohm six years earlier. He used two forms of apparatus.

In the first form, Figure 9, two wires of equal length and of different material, usually copper

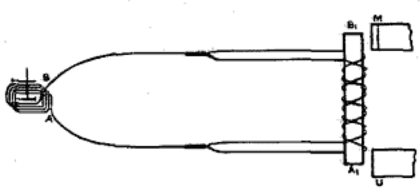

Figure 9—Christie's Differential Double Helix Resistance Balance

and iron, were wound differentially; i.e., in reversed directions, respectively, upon an iron core. The ends of the dissimilar wires were joined, and were connected to a galvanometer. The core was then placed across the poles of a large magnet. When the core was suddenly

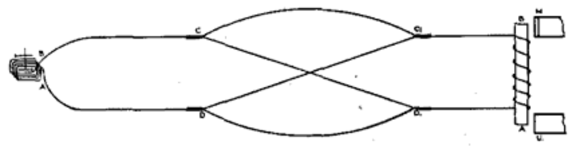

Figure 10—Christie's Single Helix Four-wire Resistance Balance

removed, the deflection, if any, of the galvanometer was observed.

In the second form the arrangement was as represented in Figure 10. Here dissimilar wires were again connected in pairs, CC^1, CD^1, and DC^1, DD^1. In Christie's own words: "On the contact of the ends of the iron cylinder with the poles of the magnet being made or broken, a current of a certain intensity being excited in the helix round the iron cylinder, became, at the points C^1D^1, the source of currents in the copper and iron wires; at the points CD, equal facilities were afforded by the wires CB, DA, for the transmission of these opposing currents to the galvanometer, where consequently, their difference might be very accurately measured. Or viewing the subject in a somewhat different light, at the points C^1D^1, two routes are presented to the current excited in the wire of the helix, one through the copper wires, the other through the iron, and the effect at the galvanometer would measure the difference in the conductivity powers of the two metals."

Again, he states: "When I first made use of the arrangement which I have described, the subject being quite new to me, I was not aware of that employed by M. Becquerel. There is some similarity in the two, but the principles on which their application depends are very different. M. Becquerel's depends upon two equal currents, in separate wires, being equally diminished by two other currents, likewise in separate wires: mine, on the effect of a current in a single wire being counteracted by an equal and opposite current in the same wire, or that the opposite electricities neutralise each other, so that no current exists in the wire of the galvanometer. It appears to me that my arrangement combines the advantages of greater simplicity and greater accuracy."

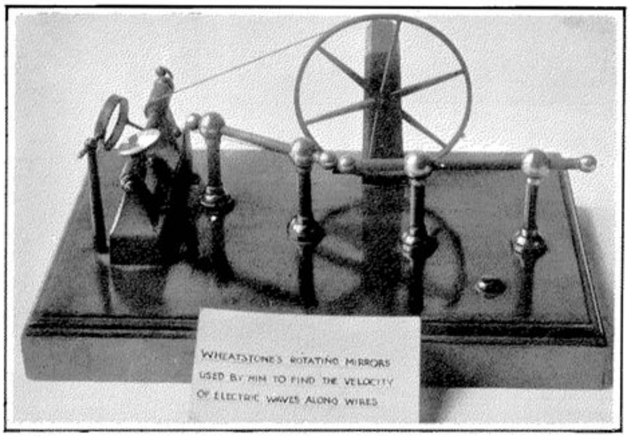

Figure 11—Spark-gap and Rotating-mirror

The dynamical method of computation adopted by Christie should be examined in detail; it illustrates the difficulties encountered by those who, in Wheatstone's phrase, had "not yet generally understood" Ohm's law, in dealing with network problems.

Wheatstone's investigations of the "Velocity of Electricity and the Duration of Electric Light" are described in the Philosophical Transactions of the Royal Society of 1834. Examples of his original pieces of apparatus with their revolving mirror, from the King's College Collection, are illustrated in Figures 11 and 12. The story of his preliminary failures and of his constant determination to overcome all obstacles in this research must be read in detail to be appreciated. Some of his experiments on the time occupied by sparks to pass through insulated wire were carried out at "the Gallery in Adelaide Street." The greatest elongation he observed of the projected image of the spark was 24 degrees, corresponding to 1/24000 second, and for the velocity through the wire he obtained "288,000 miles in a second." In this trial the mirror rotated 800 times in a second. He also investigated the rate at which an electric wave travels through a wire, by suspending half a mile of copper wire in the vaults under King's College. Three interruptions of the circuit were made at three pairs of brass knobs. He repeated this research with four miles of wire.

With reference to these experiments Oliver Heaviside long afterwards pointed out (Electrical Papers, Part II, p. 395) that Wheatstone's result: "has not been supported by any later results, which are always less than the speed of light (even in a distortionless circuit). But a reference to Wheatstone's paper on the subject will show, first, that there was confessedly a good deal of guesswork; and next, that the repeated doubling of the wire on itself made the experiment, from a modern point of view, of too complex a theory to be examined in detail, and unsuitable as a test."

There is not space here to recount the wonderful story of Wheatstone's share in the development of telegraphy. The lamentable dispute with his partner, William Fothergill Cooke, will exemplify to all time the need for definite agreements between the principals in such enterprises, and the deplorable waste of energy, time, and happiness that results from personal friction. It must suffice to state with regard to the crowning achievement that Wheatstone's contemporary, De la Rive, said, "the philosopher who was the first to contribute by his labours, as ingenious as they were persevering, in giving electric telegraphy the practical character that it now possesses is undoubtedly Mr. Wheatstone." Of the combined efforts of the partners, it was declared by the late Willoughby Smith on the occasion of the Extraordinary General Meeting of the Society of Telegraph Engineers and of Electricians held in Paris during the Exposition Internationale d'Electricité, September 21, 1881, that "no account of a practical electric telegraph had been published

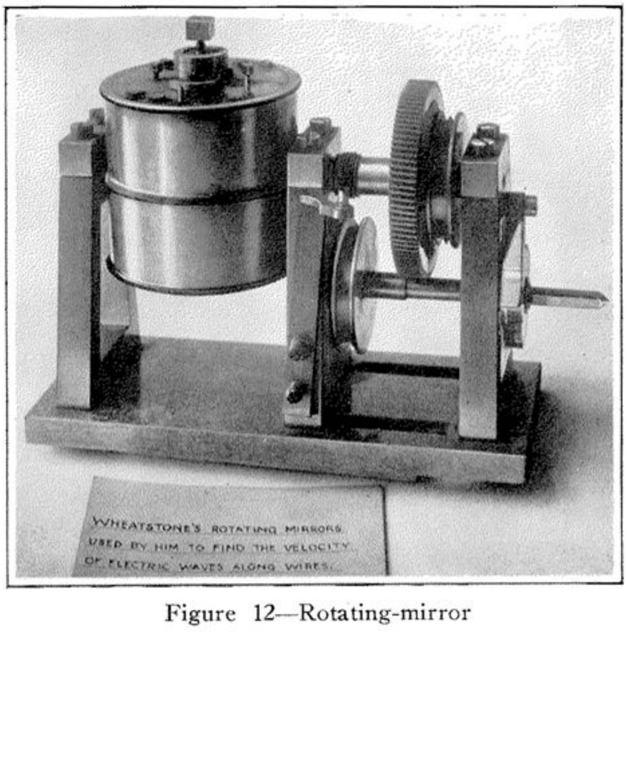

Figure 12—Rotating-mirror

prior to the date of Messrs. Cooke's and Wheatstone's patent of June, 1837."

Among the illustrations of Wheatstone's apparatus may be seen the original of his Letter Showing instrument (Figures 13-A and 13-B). The maker was Ruhmkorff, Paris. Figure 14 shows Wheatstone's Relay. A V-shaped piece of metal attached to a magnetic needle is brought—when the needle is deflected—into contact with two mercury surfaces in a divided

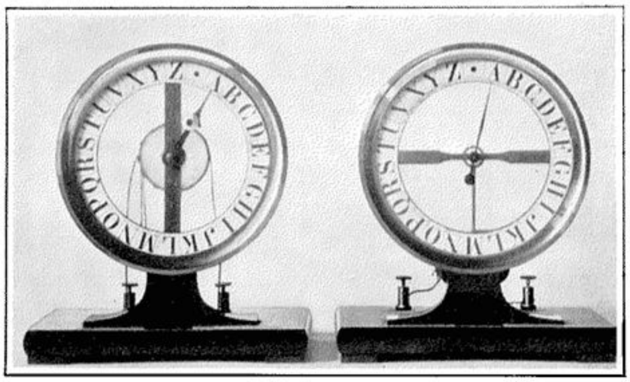

Figure 13-A—"Letter-showing Telegraph" (Front)

insulating cup. Figure 15 depicts Wheatstone's tape-puncher; Figure 16 Wheatstone's five-needle telegraph and Figure 17 Wheatstone's single-needle telegraph "sender" and "receiver."

The tale of the five-needle electric telegraph (1837) is well told by Professor J. A. Fleming

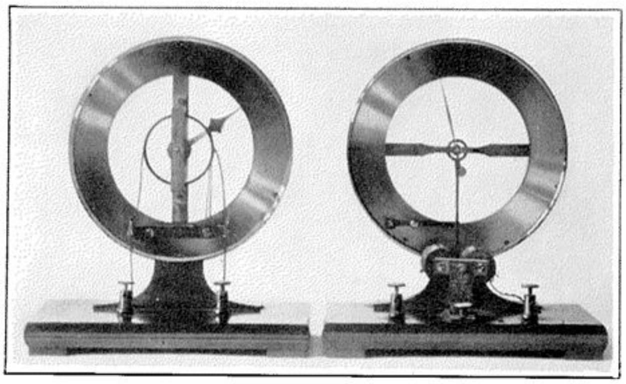

Figure 13-B—"Letter-showing Telegraph" (Back)

(Fifty years of Electricity). This telegraph was being worked between Fenchurch Street and Blackwall railway station, when three of the five dials broke down. The telegraph clerks, however, made up a code for working with the remaining two and the result was quite as good,

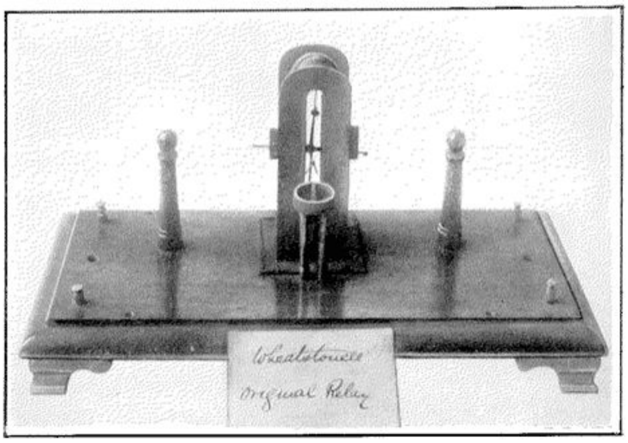

Figure 14—Original Relay

if not better, than before. Thereafter one needle was found sufficient.

Figure 18 reminds us that Wheatstone contributed to the development of the dynamo. S. P. Thompson in his treatise on the dynamo has indicated the main features of Wheatstone's part in that work. Wheatstone began his improvements in 1841, with a machine in which for the first time the armature coils were so grouped as to give a really continuous current.

In 1856 C. W. Siemens took out a provisional patent for the shuttle-wound longitudinal armature, invented by Dr. Werner Siemens. On January 17, 1867, Dr. Werner Siemens described

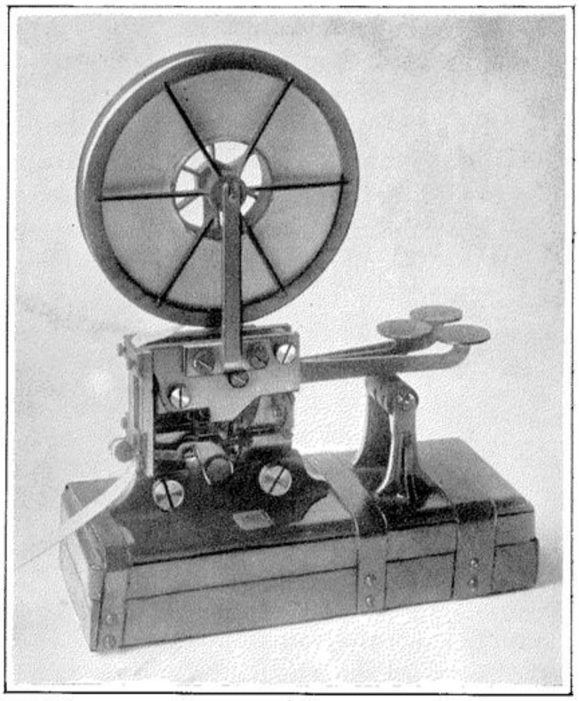

Figure 15—Tape Puncher

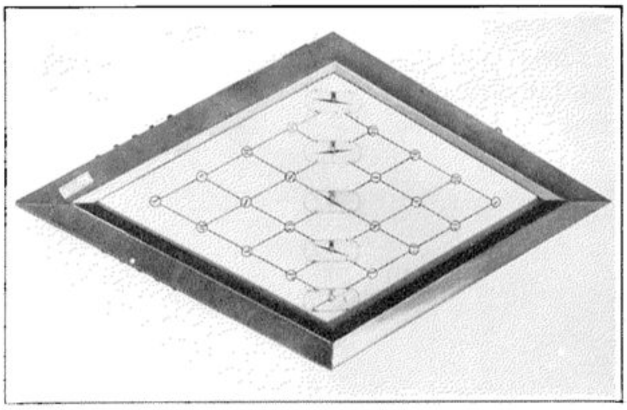

Figure 16—Five-needle Telegraph

a self-exciting dynamo in which the exciting coils were in the main circuit in series with the armature coil. On February 14, 1867, Wheatstone described to the Royal Society his invention of a similar machine in which the exciting coils were connected as a shunt. A self-exciting machine without permanent magnets had been constructed for Wheatstone by Stroh in the summer of 1866. In 1867 Ladd exhibited a self-exciting machine having two shuttle-wound armatures—a small one to excite the common field magnet, a large one to supply currents for electric light.

It is fitting that there should be found with Wheatstone's apparatus a tribute to the work of Henry. The precise history of the coils of copper strip, insulated with silk (Figure 19) cannot be ascertained, but the label, which has been attached to them for some years, declares

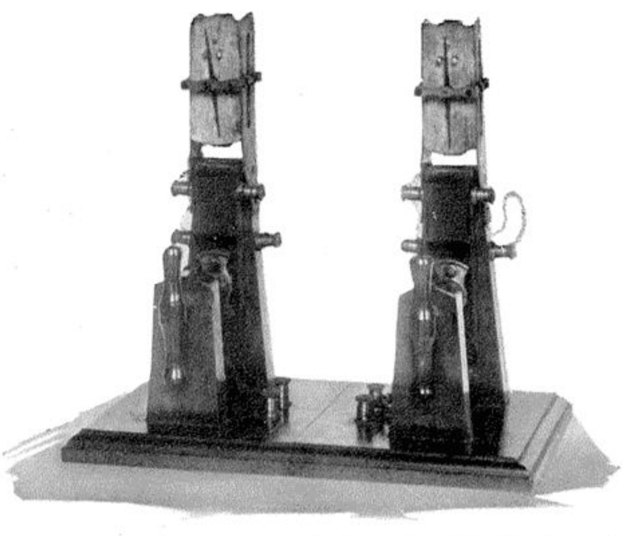

Figure 17—Single-needle Telegraph "Sender" and "Receiver"

them to have been used by Henry in his experiments on induced currents. Henry visited England in February, 1837, and met Wheatstone, Faraday, and Daniell at King's College. The three philosophers there exchanged ideas, and carried out experiments together. It is

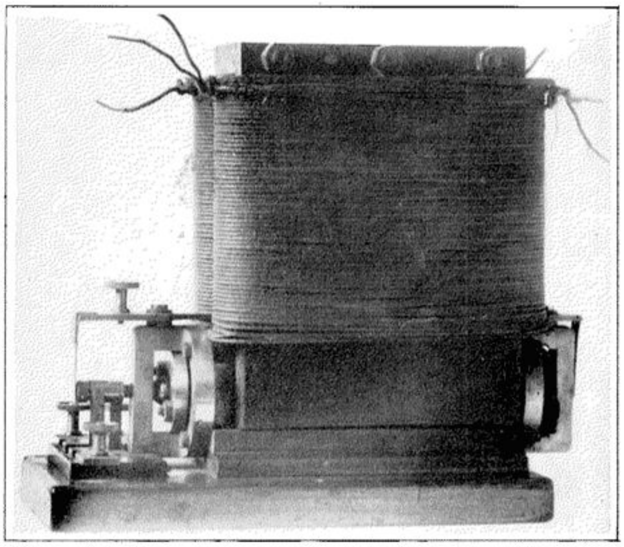

Figure 18—Wheatstone's Dynamo

possible that these coils were used by Henry in this demonstration; but whatever their origin, they recall a fellowship that made history, and a meeting which Henry in subsequent years remembered with pleasure.

The relics include two photographs, one of

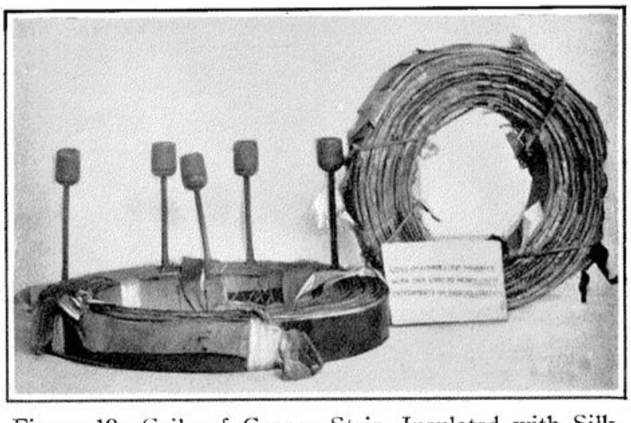

Figure 19—Coils of Copper Strip, Insulated with Silk, used by Henry in his experiments on induced currents

Wheatstone, reproduced in the frontispiece, and the other (Figure 20) of Wheatstone in a group with his friends: Faraday, Huxley, Brewster and Tyndall. In Figure 20 Wheatstone is holding a Morse Key, while his companions are examining his Inkwriter, which is upon the table. The cell at the side of it appears to be a "Bunsen," but it may have been a "Daniell." It is appropriate that Wheatstone should be there amongst his peers: Faraday, the prince of experimenters; Huxley (1825-1895), the would-be engineer who became a leading biologist and the most astute controvertialist against the dogma of his day; Brewster (1781-1868), the poet, preacher, physicist, the inventor of the Kaleidoscope, the biographer of Newton, and the writer of three hundred and fifteen papers on scientific subjects; and Tyndall (1820-1893), the Irish National-school boy who became an engineer, a student in Germany, a professor of natural philosophy at the Royal Institution, a good sportsman, a colleague of Faraday, a physicist of the first rank, who made the Alps his own, and a writer unexcelled in the whole range of scientific literature. With the exception of Brewster, none of the group received what may be called systematic education, all were ardent research workers, all became Fellows of the Royal Society, all were distinguished writers. A man is known by his friends, and by these we may know Charles Wheatstone.

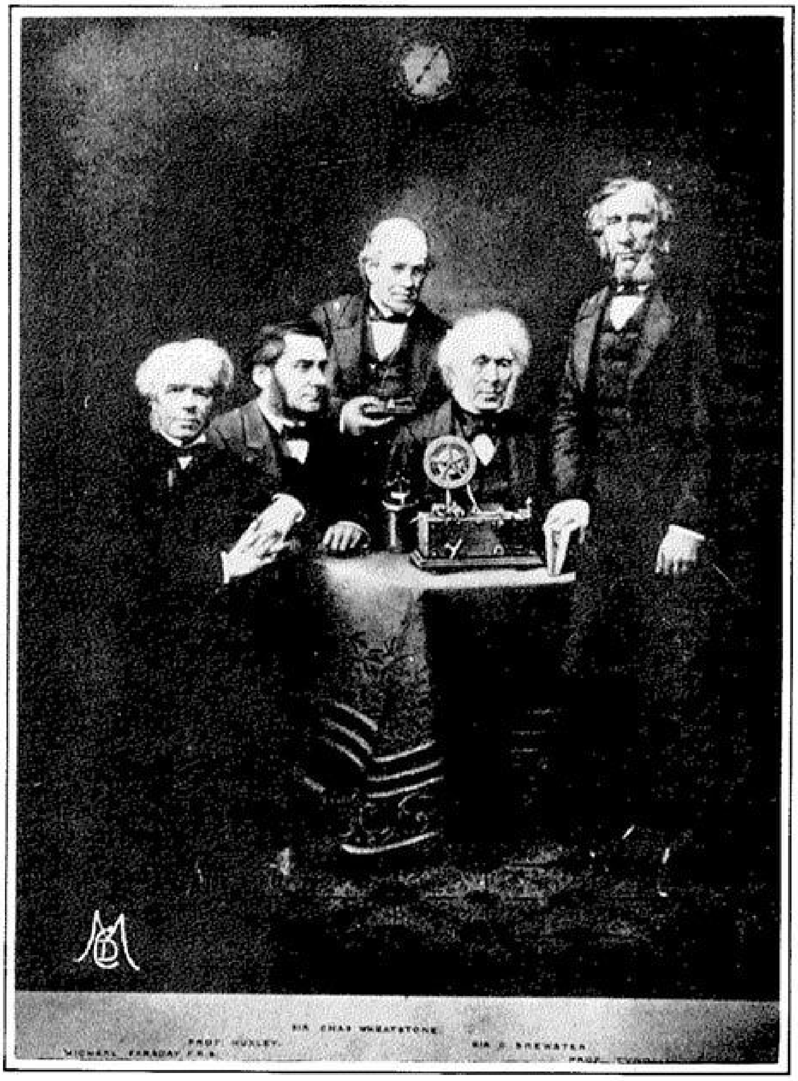

Figure 20—Michael Faraday, Professor Huxley, Sir Charles Wheatstone, Sir David Brewster and Professor Tyndall