APPENDIX D.

RESEARCHES OF PROF. D. E. HUGHES, F.R.S., IN ELECTRIC WAVES AND THEIR APPLICATION TO WIRELESS TELEGRAPHY, 1879-1886.

It may be desirable to place briefly on record the circumstances under which the following remarkable communication was written.

While revising the last sheets of this work, it occurred to the author to ask Sir William Crookes for some particulars of the experiments to which he alluded in his 'Fortnightly' article, some passages from which are quoted on pp. 201-203. On April 22, 1899, Sir William replied as follows :—

DEAR MR FAHIE,—The experiments referred to at page 176 of my 'Fortnightly' article as having taken place "some years ago" were tried by Prof. Hughes when experimenting with the microphone.

I have not ceased since then urging on him to publish an account of his experiments. I do not feel justified in saying more about them, but if you were to write to him, telling him what I say, it might induce him to publish.

It is a pity that a man who was so far ahead of all other workers in the field of wireless telegraphy should lose all the credit due to his great ingenuity and prevision.—Believe me, very truly yours, WILLIAM CROOKES.

On receipt of this letter I wrote to Prof. Hughes. In reply he said :—

"Your letter of 26th instant has brought upon me a flood of old souvenirs in relation to my past experiments on aërial telegraphy. They were completely unknown to the general public, and I feared that the few distinguished men who saw them had forgotten them, or at least had forgotten how the results shown them were produced. . . .

"At this late date I do not wish to set up any claim to priority, as I have never published a word on the subject; and it would be unfair to later workers in the same field to spring an unforeseen claimant to the experiments which they have certainly made without any knowledge of my work."

On second (and my readers will say, wiser) thoughts, Prof. Hughes sent me the following letter, in the eliciting of which I consider myself especially fortunate and privileged :—

40 LANGHAM STREET, W., *April* 29, 1899.

DEAR SIR,—In reply to yours of the 26th inst., in which you say that Sir William Crookes has told you that he saw some experiments of mine on aërial telegraphy in about December 1879, of which he thinks I ought to have published an account, and of which you ask for some information, I beg to reply with a few leading experiments that I made on this subject from 1879 up to 1886 :—

In 1879, being engaged upon experiments with my microphone, together with my induction balance, I remarked that at some times I could not get a perfect balance in the induction balance, through apparent want of insulation in the coils; but investigation showed me that the real cause was some loose contact or microphonic joint excited in some portion of the circuit. I then applied the microphone, and found that it gave a current or sound in the telephone receiver, no matter if the microphone was placed direct in the circuit or placed independently at several feet distance from the coils, through which an intermittent current was passing. After numerous experiments, I found that the effect was entirely caused by the extra current, produced in the primary coil of the induction balance.

Further researches proved that an interrupted current in any coil gave out at each interruption such intense extra currents that the whole atmosphere in the room (or in several rooms distant) would have a momentary invisible charge, which became evident if a microphonic joint was used as a receiver with a telephone. This led me to experiment upon the best form of a receiver for these invisible electric waves, which evidently permeated great distances, and through all apparent obstacles, such as walls, &c. I found that all microphonic contacts or joints were extremely sensitive. Those formed of a hard carbon such as coke, or a combination of a piece of coke resting upon a bright steel contact, were very sensitive and self-restoring; whilst a loose contact between metals was equally sensitive, but would cohere, or remain in full contact, after the passage of an electric wave.

The sensitiveness of these microphonic contacts in metals has since been rediscovered by Mons. Ed. Branly of Paris, and by Prof. Oliver Lodge, in England, by whom the name of "coherer" has been given to this organ of reception; but, as we wish this organ to make a momentary contact and not cohere permanently, the name seems to me ill-suited for the instrument. The most sensitive and perfect receiver that I have yet made does not cohere permanently, but recovers its original state instantly, and therefore requires no tapping or mechanical aid to the separation of the contacts after momentarily being brought into close union.

I soon found that, whilst an invisible spark would produce a thermo-electric current in the microphonic contacts (sufficient to be heard in the telephone in its circuit), it was far better and more powerful to use a feeble voltaic cell in the receiving circuit, the microphonic joint then acting as a relay by diminishing the resistance at the contact, under the influence of the electric wave received through the atmosphere.

I will not describe the numerous forms of the transmitter and receiver that I made in 1879, all of which I wrote down in several volumes of manuscripts in 1879 (but these have never been published), and most of which can be seen here at my residence at any time; but I will confine myself now to a few salient points. I found that very sudden electric impulses, whether given out to the atmosphere through the extra current from a coil or from a frictional electric machine, equally affected the microphonic joint, the effect depending more on the sudden high potential effect than on any prolonged action. Thus, a spark obtained by rubbing a piece of sealing-wax was equally effective as a discharge from a Leyden jar of the same potential.[1] The rubbed sealing-wax and charged Leyden jar had no effect until they were discharged by a spark, and it was evident that this spark, however feeble, acted upon the whole surrounding atmosphere in the form of waves or invisible rays,

[1] Prof. Lodge subsequently and independently observed this fact, and illustrates it beautifully in his 'Work of Hertz,' pp. 27, 28.—J. J. F.

the laws of which I could not at the time determine. Hertz, however, by a series of original and masterly experiments, proved in 1887-89 that they were real waves similar to light, but of a lower frequency, though of the same velocity. In 1879, whilst making these experiments on aërial transmission, I had two different problems to solve: 1st, What was the true nature of these electrical aërial waves, which seemed, whilst not visible, to spurn all idea of insulation, and to penetrate all space to a distance undetermined. 2nd, To discover the best receiver that could act upon a telephone or telegraph instrument, so as to be able to utilise (when required) these waves for the transmission of messages. The second problem came easy to me when I found that the microphone, which I had previously discovered in 1877-78, had alone the power of rendering these invisible waves evident, either in a telephone or a galvanometer, and up to the present time I do not know of anything approaching the sensitiveness of a microphonic joint as a receiver. Branly's tube, now used by Marconi, was described in my first paper to the Royal Society (May 8, 1878) as the microphone tube, filled with loose filings of zinc and silver; and Prof. Lodge's coherer is an ordinary steel microphone, used for a different purpose from that in which I first described it.[1]

During the long-continued experiments on this subject, between 1879 and 1886, many curious phenomena came out which would be too long to describe. I found that the effect

[1] Prof. Hughes is rightly regarded as the real discoverer of the electrical behaviour of a bad joint or loose contact, the study of which in his hands has given us the microphone; but as in the case of Hertzian-wave effects before Hertz, so, long before Hughes, "mere phenomena of loose contact," as Sir George Stokes called them, must have often manifested themselves in the working of electrical apparatus. For an interesting example see Arthur Schuster's paper read before the British Association in 1874 (or abstract, 'Telegraphic Journal,' vol. ii. p. 289), where the effects are described as a new discovery in electricity, and disguised under the title of the paper, "On Unilateral Conductivity." Schuster suspected the cause—"Two wires screwed together may not touch each other, but be separated by a thin layer of air"—but he missed its real significance. The phenomenon was a kind of bye-product, cropped up while he was engaged on other work, and so was not pursued far enough. —J. J. F.

of the extra current in a coil was not increased by having an iron core as an electro-magnet — the extra current was less rapid, and therefore less effective. A similar effect of a delay was produced by Leyden-jar discharges. The material of the contact-breaker of the primary current had also a great effect. Thus, if the current was broken between two or one piece of carbon, no effect could be perceived of aërial waves, even at short distances of a few feet. The extra current from a small coil without iron was as powerful as an intense spark from a secondary coil, and at that time my experiments seemed to be confined to the use of a single coil of my induction balance, charged by six Daniell cells. With higher battery power the extra current invariably destroyed the insulation of the coils.

In December 1879 I invited several persons to see the results then obtained. Amongst others who called on me and saw my results were—

Dec. 1879.—Mr W. H. Preece, F.R.S.; Sir William Crookes, F.R.S.; Sir W. Roberts-Austen, F.R.S.; Prof. W. Grylls Adams, F.R.S.; Mr W. Grove.

Feb. 20, 1880.—Mr Spottiswoode, Pres. R.S.; Prof. Huxley, F.R.S.; Sir George Gabriel Stokes, F.R.S.

Nov. 7, 1888.—Prof. Dewar, F.R.S.; Mr Lennox, Royal Institution.

They all saw experiments upon aërial transmission, as already described, by means of the extra current produced from a small coil and received upon a semi-metallic microphone, the results being heard upon a telephone in connection with the receiving microphone. The transmitter and receiver were in different rooms, about 60 feet apart. After trying successfully all distances allowed in my residence in Portland Street, my usual method was to put the transmitter in operation and walk up and down Great Portland Street with the receiver in my hand, with the telephone to the ear.

The sounds seemed to slightly increase for a distance of 60 yards, then gradually diminish, until at 500 yards I could no longer with certainty hear the transmitted signals. What struck me as remarkable was that, opposite certain houses, I could hear better, whilst at others the signals could hardly be perceived. Hertz's discovery of nodal points in reflected waves (in 1887-89) has explained to me what was then considered a mystery.

At Mr A. Stroh's telegraph instrument manufactory Mr Stroh and myself could hear perfectly the currents transmitted from the third storey to the basement, but I could not detect clear signals at my residence about a mile distant. The innumerable gas and water pipes intervening seemed to absorb or weaken too much the feeble transmitted extra currents from a small coil.

The President of the Royal Society, Mr Spottiswoode, together with the two hon. secretaries, Prof. Huxley and Prof. G. Stokes, called upon me on February 20, 1880, to see my experiments upon aërial transmission of signals. The experiments shown were most successful, and at first they seemed astonished at the results; but towards the close of three hours' experiments Prof. Stokes said that all the results could be explained by known electro-magnetic induction effects, and therefore he could not accept my view of actual aërial electric waves unknown up to that time, but thought I had quite enough original matter to form a paper on the subject to be read at the Royal Society.

I was so discouraged at being unable to convince them of the truth of these aërial electric waves that I actually refused to write a paper on the subject until I was better prepared to demonstrate the existence of these waves; and I continued my experiments for some years, in hopes of arriving at a perfect scientific demonstration of the existence of aërial electric waves produced by a spark from the extra currents in coils, or from frictional electricity, or from secondary coils. The triumphant demonstration of these waves was reserved to Prof. Hertz, who by his masterly researches upon the subject in 1887-89 completely demonstrated not only their existence but their identity with ordinary light, in having the power of being reflected and refracted, &c., with nodal points, by means of which the length of the waves could be measured. Hertz's experiments were far more conclusive than mine, although he used a much less effective receiver than the microphone or coherer.

I then felt it was now too late to bring forward my previous experiments; and through not publishing my results and means employed, I have been forced to see others remake the discoveries I had previously made as to the sensitiveness of the microphonic contact and its useful employment as a receiver for electric aërial waves.

Amongst the earliest workers in the field of aërial transmission I would draw attention to the experiments of Prof. Henry, who describes in his work, published by the Smithsonian Institute, Washington, D.C., U.S.A., vol. i. p. 203 (date unknown, probably about 1850), how he magnetised a needle in a coil at 30 feet distance, and magnetised a needle by a discharge of lightning at eight miles' distance.[1]

Marconi has lately demonstrated that by the use of the Hertzian waves and Branly's coherer he has been enabled to transmit and receive aërial electric waves to a greater distance than previously ever dreamed of by the numerous discoverers and inventors who have worked silently in this field. His efforts at demonstration merit the success he has received ; and if (as I have lately read) he has discovered the means of concentrating these waves on a single desired point without diminishing their power, then the world will be right in placing his name on the highest pinnacle in relation to aërial electric telegraphy.—Sincerely yours, D. E. Hughes.

J. J. Fahie, Esq.,
Claremont Hill, St Helier's, Jersey.

On the publication of this letter in the 'Electrician' (May 5, 1899), Mr John Munro called on Prof. Hughes, and was accorded the privilege of inspecting his apparatus, mostly self-made and of the simplest materials, and his note-books, filled with experiments in ink or pencil, dated or dateless, and some marked "extraordinary," "important," and so on. An interest-

[1] The 'Polytechnic Review,' March 25, 1843, says: "Professor Henry communicated to the American Society that he had succeeded in magnetising needles by the secondary current in a wire more than 220 feet distant from the wire through which the primary current, excited by a single spark from an electrical machine, was passing." Indeed Prof. Henry noted many cases of what we now call Hertzian-wave effects, but what he and every one else in those days thought were only extraordinary cases of induction. Many experimenters after Henry must have observed similar effects. See for example 'Telegraphic Journal,' February 15, 1876, p. 61, on "The 'Etheric' Force"; and the 'Electrician,' vol. xliii. p. 204.—J. J. F.

ing account of this interview was afterwards published by Mr Munro,[1] from which I make a few extracts, as they help to illustrate and supplement the Professor's own account.

After satisfying himself as to the cause of the trouble in his induction-balance experiments as stated above (p. 296), Prof. Hughes joined a single cell B (fig. 1) in circuit with a clockwork interrupter I, and the primary coil C of the induction balance. This "transmitter" was connected by a wire W, several feet in length, to the "receiver," which consisted of a telephone T in circuit with a microphone M. With such an arrangement the "extra spark" of the transmitter was always heard in the telephone. These sounds were found to vary with the conditions of the experiment: thus, with an electromotive force of $\frac{1}{50}$ volt the sound was stronger than with several cells; it was also louder and clearer when the contact points of the

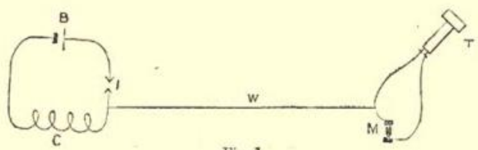

Fig. 1.

interrupter were of metal—not metal to carbon, or carbon to carbon. Again, an iron core in the coil C, though productive of a stronger spark, rather diminished than increased the corresponding sound in the telephone. Indeed, the spark from the Faraday electro-magnet of the Royal Institution, excited by a large Grove battery, had little effect, and even a dynamo at work beside the receiver gave a very poor result.

Prof. Hughes tried many experiments to satisfy himself that his receiver (his microphone and telephone) was influenced by the extra spark solely, and not by the ordinary electro-magnetic induction. He inserted coils in the transmitting and receiving circuits, placing them parallel, and at right angles to each other—that is, in positions favourable and unfavourable to such induction—but without modifying the effect. He also reduced the number of turns of wire on the coil C, and even removed

[1] 'Electrical Review,' June 2, 1899.

it altogether, connecting the battery and interrupter by only three inches of wire, and still heard the sounds as distinctly as before. That electro-static induction had no part in the phenomenon was shown by inserting charged conductors of large surface (for example metal discs) in the two circuits and shifting their positions with respect to each other without producing any effect on the receiver.

Having concluded from these and numerous other observations that the results were conductive in principle rather than inductive, and were due to electrical impulses or waves set in motion by the sparks at the interrupter and filling all the surrounding space, Prof. Hughes set himself to find the most sen-

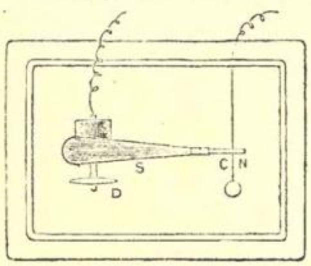

Fig. 2.

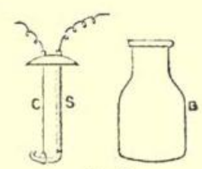

Fig. 3.

sitive form of microphone to receive the waves. Contacts of metal were found to be apt to stick together, or "cohere," as we now say. A microphone which is both sensitive and self-restoring or non-cohering is made with a carbon contact resting lightly on bright steel, as shown in fig. 2, where C is a carbon pencil touching a needle N, and S an adjustable spring of brass by which the pressure of the contact can be regulated by means of the disc D. An extremely sensitive but easily deranged form of microphone is shown in fig. 3, where S is a steel hook, and C a fine copper wire with a loop on the end which has been oxidised and smoked in the flame of a spirit-lamp. The carbonised loop and steel hook are placed in a small bottle B for safety.

Another form of microphone which the Professor tried was a tube containing metal filings, which forestalls the Branly tube, but as the coherence of the filings was a disadvantage he abandoned it. Contacts of iron and mercury were sensitive, but very troublesome; while contacts of iron and steel cohered, but were sensitive, and kept well when immersed in a mixture of petroleum and vaseline, which, though an insulator, does not bar the electric waves.

Some of these microphone arrangements were found to be very sensitive to small charges of electricity—far more so than the gold-leaf electroscope and the quadrant electrometer. Even a metal filing on a stick of sealing-wax carried enough electricity from a Leyden jar to affect the microphone and give a

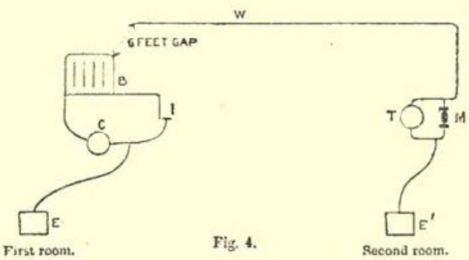

Fig. 4.

sound in the telephone, while it had no effect on the electroscope or the electrometer.

With such delicate receivers Prof. Hughes discarded the connecting wire W in fig. 1, thus separating the receiver from the transmitter, and producing the germ of a wireless telegraph. His first experiment of this kind was made between October 15 and 24, 1879, the transmitter being in one room and the receiver in an adjoining room, but a wire from the receiver limited the air gap to about 6 feet. Fig. 4, which is roughly copied from the Professor's own diagram, shows the arrangement, where W is the wire, B the battery, I the interrupter, C the coil, T the telephone, M the microphone, and E, E′ the earth (gas-pipes). In another experiment, made about the middle of November 1879, he connected a fender to the interrupter "to act as a radiator," and afterwards, instead of the fender, he used wires (answering to the "wings" of Hertz) on both transmitting and receiving apparatus, the wires being stiffened with laths to hold them in place.

The use of an "earth" connection led him to try the effect of joining the telephone to a gas-pipe of lead, and the microphone to a water-pipe of iron, as shown in fig. 5. The result was an improved sound in the telephone, and he concluded that the different metals formed a weak "earth battery," from which a permanent current ran through the circuit. On this supposition he reasoned that the electric waves influencing the microphone, and perhaps changing its resistance, would rapidly alter the strength of this current, and so account for the heightened effects in the telephone. Acting on this idea, he included an E.M.F. in the receiving circuit. A single cell was more than enough, and had to be reduced to as little as $\frac{1}{23}$th of a volt in order not to permanently break down the contact resistance of the microphone.

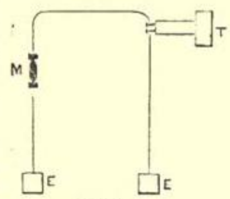

Fig. 5.

"Thus," says Mr Munro, "Prof. Hughes had step by step put together all the principal elements of the wireless telegraph as we know it to-day, and although he was groping in the dark before the light of Hertz arose, it is little short of magical that in a few months, even weeks, and by using the simplest means, he thus forestalled the great Marconi advance by nearly twenty years!"

In the fifty years (just completed) of a brilliant professorial career at Cambridge, Sir George Stokes has given, times out of number, sound advice and helpful suggestions to those who have sought him; but in this case, as events show, the great weight of his opinion has kept back the clock for many years. With proper encouragement in 1879-80 Prof. Hughes would have followed up his clues, and, with his extraordinary keenness in research, there can be no doubt that he would have anticipated Hertz in the complete discovery of electric waves, and Marconi in the application of them to wireless telegraphy, and so have altered considerably the course of scientific history.

As a recent commentator pithily says: "Hughes's experiments of 1879 were virtually a discovery of Hertzian waves before Hertz, of the coherer before Branly, and of wireless telegraphy before Marconi and others." The writer goes on to say, "Prof. Hughes has a great reputation already, but these latter experiments will add enormously to it, and place him among the foremost electricians of all time"[1]—praise which, knowing the learned professor as I do, I consider none too great.

APPENDIX E.

Reprint of Signor G. Marconi's Patent.

No. 12,039, A.D. 1896.

Date of Application, *2nd June* 1896. *Complete Specification Left*, *2nd Mar.* 1897; *Accepted*, *2nd July* 1897.

PROVISIONAL SPECIFICATION.

IMPROVEMENTS IN TRANSMITTING ELECTRICAL IMPULSES AND SIGNALS, AND IN APPARATUS THEREFOR.

I, Guglielmo Marconi, of 71 Hereford Road, Bayswater, in the county of Middlesex, do hereby declare the nature of this invention to be as follows:—

According to this invention electrical actions or manifestations are transmitted through the air, earth, or water by means of electric oscillations of high frequency.

At the transmitting station I employ a Ruhmkorff coil having in its primary circuit a Morse key, or other appliance

[1] The 'Globe,' May 12, 1899. Prof. Hughes died, full of honours, on January 22, 1900, aged sixty-nine. See, amongst other obituary notices, the 'Times,' January 24, and the 'Electrician,' January 26.