The Development of the Coherer*

And Some Theories of Coherer Action

By E. C. Green

THE electric wave detecting device, first known as a Branly tube and later as a coherer, has been the subject of much research. Many experimentalists in past years noticed that a number of metals, when powdered, were practically non-conductors when a small electromotive force was impressed on the loosely compressed particles, while they became good conductors when a high electromotive force was applied.

This knowledge can be traced as far back as 1835 to Monk of Rosenschoeld[1] who described the permanent increase in conductivity of a mixture of tin filings, carbon and other conductors, due to the discharge through them from a Leyden jar. It seems that no attention was given to Rosenschoeld's observations at that time.

In 1852, S. A. Varley observed the high resistance of a mass of loose metallic powder and, it is said, four years later during a thunderstorm he noticed a very remarkable fall in its resistance.[2]

In 1866, C. Varley and S. A. Varley obtained a British Patent No. 165 in the specification of which was described a device for protecting telegraphic instruments from lightning. This device consisted of two copper points, almost touching each other, set in a small box filled with powdered carbon. They stated that powdered conducting matter offers|great resistance to the flow of current at moderate voltage, but offers little resistance at high voltage. Even this announcement failed to create much attention.

Some very important observations were made by Prof. D. E. Hughes in 1878, while engaged in research work on the microphone.[3] In some of his experiments he used a tube of glass, filled loosely with zinc and silver filings, placed in series with a telephone and a single voltaic cell. Hughes seems to have discovered the very important fact that such tubes, when so used, were sensitive to electric sparks at a distance, as indicated by their sudden change in resistance. He showed these experiments privately to many scientific friends, but it was about twenty years later before his results were made public.[4] In the meantime other scientists had observed the same facts. In Italy, Prof. T. Colzecchi-Onesti made experiments on the changes in resistance of metallic powders. loosely compressed, under the action of various voltages. These observations were described in full in the Italian Journal, Il Nuevo Cimento, 1884 vol. 16, p. 58, and vol. 17, p. 35. He did not add very much, however, to observations already made by the Varley brothers.

In 1890, Prof. E. Branly of Paris published an account of a very comprehensive series of observations on the same subject that confirmed the work of previous observers and added a great deal of new information.

While Professor Hughes seems to have discovered the fact that loose masses of powdered conductors are sensitive to electric sparks at a distance, it remained for Professor Branly to make conclusive observations and thoroughly demonstrate this fact. In the majority of common metals he observed that the electric spark caused an increase in conductivity, while a few metals exhibited a decrease in conductivity,[5] such as the contact between lead and lead peroxide. To Professor Branly belongs the honor of giving to science a new weapon in the form of a tube or box containing metallic filings rather loosely packed between metal plugs. This tube was known as the Branly Metallic Filings Tube or Cymoscope, and is shown in diagrammatic form in Fig. 1.

He also showed that such a tube may be a conductor of very low conductivity when the filings are loosley arranged, but that the conductivity of the filings is suddenly increased by a nearby discharge of a Leyden jar or by any other nearby electric spark.

He used a galvanometer in series with such a tube and a single cell to detect the changes in conductivity. When an electric spark was made at a distance the galvanometer needle would become suddenly deflected, showing the greatly increased conductivity.

Branly observed that the same effect occurred in the case of two slightly oxidized steel or copper wires crossed in light contact, and further observed that this contact resistance dropped from several thousand ohms to a few ohms when an electric spark was produced many yards away.

Branly's work did not secure the notice it deserved until 1892 when Dr. Dawson Turner described Branly's experiments and his own additions to them, at a meeting of the British Association in Edinburgh.[6]

After the reading of Dr. Turner's paper Prof. George Forbes raised a very important question by asking whether it was not possible that Hertz waves might in a similar manner break down the resistance of a tube of loose metallic fillings. This question showed that the real cause of coherence was not fully comprehended at that time.

In 1893, W. B. Croft exhibited Branly's experiments at a meeting of the Physical Society in London and read a

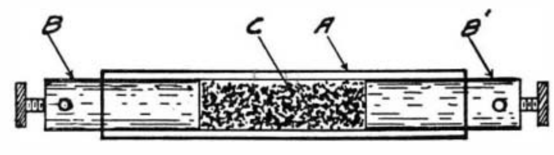

Fig. 1—Branly metallic filings tube. A, insulating tube; B, B[1], metal plugs; C, metallic filings, loosely packed

paper on "The Action of Electric Radiation on Copper Filings."[7] In the exhibition of Branly's experiments Croft used a glass tube filled loosely with copper filings, connected in series with a galanometer and a battery. No current passed when the filings were loosely arranged, but when a spark was made nearby the galvanometer deflected, showing the passage of current, and remained so until the tube was tapped back into a nonconducting state. This paper brought up the question as to how the electric spark caused the change in conductivity. Mr. Croft stated that the filings tube changed to a conductive state before the actual spark passed when the static electrical generator was started. Some thought the light from the spark caused the action.

In the same year, Prof. G. M. Minchin read a paper entitled "The Action of Electromagnetic Radiation on Films containing Metallic Powders."[8] In this paper Minchin made special reference to the Branly tube,

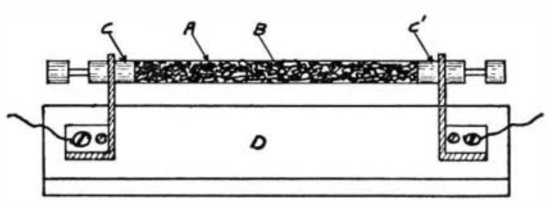

Fig. 2—Lodge coherer. A, glass tube; B, iron filings or borings; C, C[1], metal plugs; D, insulating base

and stated that: "The waves sent out from the spark at once render the column [of metallic filings] a conductor."

It seems clear, therefore, that at the end of 1893 Professor Minchin and a few other physicists had clearly recognized that the action discovered by Branly had its origin in electromagnetic radiation.

This paper was followed by one from Sir Oliver Lodge, entitled "On the Sudden Acquisition of Conducting Power by a Series of Discrete Particles."[9] In his discussion, allusion was made to an observation he had frequently made in connection with his experiment of the Syntonic Leyden jar; viz., to the effect that if the two metal knobs of the receiver were very close together, a battery and electric bell being in series, the occurrence of an electric oscillation in the circuit caused the knobs to make a good contact and cause the electric bell to ring. This action was produced entirely by electric radiation.

In June, 1894, Lodge gave a lecture at the Royal Institution, entitled "The Work of Hertz."[10] In this lecture, the Branly tube was again described and several were exhibited. Lodge was the first to give the name Coherer to the Branly tube, a follows: "*A coherer is a device in which a loose or imperfect conducting contact between pieces of metal is improved in conductivity by the impact on it of electric radiation.*" Lodge's lecture caused widespread interest in Branly's discoveries and pointed out more forcibly that a new and highly sensitive means of detecting electric radiation had been evolved. The coherer used by Lodg consisted of a glass tube 1 cm. or less in diameter and about 7 cm. long, filled loosely with coarse iron filings between two metal plugs. A diagram of this tube is shown in Fig. 2. He also tried brass borings and various other metals, filling the tube with air, hydrogen and even sealing it off at a vacuum. Lodge also experimented with various forms of light contact coherers, such as a steel sewing-needle resting lightly on an aluminium plate, and also slightly oxidized steel rods in light contact.

Up to this time the coherer was found to be a very capricious instrument; in instances highly sensitive to electric sparks, and then, all conditions being apparently

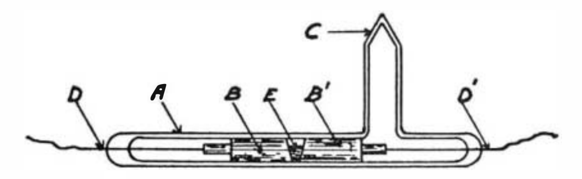

Fig. 3—Marconi coherer. A, glass tube exhausted; B, B[1], metal electrodes; C, side tube for exhaustion; D, D[1], platinum terminal wires; E, nickel-silver granules

the same, it became far less sensitive. The metals forming the most reliable coherers were iron, steel, nickel, copper, brass and zinc, while the noble metals were much less reliable.

The man who really made the coherer famous, G. Marconi, began his work in Italy in 1894 and devoted his attention to the further development of the Branly coherer. He made a systematic and scientific study of the relative advantages of various metals as coherer material and selected for his work a mixture of 95 per cent nickel and five per cent silver filings carefully sifted to the same degree of fineness. He also modified his coherer tube, Fig. 3, very greatly from that previously used by other experimenters.[11] Instead of a long tube of large diameter as used by Lodge, he used a tube, *A*, 3 or 4 cm. long, having an internal diameter of 4 or 5 mm. He placed in this tube two silver plugs, *B*, *B'*, with edges beveled, highly polished, and slightly amalgamated with mercury. This gave to the interspace a wedge shape, the large part being at the top of the tube and about 2 or 3 mm. wide. This interspace was about half-filled

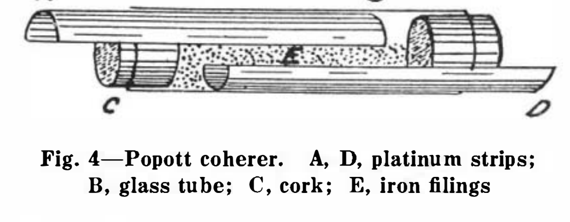

Fig. 4—Popott coherer. A, D, platinum strips; B, glass tube; C, cork; E, iron filings

with the nickel-silver granules, *E*. The tube was then exhausted and sealed at *C*, platinum wires, *D*, *D'*, being fastened to the silver plugs and brought out at either end. This tube was much more sensitive and reliable as an electric wave detecting device than anything that had previously been designed.

Marconi then proceeded to work out devices for employing his improved coherer as a relay upon a relay in a telegraphic outfit for receiving wireless messages. This last application caused world-wide interest in the coherer and numerous experimenters began work upon it.

Prof. A. S. Popoff of Russia in 1896 used his filings coherer to study the phenomena of atmospheric electricity, and also used it to detect and make records of lightning discharges at a distance. His coherer, a diagram of which is given in Fig. 4, was made of a glass tube, *B*, with two platinum leaves, *A* and *D*, down opposite sides, the intervening space being loosely filled with iron filings, *E*. The tube was then corked up at *C*.

Toward the close of 1896 Guglielmo Marconi left Italy for England and there explained his wireless

*Republished from the *General Electric Review*.

[1]See paper read before the St. Louis International Electrical Congress, 1904, by K. E. Guthe, on "Coherer Action."

[2]See *The Electrician*, vol. 40, page 86.

[3]See D. E. Hughes, Proc. Roy. Soc. Lond., May 9, 1878, vol. 27, p. 35.

[4]See Prof. Hughes' letters in *The Electrician*, May 5, 1899.

[5]See E. Branley, *Comptes Rendus*, 1890, vol. 111, p. 785, also 1891, vol. 112, p. 90, or *The Electrician*, 1891, vol. 27, pp. 221, 448.

[6]See Dr. Dawson Turner, *The Electrician*, 1892, vol. 29, p. 432, "Experiments on the Electrical Reistance of Powdered Metals."

[7]See W. B. Croft, Proc. Phys. Soc. Lond., vol. 12, p. 421.

[8]See Prof. Mimchin, Proc. Phys. Soc. Lond., Nov. 24, 1893, vol. 12, p. 455.

[9]See Proc. Phys. Soc. Lond., 1893, vol. 12, p. 461. Also Phil. Mag., Jan., 1894, vol. 37, p. 24.

[10]See Proc. of the Royal Institution, 1894, vol. 14, p 321.

[11]See British Patent Specification of G. Marconi, No. 12039, June 2, 1896.

coherer apparatus to Sir W. H. Preece, then the Engineer-in-Chief of the British Government Telegraph Department of the Great Post Office. Preece delivered a lecture before the Royal Institution on June 4, 1897, at which he exhibited Marconi's apparatus and stated that: "Marconi has produced from known means a new electric eye, more delicate than any known electrical instrument, and a new system of telegraphy that will reach places hitherto inaccessible."[12]

After this, many well-known scientists constructed various forms of coherers, most of which were designed for more rapid operation so as to be more adaptable for wireless work. Some were made of steel and mercury, copper and mercury, carbon and mercury, ball coherers, single contact coherers, etc. These were all low-voltage coherers, having a critical voltage of from 0.3 to 3 volts.

De-coherence was produced in the metallic filings coherer by tapping, slowly revolving the coherer tube, attaching the coherer to the armature of a relay, by clock-work tappers, etc. Marconi's scheme for producing de-coherence is shown in Fig. 5. It seems T. Tommasina was the first to use electromagnetic means directly for producing de-coherence.[13] He placed an electromagnet over the tube and in series with the coherer so that when the tube became sensitive the magnet was energized and lifted the granules to the top of the tube, thus producing de-coherence. This was applied to iron, nickel and cobalt coherers.

Various ingenious schemes have been developed for varying the sensitiveness, or critical voltage, of these coherers. Marconi made use of the wedge-shaped electrodes, *B*, *B'*, Fig. 3, in his coherer tube to produce this change. By taking hold of the sealed-off glass projection, *C*, the tube can be turned on its axis into various positions, so that the filings lie in a broader or narrower portion of the gap between the bevelled silver electrodes.

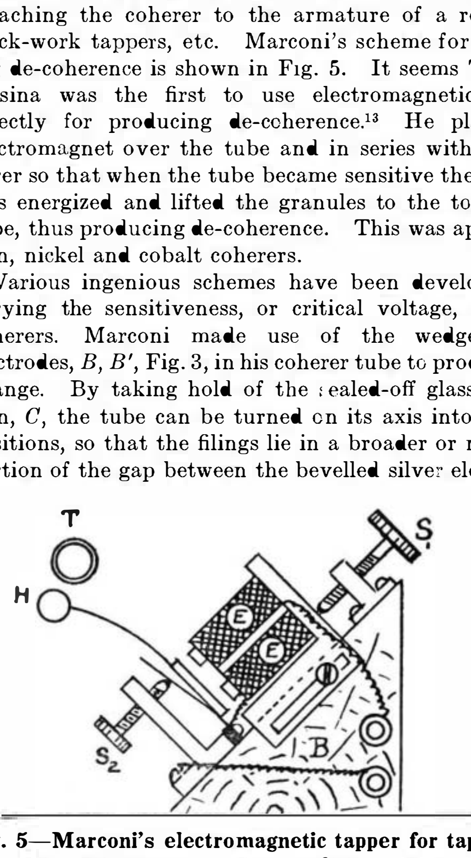

Fig. 5—Marconi's electromagnetic tapper for tapping his sensitive tube to a receptive condition. E, E, electromagnet; H, hammer; T, sensitive tube shown in cross section; S_1, S_2, adjusting screws

M. Blondel made a coherer with a side pocket into which some of the granules could be shaken from between the electrodes, or vice versa. This coherer is illustrated in Fig. 6.

In the various types of single-contact coherers the degree of sensitiveness was altered by changing the number of such coherers in series.

When the Consulting Engineering Laboratory of the General Electric Co. took up the development of a coherer to be used in connection with discharge alarms for lightning arresters, high frequency alarms, etc., the problem had previously been the design of a coherer that would be as sensitive as possible and yet act reliably. The alarm coherer presented an entirely different problem. The task now was to make the coherer less sensitive and to shield it from all wireless effects so it would only respond when voltage was present, not due to Hertzian waves but due to direct contact with an energized source of voltage.

As the result of exhaustive experiments with aluminum, copper, magnesium, cobalt, iron, nickel-plated lead shot, tungsten, molybdenum, nickel, silver, and various other metals, 40-60 mesh pure nickel granules were selected. These were oxidized and sealed off in a tube containing a sufficient amount of gas to stabilize the oxidization of the granules. This residual gas thus prevents a rise in the critical voltage. The tubes may have a critical voltage of from 10 to 700 volts, depending upon how far the oxidization of the granules is carried.

After experimenting with tapping, rotating, and electromagnetic means of de-coherence, it was decided to use a tube shaped as shown in Fig. 7 and surrounded by a solenoid. This construction serves a double purpose in de-cohering the tube, for it lifts the granules away from the electrodes sealed in the bottom of the tube, thus breaking the circuit through the coherer, and then shakes up the granules and rearranges them by dropping them back when the solenoid is de-energized. Only one operation of this de-cohering device is necessary to produce perfect de-coherence in every case; while by the tapping method current continues to flow through the granules while being tapped and it often requires a number of operations to produce like results.

The sensitiveness of this coherer may be fixed by the amount the granules are oxidized and by the length of the "pantlegs" on the coherer tube.

To prevent the coherer from operating due to wireless effects, a high critical voltage coherer has been developed and in each lead running to it is placed a spark-gap which is set at such a value as to prevent any accumulation of static voltage from jumping over and reaching the tube The coherer circuit is also operated by means of dry cells placed close to the coherer to cut down the antennae effect of the leads. The contact on the armature of the small relay in series with the coherer tube has been insulated from the armature, so as to prevent surges being set up in the relay winding by current flowing through the armature and core of the relay.

These combined precautions make the present form of coherer very reliable and quite free from wireless effects.

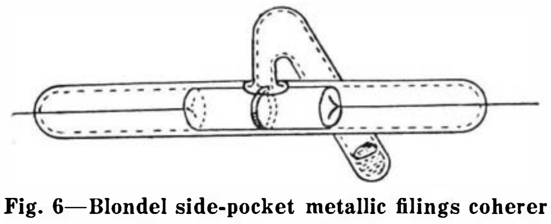

Fig. 6—Blondel side-pocket metallic filings coherer

In the best of former coherers a very slight leakage current was always noticeable; in the present coherer no deflection of a microammeter needle can be observed when 100 volts is applied to the terminals of a coherer having a critical voltage of 150 volts, while the operating voltage of the coherer circuit is only six volts. This demonstrates the great factor of safety as to leakage current.

The volt-ampere characteristics of one of these coherers is shown in Fig. 8.

THEORIES OF COHERER ACTION

A few of the theories that have been advanced to account for the phenomenon of coherence under the impact of electromagnetic waves will be briefly dealt with.

It is clear that the agency which actually causes coherence is electromotive force, and that the problem to be explained is the reason why electromotive force when acting on certain materials which are in light, or imperfect contact, brings the contact surfaces into a better conducting state while with a few other substances the action reduces the conductivity.

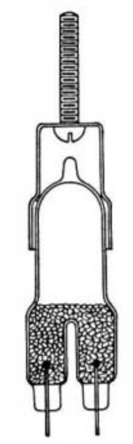

Fig. 7—Coherer which forms a part of discharge alarm and high-frequency alarm devices

At an early date Lodge advanced the opinion that coherer action was due to the welding together of the metallic surfaces in light contact. Many observers claim this process can be witnessed through the microscope. This theory of welding, however, does not explain how highly oxidized granules or carbon dust coheres, as it is impossible to weld either of these at such temperatures as are present in these cases.

T Sundorph[14] claims that in the filings coherer the action is due to the formation of conducting chains of particles stretching between the electrodes. T. Tommasina supports this theory and says these chains are more easily formed when the surrounding medium is distilled water, or some dielectric other than air.[15] In these experiments it seems that a considerable potential difference must have been employed, far in excess of that necessary to cause coherence.

This theory of conducting chains does not show why some substances, such as potassium, arsenic, lead and lead peroxide, etc., become less conductive, and therefore does not satisfy the requirements.

Lodge has shown that two conductors separated by a film of air one ten-thousandth of a millimeter thick, and having a difference in potential of one volt, are drawn together by electrostatic attraction with a force of 646.8 pounds per square centimeter of contact surface.

He claims this force squeezes out the gaseous dielectric film separating the granules and thus causes coherence. This, however, also fails to show why other substances exhibit the negative conducting qualities under similar conditions.

Another theory of coherer action is based on the electronic theory of electricity. According to this theory, the conduction of electricity in conductors is due to the motion of free electrons, or negative ions, in them. In each conductor there is a certain number of these free ions per unit mass. The following is taken from Fleming's "Principles of Electric Wave Telegraphy and Telephony," second edition, page 445.

"Sir J. J. Thompson has shown that an ion cannot fly off spontaneously and leave the conductor in which it is located,[16] since the instant it attempts to depart from the surface it is subjected to a force which is numerically equal to $\frac{e^2}{4d^2}$, where e is the ionic negative charge (viz., 3.4×10^{-10} electrostatic units) and d is the distance from the surface. Now suppose that two metal surfaces are very near together, and at a difference of potential of V volts, or $\frac{V}{300}$ electrostatic units. Let the distance between these surfaces be microscopic, and equal to X

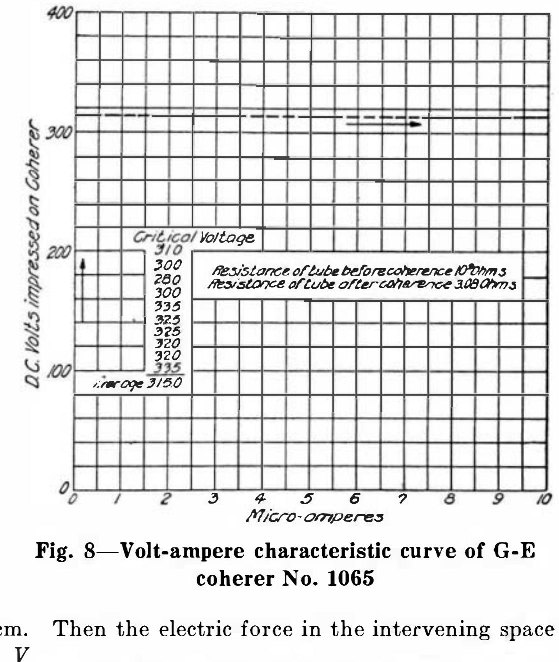

Fig. 8—Volt-ampere characteristic curve of G-E coherer No. 1065

cm. Then the electric force in the intervening space is $\frac{V}{300\,X}$ electrostatic units, and if this is equal to or greater than $\frac{e^2}{4\,X^2}$ then negative ions may pass from one mass of metal into the other and thus cause current to flow.

For example, if there is such a value of X and V that $\frac{V}{300\,X}=\frac{e^2}{4\,X^2}$ or $X=75\,\frac{e^2}{V}$, this transference of ions can take place. Moreover, when this transference of ions begins, it increases the potential difference between the two masses and this causes them to be drawn still closer together by electrostatic attraction.

When very great differences in conductivity exist between the two surfaces in contact, the action may result in the accumulation of negative ions at the bounding surface in such a manner as to stop the flow of current across the junction. This would explain the decreased conductivity between lead and lead peroxide."

Some of the latest experimenters claim that there can be no passage of ions from one conductor to another unless the surfaces are really in contact, so it seems the real way in which coherence occurs is still a problem to be solved.

New Zenith Telescope

Most of the instruments in present use for zenith measurements depend in some way or another on a telescope adjusted on the nadir by means of reflection, or by a level, or by a plumb-line, and in general the telescope is liable to flexure or change of collimation during the movement from one position to another. A form of instrument is designed to avoid these disadvantages, consisting of two telescopes rigidly connected, parallel to each other, one with objective pointing to the zenith, the other towards the nadir. The whole is mounted so as to permit of rotation through 18° about a vertical axis, so that no change with respect to gravitation is involved. —Note in *Science Abstracts* on a paper by G. Biogourdan in *Comptes Rendus*.

[12]See *The Electrician*, vol. 39, p. 217.
[13]See *Comtes Rendus*, 1899, vol. 128, p. 225.
[14]See *Wied Annelen*, 1899, vol. 68, p. 594.
[15]See *Comtes Rendus*, 1899, vol. 129, p. 40.
[16]See "Conduction of Electricity Through Gases," p. 144.