

This is evident from the fact that in some cases the metallic particles (e.g., iron or steel) are artificially prepared by oxidizing them in order to make of them a good coherer. The poorly conductive film may also be present in some cases in the form of a sulphide of the metal. On account of the readiness with which many metals (called the "baser metals") enter into combination with the oxygen or sulphur dioxide of the air, a thin film of oxide or sulphide is always present on the surface of most of the baser metals, unless special care is taken to remove it.

Apart, however, from the existence of such films of foreign matter at the contact, it seems not impossible that the high resistance before the arrival of the waves may be a property of the surfaces of even pure metals when these surfaces touch only very lightly.

If we assume the presence of the poorly conductive film at the contacts of the coherer, we may suppose that, on the arrival of the electric waves, the poorly conductive film is removed by the heat developed by the oscillatory currents. This starts the local current, which, developing further heat, still further improves the contact and permits the passage of further current. Instead of heat being the chief agency in removing the oxide or other poorly conductive film, or in bringing together the loose contacts, it may be that this is done by the electric attraction between the filings, which before the current starts will be charged with opposite signs of electricity, and which under the added e.m.f. produced by the electric oscillations may attract each other strongly enough to pull the contacts together.

We shall learn more about the electrical properties of high resistance contacts when we come to the study of *crystal rectifiers*. It is therefore proposed to omit further discussion of the specific action of the coherers, because of the more general character of the information to be presented later.

In the meanwhile some of the other detectors which do not depend on the properties of a loose contact are discussed.

MAGNETIC DETECTORS

Rutherford's Magnetic Detector.— In 1895 and 1896 Professor E. Rutherford¹ discovered a sensitive method of detecting electric waves by causing the electric oscillations set up by the

¹ E. Rutherford, "A Magnetic Detector of Electrical Waves and Some of Its Applications." *Phil. Trans. Roy. Soc. London*, 1897, Vol. 189, A., p.1; also *Proc. Roy. Soc. London*, 1896, Vol. 60, p. 184.

waves to demagnetize a bundle of fine steel wires. This bundle of steel wires consisted of about twenty pieces, each 1 cm. long and .007 cm. in diameter. The individual wires were insulated from one another by shellac varnish, and the bundle was placed within a small coil of about 80 turns of insulated copper wire. The bundle of steel wires was magnetized by the use of a magnet, and was then brought up near a magnetometer, consisting of a small compass needle suspended by a fine fiber and carrying a small mirror by which its deflections could be read. The needle of the magnetometer was deflected by the magnetized bundle of steel wires. If now electric oscillations were passed through the coil surrounding the bundle of steel wires, these wires lost some of their magnetism, which was shown by a diminished deflection of the neighboring magnetometer. Rutherford found that by connecting the coil around the wire bundle to a resonator, electric waves from a small Hertz oscillator placed at a distance of a half mile across the city (Cambridge, England) could be detected. With this instrument Rutherford performed many interesting experiments and carried out an important research on the damping of electric oscillations.

Marconi's Continuous Band Magnetic Detector. — In 1902 Marconi devised two other forms of magnetic detector, one of which has met with extensive use in practical wireless telegraphy, and is here described. Reference is made to Fig. 100. A band made up of a bundle of fine, hard-drawn iron wires, insulated from one another to prevent eddy currents, is carried on the periphery of two wooden discs, one of which is turned by a clockwork or a motor, so that the band moves at the rate of 7 or 8 cm. per second. This endless band of iron wire passes axially through a small glass tube *g*, around which two coils are wound. One of these coils, *b*, is connected into the oscillation circuit. In the example shown, the receiving circuit is of the simple type consisting of antenna, detector and ground. In this case the coil *b* is put directly into the antenna circuit, so that electric oscillations from the antenna, *A*, pass through this coil of the detector. We shall call the coil *b* the *oscillation coil* of the detector. Around the oscillation coil is a second coil, *C*, connected in series with a telephone receiver.

To produce a state of magnetization in the moving band, two permanent horseshoe magnets are placed near it. Two like poles, *NN*, of the magnets are placed above the center of the oscillation coil, and the other two poles, *SS*, are placed near the

band where it approaches and leaves the coils. These magnets induce magnetic *poles* in the moving band. One of these induced poles, say the South pole, is within the coils, and the two other

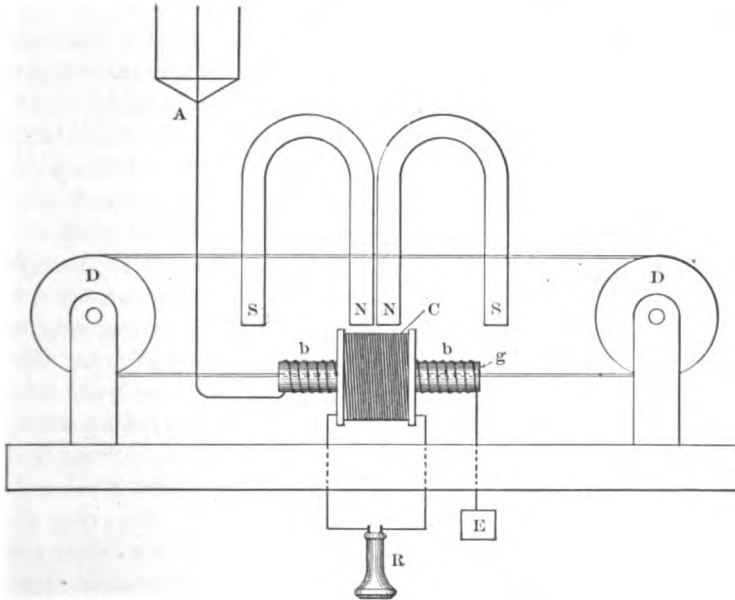


FIG. 100. Marconi magnetic detector.

consequent poles (North poles in our illustration) are near the point where the band enters and leaves the coils.

General Facts in Regard to the Explanation of the Action of the Marconi Magnetic Detector. — If we confine our attention to a point on the moving band, it is seen that, as the band moves forward, this point becomes a North pole outside the coils, changes to a South pole within the coils, and becomes again a North pole after issuing from the coils. There is, however, within the coils, *a steady state of magnetization*, for although the band is in motion, every particle of the band, as it passes a particular point within the coils, comes to a particular state of magnetization, so that the magnetic condition is fixed with respect to the magnetizing magnets. This gives a steady state of magnetization within the coils and produces no inductive effect in the form of currents in the telephone circuit.

If now a train of electric oscillations passes through the oscillation coil *b*, the magnetization of the part of the band within the

coil is changed, and this change of the magnetization produces a transient current in the coil C , and the telephone gives a click. A whole series of trains of electric oscillations gives a series of clicks, producing a musical note with a pitch depending on the frequency of arrival of the trains; and this is the frequency of the sparks at the sending station. So that one hears, when listening into the telephone attached to the magnetic detector, a sound like that produced by the spark at the sending station. The pitch of this sound is determined by the period of the vibrator of the sending induction coil; or, in case an alternating current transformer is used to charge the sending antenna, the fundamental pitch of the spark, and consequently the note that one hears at the receiving station, is determined by the number of reversals per second of the alternating current supply at the sending station, although other notes may be superposed on this fundamental note, due to the fact that with some adjustments more than one spark at the sending station occurs at each reversal of the alternating source.

We shall now discuss the nature of the change occurring in the magnetization of the iron band of the detector under the action of the oscillations set up by the incoming waves. The very rapid oscillations produced by the electric waves used in wireless telegraphy cannot produce a sound in a telephone either when applied to it directly or inductively, because, on account of the self-inductance that is necessary to the telephone, these very rapid oscillatory currents cannot traverse its circuit. If they could traverse its circuit, the diaphragm of the telephone could not take up such rapid vibrations, and if it did we could not hear them, for the highest note audible to the human ear makes only 35,000 vibrations per second. Our wireless telegraph detectors must be so constructed that the rapid oscillations of a train of waves act *integratively* upon it, so that the *train* produces a single response in the telephone; and a series of trains produce a series of responses. This series of responses we can hear in the telephone, because the series of trains of waves follow each other with a periodicity that is audible.

In regard to the manner in which a train of oscillations act integratively upon the magnetized moving iron band of Marconi's form of the magnetic detector, I shall present a few paragraphs of explanation.

Explanation Assuming a Suppression of Hysteresis by the Oscillations. — Many experiments have been made in the effort

to discover just what is the effect produced on the magnetization of the bundle of iron wires by the oscillations within the coil surrounding the bundle. A steady current in the coil would magnetize the iron wires of the bundle. An oscillatory current, according to the experiments of C. Maurain,¹ produces a suppression of hysteresis in the iron.

In explanation of the term "hysteresis," reference is made to Fig. 101, in which *magnetizing force* is plotted horizontally and the *magnetization* produced by it is plotted vertically. This curve represents the *hysteresis* in a specimen of hard-drawn iron wire such as is used in the magnetic detectors. If we start with the magnetizing force equal zero, and increase it to *OL*, the magnetization follows the curve *OA*. If now we reduce the magnetizing force gradually to zero, the magnetization follows the curve *AC*. That is, the state of magnetization produced by the magnetizing force when it is decreasing is not the same as the state of magnetization produced by the force when it is increasing, and after the force is removed, some magnetization represented by *OC* is left in the specimen. In order to reduce this magnetization to zero, it is necessary to apply a reversed magnetizing force *OD*. If we go on increasing the reversed magnetizing force to *OM*, the magnetization follows the branch *DE* of the curve. On decreasing and again reversing the force, the magnetization traces out the branch *EFGA*. The complete diagram is called a *hysteresis cycle*.

Hysteresis is the property of iron, steel and other magnetizable metals characterized by the fact that the change in magnetization due to the application of a magnetizing force depends on the previous state of magnetization of the specimen. The state of magnetization assumed by a specimen when the magnetizing force is gradually removed is not the same as the state of magnetization assumed by the specimen when the force is gradually applied. The magnetization produced by a given magnetizing force is not completely annulled by withdrawing the magnetizing force. The hysteresis effect is small in very soft iron, is increased by hardening the iron, and is very great in glass-hard steel.

According to the experiments of C. Maurain, which we are now discussing in their application to the magnetic detector, the superposition of a sufficiently strong oscillatory magnetizing force upon a slowly varying magnetizing force causes a suppression of the hysteresis in the specimen. If the oscillatory force is weak, the

¹ C. Maurain, *Comptes Rendus*, Vol. 137, p. 914-916, 1903.

suppression is only partial, giving for the specimen characterized in Fig. 101 a diminished hysteresis, such as is represented in Fig. 102.

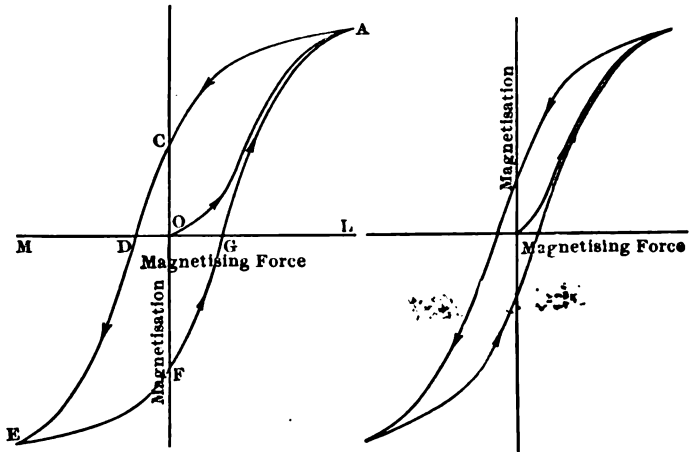


FIG. 101. Hysteresis curve.

FIG. 102. Hysteresis curve.

In terms of this result we have a possible explanation of the magnetic detector. Reference is made to Fig. 103. With the poles

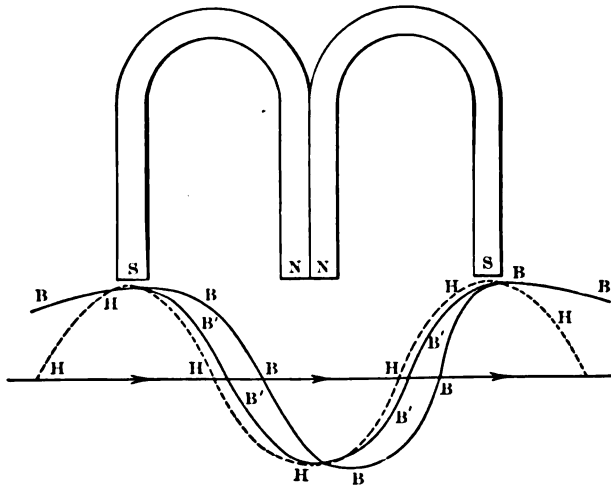


FIG. 103. Diagram in explanation of Marconi magnetic detector.

of the permanent magnet in the positions *SNNS*, the magnetizing force acting on the band will be positive under the

South poles and negative under the North poles; and following our usual method of plotting, the magnetizing force can be represented approximately by the *dotted wavy curve* H of Fig. 103. Now if we suppose the band to be moving in the direction of the arrows, the North magnetization under the first South pole will not follow the curve of force, but will *persist*, and follow approximately the continuous curve B . If now oscillations produced by the electric waves are allowed to flow around the oscillation coil, the hysteresis in the band is suppressed, so that the curve of magnetization B falls back into the position B' , which is nearer the curve of magnetizing force H of Fig. 103. This change from the condition B to B' is equivalent to a motion toward the left of the magnetic distribution in the coil, and therefore induces a current in the coil containing the telephone in circuit. When the waves cease, the state of magnetization returns to that represented by the curve B . We have thus with each train of waves a back and forth shift of magnetization of the band, and consequently a to and fro motion of the telephone diaphragm.

While this description of the process seems a very reasonable explanation of the action of the detector, yet, for the benefit of those readers who may wish a little more insight into the processes occurring in iron or steel submitted to an oscillatory field, I beg leave to present a brief account of some experiments by E. Madelung, in which he made direct observations of the effect of electric oscillation on the magnetization of iron and steel.

Experiments of E. Madelung. — A very comprehensive and beautiful series of experiments *On Magnetization by Rapid Oscillations, and on the Operation of the Rutherford-Marconi Magnetic Detector* has been made by E. Madelung, and described in his Göttingen Dissertation.¹

By means of a very ingeniously devised application of Braun's cathode tube, Madelung was able to obtain on a fluorescent screen the hysteresis cycle produced by a slowly varying magnetic force, and to obtain also the effect produced on this hysteresis cycle by superposing the rapidly oscillating magnetic force produced by sending a condenser discharge through the magnetizing coils.

Reference is made to Fig. 104. I. With a slowly varying magnetizing force the hysteresis cycle $EAKFGE$ was described. II. Upon slowly applying and withdrawing a magnetizing force

¹ E. Madelung: *Drude's Annalen*, 1905, Vol. 17, p. 861.

OM the curve AKC was obtained. III. On applying in the coil surrounding the specimen a rapidly oscillating electric current, giving a magnetizing force of initially the same amplitude OM and falling off in amplitude by damping, the spiral curve AD was described. IV. Applying a second oscillation gave a similar spiral starting with the arc DJ . The complete spiral for this case is not drawn; it is like that of AD , but is somewhat lower down. V. Applying more of these oscillations brought the spiral down into the position L , after which further oscillations simply caused the magnetization to describe over and over the closed spiral

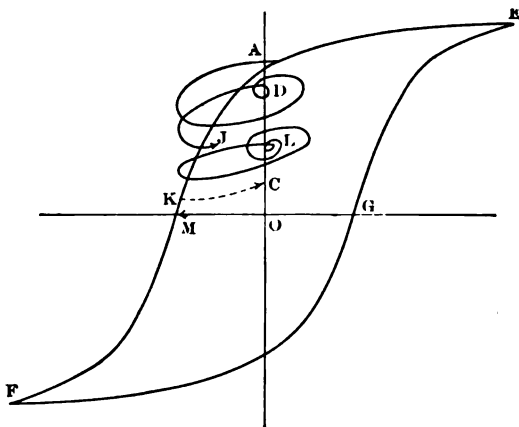


FIG. 104. Dr. Madelung's curve showing effect of rapid oscillations on magnetic hysteresis.

path L . The path L is thus the limit of the condition attained by the specimen when several oscillations are applied.

Thus a series of oscillations applied to the specimen originally in the state A reduced its magnetization to the state L .

The jump from A to L is the demagnetization effect of the oscillation, which was first utilized in the construction of a detector for electric waves by Rutherford.

Suppose now that these oscillations be applied to the specimen when it is in various different states of magnetization; Madelung found the effect shown in Fig. 105. Applied at A , the effect was a change from A to B ; applied at C , the specimen, after the oscillation, was left almost in the state C unchanged; applied at D , the effect was a change from D to E . The effect of the oscillating field is thus a hastening of the progress of the cycle in the direction it was already going under the action of the slowly varying field.

A suppression of hysteresis would attain the same end results, but instead of being contented with calling the effect "suppression of hysteresis," which is a purely negative account of the phenomenon, Madelung, by his delineation of the spiral course taken by the magnetization during the application of the oscillating magnetic force, has given us a very distinct picture of the active processes occurring in the specimen. He has shown that the magnetic state of the iron has been violently agitated by the oscillating magnetic force, and in this way the sluggishness of the specimen in following the slowly changing magnetic force has been overcome.

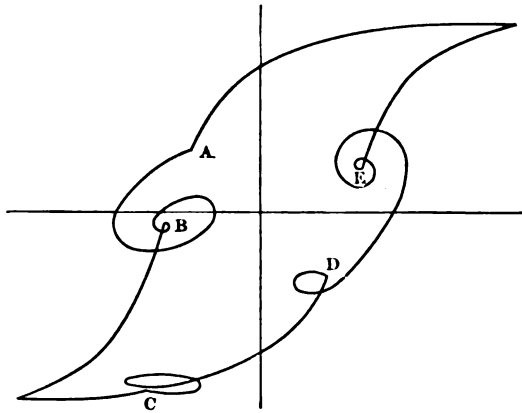


FIG. 105. High frequency oscillations superposed on different parts of cycle (Madelung).

Applying this process to our Fig. 103, we must think of the curve *B* as going through a set of vibratory tremors back and forth horizontally as it settles down toward the curve *H*. These tremors are of too high frequency to act on the telephone, which therefore responds only to the general displacement of the magnetization from the curve *B* toward the curve *H*.

Sensitiveness of the Magnetic Detectors.—The magnetic detectors are more sensitive than the coherer, but seem to be less sensitive than the electrolytic detector and some of the solid contact detectors (the crystal detectors).

THERMAL DETECTORS

There are two general classes of detectors in which the heat developed by the electric waves is made to manifest itself at the receiving station. In one of these classes, including the *bolometer*