KEMP

Apparatus & Methods for Measuring Electric Waves

Physics

B. S.

1906

UNIVERSITY
OF
ILL. LIBRARY

UNIVERSITY OF ILLINOIS
LIBRARY

Class 1906
Book K32
Volume

Je 06-10M

Apparatus and Methods for Measuring Electric Waves

by

Jacob Garret Kemp

Thesis for the degree of B. S. in Physics

in the

College of Science

of the

University of Illinois

June 1st, 1906.

1906
K32

1906
K32

UNIVERSITY OF ILLINOIS

June 1 1906.

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Jacob Garrett Kemp

ENTITLED Apparatus and Methods for Measuring Electric Waves,

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Arts.

A. P. Carman

HEAD OF DEPARTMENT OF Physics.

88025

The Rare Book & Manuscript Library
UIUC

Preface.

The object of this thesis is to give a resumé of some of the apparatus and methods for measuring electric waves. The fundamental principles will first be discussed as discovered by the eminent physicist, Dr. Heinrich Hertz. The remainder of the work will be devoted to the exposition of various apparatus and methods for showing the waves, measuring their length, resonance effects and their application.

The material for this thesis has been gleaned from the following:- Hertz's, "Electric Waves," Silvanus P. Thompson's, "Light Visible and Invisible," "Maxwell's Theory and Wireless Telegraphy," by Poincare and Vreeland, Annalen der Physik, new ser. 67, 1899, Flem ig's "Waves in Air, Water and Ether", and various other articles on the subject.

I take this opportunity to acknowledge my thanks and gratitude for the guidance and suggestions so willingly given me by Prof. A. P. Carman and Assistant Prof. C. T. Knipp of the department of Physics, University of Illinois,

J. G. Kemp.

Digitized by the Internet Archive
in 2013

http://archive.org/details/apparatusmethods00kemp

TABLE OF CONTENTS.

Resonance

Pages

Apparatus and Methods for Measuring

Electric Waves.

The theory of electric waves was set forth in 1864 by the great mathematical physicist, Prof. Clerk Maxwell, and discovered experimentally, in 1888, by the great Prof. Heinrich Hertz.

In working with oscillatory discharges Hertz was led to investigate the disturbances which they set up in the surrounding medium, and which are propagated as electric waves. To illustrate the work the most frequent use will be made of diagrams.

In fig. 1, page 2, A, is an induction coil. B is an oscillating system with spark gap between two brass balls about 1 cm. in diameter connected to the ends of two brass rods upon which are two hollow spheres of copper made so that they can be moved along the brass rods to or from the spark gap. The rectangular form, S, is of copper wire 2mm. in diameter and about 75 cm. square with a spark gap M, bisecting one side, on the ends of which are fastened two small brass balls each about .5 cm. in diameter.

When S is connected as shown by a metallic conductor with the brass rod R, and the oscillating circuit set to vibrating by turning the current from storage cells or other electrical source thru the induction coil, oscillations are produced in S, which are shown by the sparking between the balls 1 and 2, fig. 1, page 2 .

Hertz explains this phenomenon as follows:- The electrical waves rushing thru the metallic conductor reach the ball 2

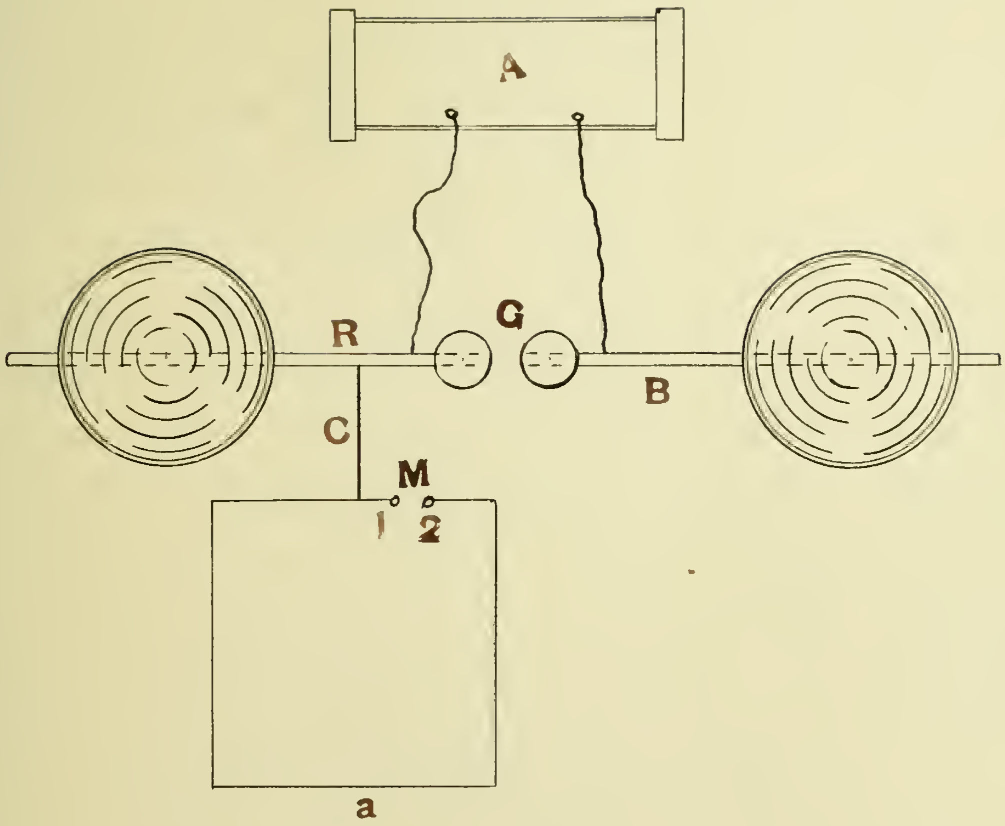


Fig. 1. Hertzian oscillating system.

in an appreciable interval of time later than they reach ball, 1, that is, the change of potential proceeding from the induction coil reaches ball 1 in an appreciable shorter time than the ball 2, thus causing a difference of potential which is shown by the resulting sparks which are produced in gap between 1 and 2. This is somewhat surprising when we consider that electric waves in copper wires are propagated with a velocity which is approximately the same as that of light.

To avoid confusion the sparks in the side circuit S, will be called side sparks. If the conductor G be slipped along the side circuit S, away from the ball 1, the side sparks will grow fainter till a point symmetrically placed with respect to the gap is reached the side sparks entirely disappear. This verifies Hertz's explanation of the cause of the side sparks.

Hertz then tried the side circuit without the metallic connection to the oscillating system and side-sparks appeared for different positions with reference to the spark gap G and the oscillating system. These positions can best be explained with the aid of fig. 2, page 4 . By means of apparatus similar to fig. 2, page 4 Hertz investigated the disturbances of the surrounding medium when the oscillating system was vibrating. At every oscillation an electric wave is sent off from the apparatus into the surrounding space with the velocity of light. The wave is propagated with the greatest intensity in the direction at right angles to the metal rods along which the electricity is oscillating.

In order to detect these waves the resonator, or circular copper circuit with a spark gap between two brass balls must

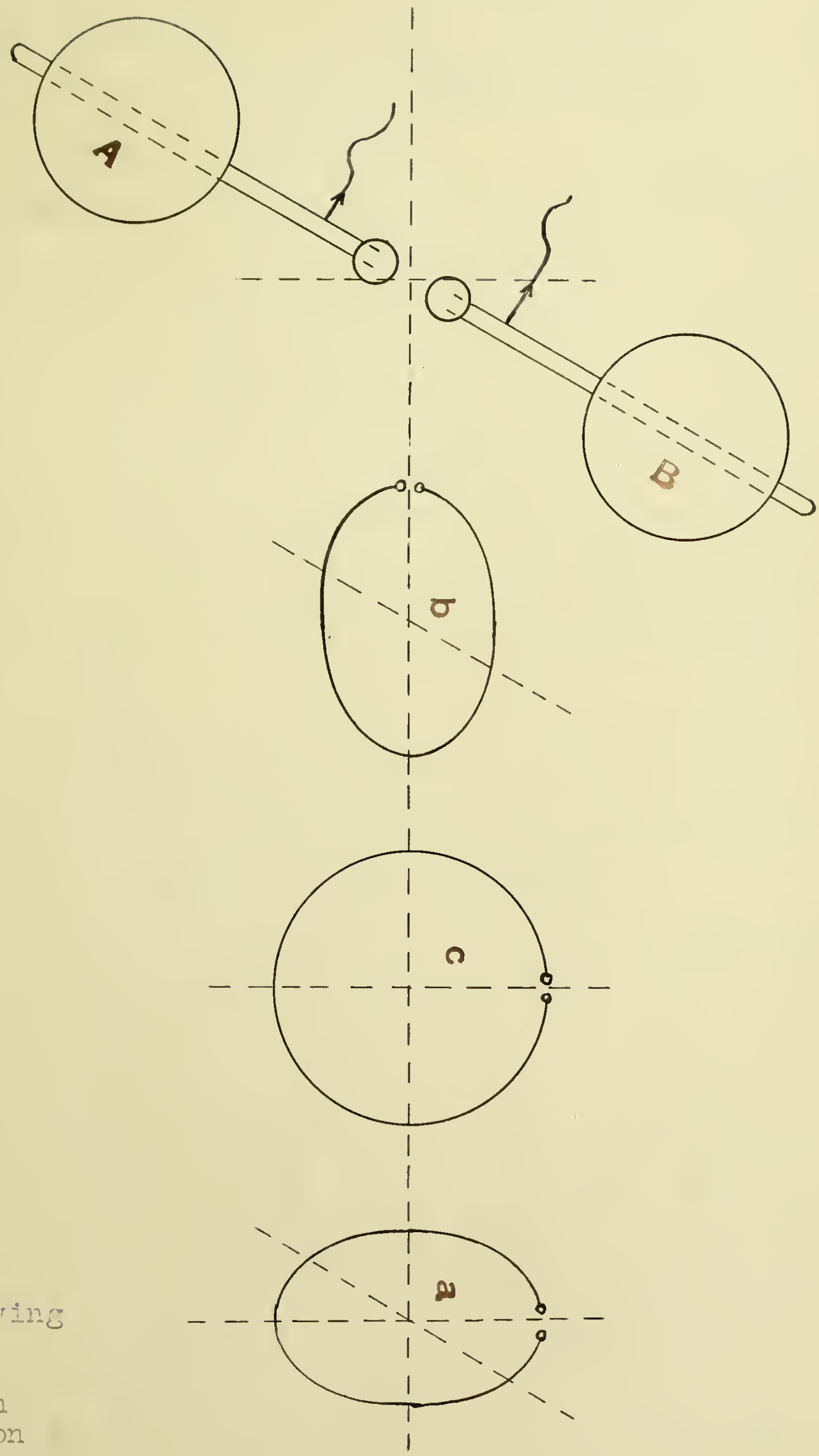


Fig. 2 diagram showing
positions.

a, first position
b, second position
c, third position

be of such a size that its natural electrical period of vibration agrees with the period of the waves emitted by the oscillator. The dimensions of the resonator are determined by the theoretical equation $T=2\pi\sqrt{CL}$ which gives T in terms of the capacity, C, and the self-induction L, the quantity $2\pi\sqrt{CL}$ being determined by the length of the ring or by experiment.

In determining the different positions of the resonator the following convention will be observed:- The axis of the radiator or oscillator is the line joining the centers of the spark balls, the line thru the spark perpendicular to this line will be called the base line. Also the line joining the spark balls of the resonator will be called the spark axis of the resonator. If the resonator is set in front of the oscillator with its center on the base line, then there are three principal positions which the resonator may occupy.

1. Its plane may be parallel to the axis of the radiator and perpendicular to the base line as position, a, Fig. 2, page 4 , which shall be called the first position.

2. The resonator may have its plane in the plane containing the radiator axis and the base line, as in position, b, Fig. 2, page 4 , which will be called the second position.

3. The resonator may have its plane perpendicular to the plane containing the radiator axis and the base line, and placed so that its plane passes thru the spark gap, with its center on the base line, as position, C, Fig. 2, page 4 , which will be called the third position.

When the resonator is placed in each of these three positions respectively, but not too close to the radiator, and if

at the same time the resonator is turned round in its own plane so as to bring the spark axis of the resonator into various positions, different phenomena present themselves.

In the first place, if the resonator is placed in the first position, and with the spark axis of the resonator parallel to that of the radiator, then when the radiator is in action small sparks also occur between the small balls of the resonator; but, if the resonator is turned round in its own plane so that the spark axis of the resonator is perpendicular to that of the radiator, then no sparks occur at the resonator.

In the next place, if the resonator is placed in the third position with its plane perpendicular to the axis of the oscillator, then no sparks are seen, whatever the position of the spark gap of the resonator.

When the resonator is placed in the second position with its plane parallel to and passing thru the axis of the radiator, then sparks are seen in the resonator air gap when that gap is turned toward the oscillator; but they become less and less bright as the resonator is turned round in its own plane, until when the spark gap is turned so that it is in the base line the sparks cease altogether.

Hertz gave as an explanation of these phenomena as follows. No difference of potential could be created between two balls connected by a short loop of wire by means of low frequency oscillations, but a difference of potential can be produced by means of very high frequency oscillations. These high frequency electric displacements travel thru the dielectric or ether to the

resonator. If the spark gap of the resonator is held parallel to the spark gap of the radiator, then displacement or electric force arriving at the resonator fills the spark gap of the resonator and creates there an alternating displacement, and an alternating potential difference between the balls. When this reaches a certain amplitude the air insulation in the gap breaks down and a small spark is produced between the ball terminals of the resonator. Even when the resonator and the spark balls are connected by the resonator wire the sparks are still visible, since the inductance of that wire makes it a practically perfect insulator to very suddenly applied potential differences.

If, however, the resonator is held in a position so that the line joining the spark balls is in a direction at right angles to the spark axis of the radiator, then no sparks will occur in the resonator, because the electric force arriving there is not in a direction to create potential difference between the balls. If, however, the plane of the resonator is in the plane containing the base line and the spark axis of the radiator, and, if the spark gap of the resonator is so placed that its direction is perpendicular to the axis of the radiator, then feeble sparking is seen in the resonator gap. This, however, is because the electric force distribution is disturbed by the metallic circuit of the resonator.

The direction of the electric force, and, therefore, the displacement traveling thru space is then in the direction of the spark balls of the resonator and no longer parallel to the spark axis of the radiator, but is slewed round so as to be inclined in a direction to the spark axis of the resonator. Hence the effect

is to cause a displacement across the spark gap of the resonator, and therefore to create a spark.

If the spark formation is due to the action of the electric force propagated from the radiator, what are the functions of the wire of the resonator?

The resonator is a circuit possessing capacity and inductance, the spark balls forming, so to speak, the condenser portion of the circuit, hence it has a natural free period of electrical vibration. If in the space between the balls alternating electric displacement is produced, being propagated to that point thru the ether or dielectric, this displacement may or may not synchronize in period with the free period of vibration of the resonator. If it does time in with it, then the amplitude of the displacement oscillations is increased, and a point is reached at which the air insulation breaks down and sparks then pass.

Owing to the fact that the resonator is a nearly closed circuit, it is a very bad radiator, and such a resonator has a very small coefficient of damping. If it is a circular resonator, about 35 centimeters in diameter as used by Hertz, it may make 1000 vibrations before the oscillations are damped out.

It is obvious, therefore, that oscillations can be most easily set up in the resonator circuit when the vibrations of electric displacement, which gives rise to these oscillations propagated to the spark gap, are in a direction parallel to the spark axis of the resonator.

In the case in which the resonator is placed with its plane lying in the plane containing the axis of the radiator and the base line, the distribution of electric displacement is dis-

turbed, as already explained, by the metallic circuit of the resonator, and the advancing wave surface of displacement is distorted so that in crossing the spark gap of the resonator the displacement has a component parallel to the spark axis of the resonator, and therefore the conditions are such as to be favorable to the production of at least feeble sparking.

It is to Hertz that we owe the exact demonstration of the vibratory nature of the discharge by the production of phenomena of interference and resonance. The occurrence of interference proves that an electric vibration is formed of two equal and symmetrical parts, like a sonorous or a luminous vibration.

At the same time Hertz proved that electric vibrations are propagated by the ether, that is to say, by the same medium that transmits luminous vibrations. He also recognized that electric vibrations, like light waves, are transversal. It results, from all his researches, that the only difference between electric and light waves is in the period of vibration. All the undulatory phenomena of optics are repeated in electric vibrations.

We may then regard electric waves precisely as we regard the waves of light, and the terms period, wave length, and wave surface need not be defined anew.

Propagation in Space.

Hertz's most famous discovery with the above described simple resonator was the proof that he was able to give of the existence of stationary electric waves set up in the ether bounded by a sheet of metal and the radiator. He attached to an induction coil terminals a radiator composed of two square sheets of metal 40 cm. in size, each having a brass rod 30 cm. long attached to it ending in a brass ball. These plates were arranged with the rods in one line and the balls about a centimeter apart, the direction of the rods being vertical. As a resonator he used a circular wire 35 cm. in diameter with the ends nearly meeting each attached to a brass ball, which furnished the spark gap. A large sheet of metal was set up at the end of the room, and the radiator with the axis vertically placed at the opposite end. Figure 3, page 11 shows the arrangement of the apparatus. The resonator was then held with its plane parallel to the metal sheet and its spark gap parallel to the spark gap of the radiator.

Under these conditions, if the resonator was held near the metal sheet no sparking occurred, but if moved away from it in the direction of the radiator sparks appear as at position B Fig. 3, page 11 , where the sparks have maximum brilliancy, but, if the resonator was moved still farther from the metal sheet a position was found in which the sparks again ceased as at C. Fig. 3, page 11 .

All along the base line, therefore, perpendicular to

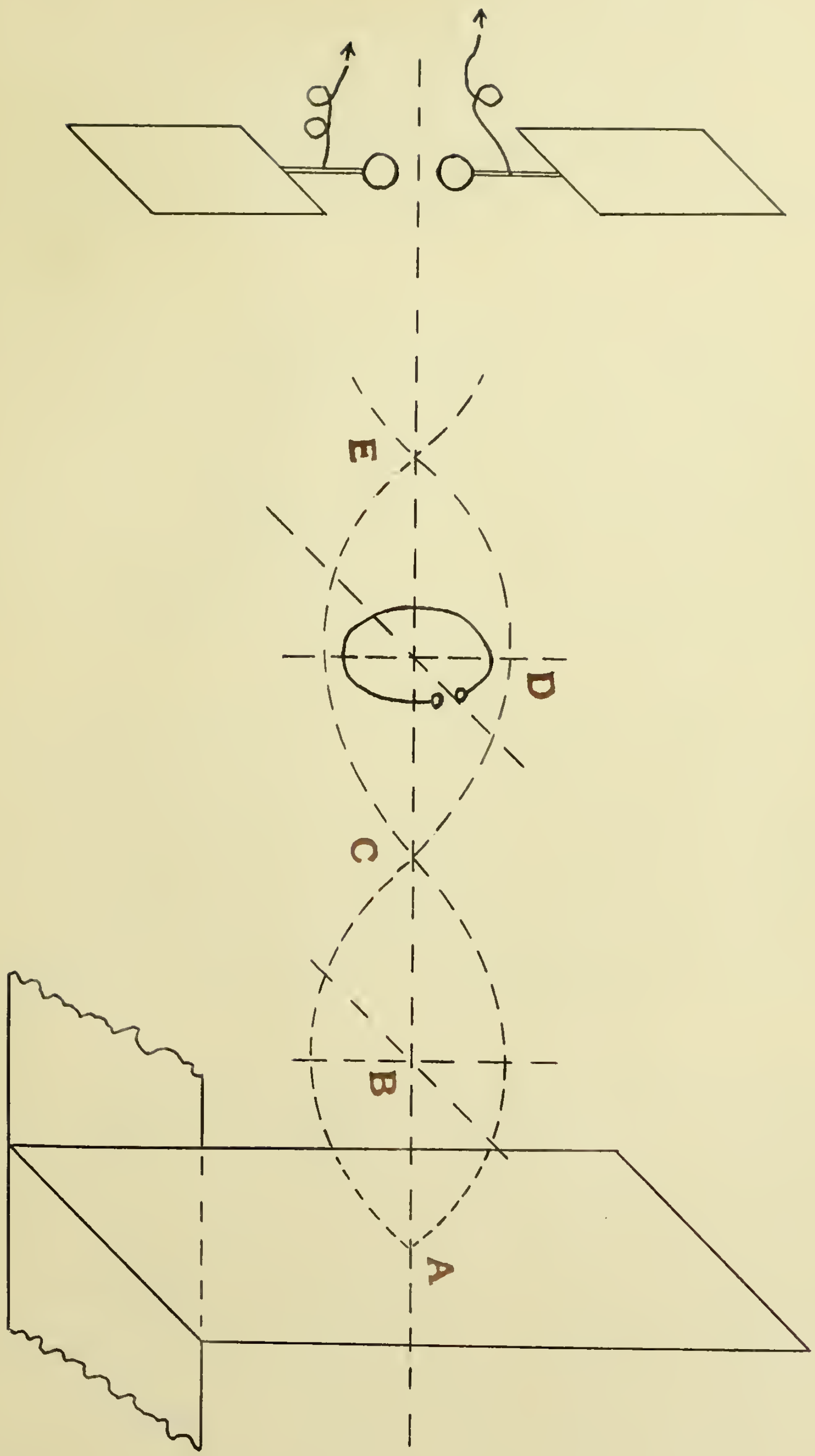


Fig. 3 Electric wave in space.

the metal sheet, it was found that there were positions of maximum and minimum sparking indicating a periodicity in the distribution of electric force. The maximum points are represented in Fig. 3, page 11 as B and D, which are called "loops" or antinodes. The minimum points are A, C, and E which are called nodes. In this manner the waves of electric force, or electric waves were determined.

A very important discovery in connection with this phenomenon was made by Sarsin and De la Rive (Comptes Rendus, March 31, 1891), who found that the distance between two non-sparking planes essentially depended upon the size of the resonator and was approximately equal to four times the diameter of the circular resonator.

The earliest view taken of the effect was that the radiator creates stationary dielectric or ether waves of definite wave length, and that the resonator indicates this wave length by sparking when held as described at places of maximum electric force. But it is found that the size of the radiator very little affects the result.

Another hypothesis was that the radiator sends out waves of all wave lengths, resembling therefore white light, and that the resonator picks out and responds to its own particular wave length. Altho this hypothesis seems probable it is not justified by any facts. An explanation was given by M. Poincare, in 1891, and also by Prof. J. J. Thomson ("Recent Researches on Electricity and Magnetism." P.402). The radiator, as shown by Bjerknes, is a very strongly damped system, and at each discharge hardly makes more than a dozen oscillations, even if so many, before its

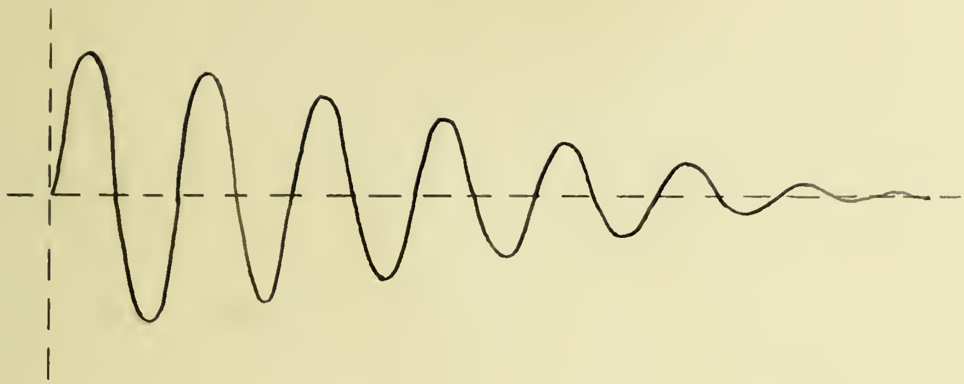


Fig. 4. Feebly damped oscillations in resonator

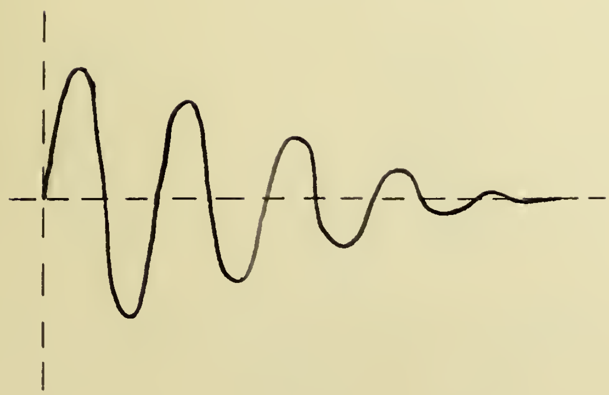


Fig. 5. Strongly damped oscillations in resonator.

electrical vibrations are damped out as shown in the Fig. 4 and Fig. 5, page 13. Suppose the resonator held at a distance from the metal wall equal to a quarter wave length corresponding to this particular resonator, then as the electric force passes over it, it will create a displacement between the spark balls. This displacement travels on, is reflected from the wall and returns. If it returns at such a moment to assist the displacement then being made between the spark balls of the resonator, the amplitude of this displacement is increased and a succession of such assistances will break down the insulation of the air and a spark will occur. It is clear, therefore, that this reenforcement of the displacement amplitude will occur when the distance of the resonator from the metallic wall is a quarter of its own wave length. Sarsin and De la Rive used resonators of various diameters (D) as shown in the table below, and measured the distance $\frac{x}{2}$ between places of maximum sparking in the resonator.

D	4D	$\frac{x}{2}$
100 cms.	400 cms.	406 cms.
75 "	300 "	282 "
50 "	200 "	222 "
35 "	140 "	152 "
25 "	100 "	120 "
20 "	80 "	86 "
10 "	40 "	38 "

Accordingly the positions of the resonator when the maximum sparking takes place in its air gap reveal, not the wave length of preexisting stationary waves, but the oscillation period or wave length corresponding to the resonator. Nevertheless they prove the existence of ether waves in the space between the metal sheet and the radiator.

Prof. J. J. Thomson notes one point as yet unexplained. The above table shows that the wave length is eight times the diameter of the resonator. If this is really the wave length of the free oscillations of the radiator system we should have expected it to be equal to 2π times the diameter of the circular radiator and not eight times.

By making an estimate of the vibration period of the oscillator and measuring the wave length or double distance between two maximum sparking places as the resonator was moved along the base line, Hertz was able to make an approximate estimate of the velocity of propagation of these electric waves, and showed that it was of the same order as that of light. Since his time more accurate work has confirmed the above estimate, and has shown that there is an almost absolute identity between the experimentally-determined velocity of light thru air and that of electrically-produced waves thru the same medium. Hertz also showed that these waves were guided in direction by metallic wires.

Propagation along Parallel Wires.

In studying the propagation of electric waves along wires experimentalists have generally employed some modification of conductor system usually called the Lecher arrangement. In this arrangement a Hertz oscillator consisting of two metallic plates, as already described, and shown in Fig. 6, page 18, is attached to the secondary circuit of an induction coil, and two other insulated metallic plates are placed parallel and opposite to these respectively, but separated a little distance, the dielectric between them being air or any suitable solid. To these last plates are attached long copper wires which extend parallel to each other thru space and insulated from any part of the building or the earth. When the coil is in operation and sparks passing between the primary spark balls, the rapid oscillation of potential of the plates of the Hertz oscillator creates similarly rapid changes of potential of the secondary plates, and hence produces electric oscillations in the long wires. The condition of these wires when of suitable length is then as follows. At certain places there are alternations of potential which may be called potential loops, and at other intermediate positions there are potential nodes or places of minimum potential variation. There is also a variation of current in different parts of the wires. In some places the current has a maximum value and in others a minimum. Accordingly when we are dealing with the propagation of these rapid oscillations along wires, it is curious to

find that the current has not always the same strength in different parts of the same wire. Strong currents may exist in some places and yet little or no current at all in other parts of the same continuous wire.

If the ends of the wires are free or open, as shown in Fig. 6, page 18, the current is necessarily zero at the free ends (C). In all these cases the places of maximum potential variation are those of minimum current or vice versa, as shown in the diagram Fig. 6, page 18, the waves or curves represent the variation of current by the perpendicular distance from the wire to the curve. At G, A, B, and C, the current is zero, while at the same points the potential is a maximum; the points F, E, and D, represent maximum current while at the same points the potential is a minimum.

There are many ways in which this distribution of current and potential along the wires of the Lecher apparatus can be explored. Hertz studied the propagation along wires by placing his resonator with spark gap parallel to the wire along which the waves were traveling, and moving it to different positions. If, for instance, a wire attached to a plate placed opposite to one of the plates of a Hertz radiator is stretched out parallel to the base line, and if a Hertz resonator is placed with its center on the base line and its spark gap parallel to this wire, then, if the plane of the resonator is at the same time perpendicular to the plane containing the spark axis of the radiator and the base line, we have seen that under these conditions the direct action of the radiator produces no sparking in the resonator. If, however, the resonator is placed in this position and moved along

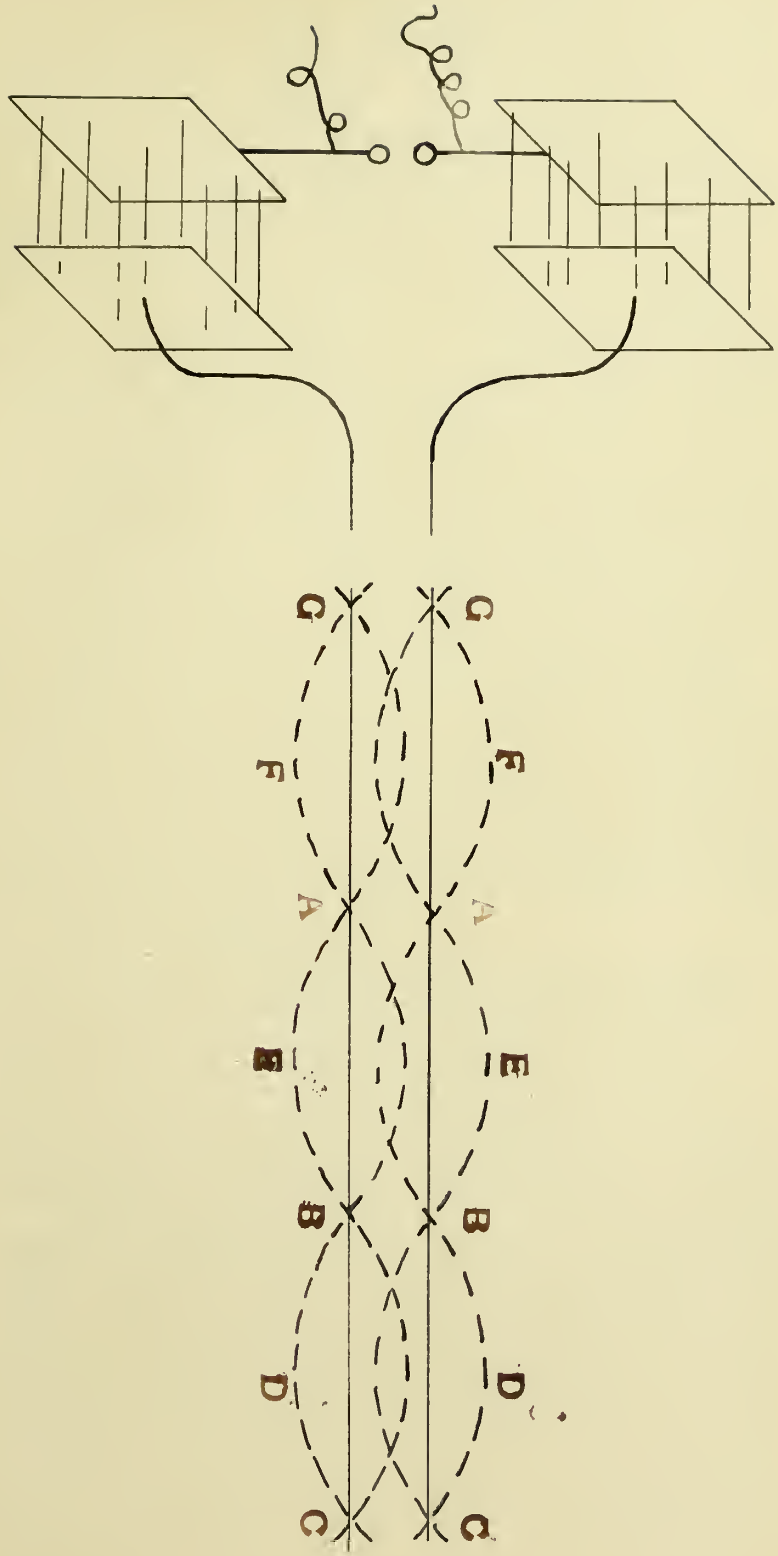


Fig. 6. Diagram showing Lecher system used by Hertz.

with its spark gap parallel and near to the stretched wire, small sparks are seen at the resonator balls at some places, but not at others, thus showing a variation in the distribution of potential at different places along stretched wires.

Another method due to Lecher, is to bridge over the wires with a vacuum tube, which can be slid along into different positions. The vacuum tube may have in it rarified air with a trace of turpentine vapor, or it may be made of fluorescent glass. In any case the tube is found to become luminous in some positions and not in others. The vacuum tube may be placed across the open ends of the wires, and these may be bridged across by short metal wires which are slid along into various positions, when the illumination of the vacuum tube at the ends of the wires is not changed. Thus we see that for some positions of the bridges the vacuum tube will not glow and in others it will glow. These positions are called respectively the anti-nodes or loops and the nodes of the stationary electric waves.

There are other methods of determining these nodes. Arons placed the wires in vacuum tubes which glowed with a varied intensity, from zero at the nodes to a maximum at the anti-nodes. But this is an unwieldy arrangement and difficult to make. The other method is by W. D. Coolidge, described in, Annalen der Physik, new ser. 67, 1899. This method has the advantages of the Arons arrangement and the wires are left uncovered.

Coolidge Method.

If the variations of the potential are of sufficient amplitude along the parallel wires, the position of nodes and anti-nodes can actually be seen in a dark room by the unequal distribution of a luminous glow surrounding the wires, bright at some places but less bright or absent altogether at others. In order to get the desired amplitude Coolidge used a modification of the Blondlot oscillator a drawing of which is given in Fig. 7, page 21 also a photograph on page 21 .

A glass vessel about 12 cm. in height, about 15 cm. in diameter is fastened to a cast iron base by means of a glass rod about 3 cm. in diameter and about 25 cm. high. The primary coil is made in two pieces with small brass balls at one end of each half, the diameter of this coil which is of one turn, is about 10 cm. in diameter and the wire diameter of which it is made is about 2 mm. The secondary is a continuation of the parallel wires into the side of the glass vessel and bent into nearly a complete circle with the diameter the same as the primary. The primary is placed on top of the secondary. Between the primary and secondary is placed a mica disc, the diameter of which is the same as the glass vessel. A hard rubber lid is placed on the glass vessel thru which connections from the primary are brought where they may be connected to the induction coil terminals. The vessel is then filled with heavy oil. When oscillations are produced in the oscillating circuit, which will be described below,

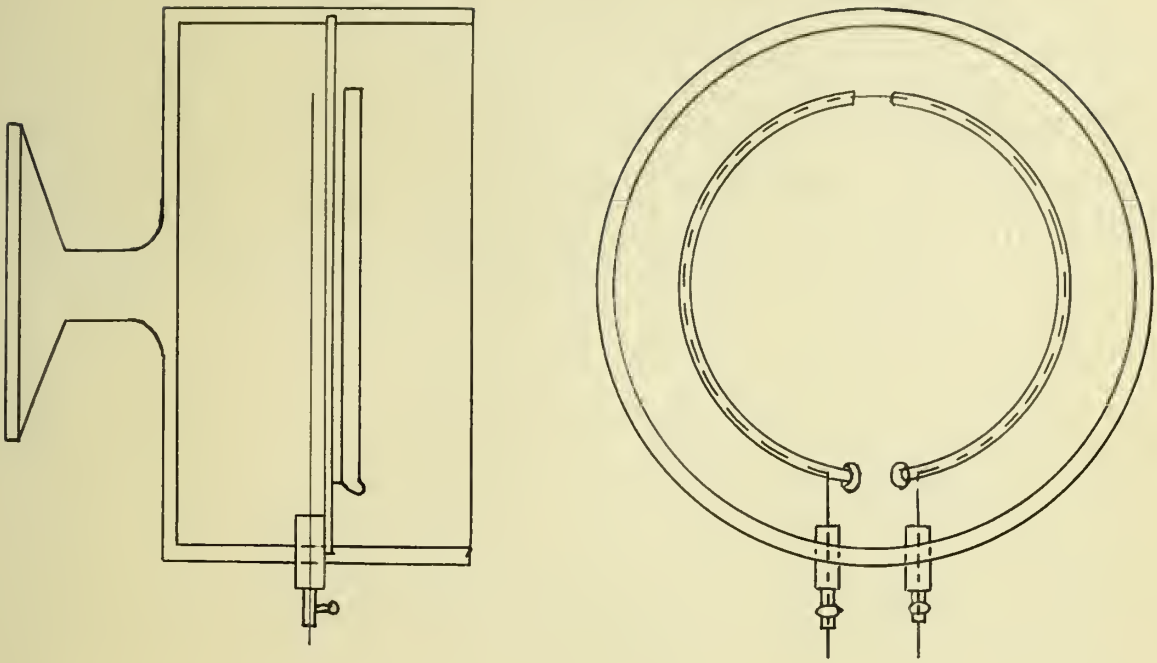


Fig. 7. Drawing of the modification of Blondlot's oscillator

the oscillations produce periodic currents in the primary which excite induced currents of the same period in the secondary or parallel wires. The connections of the oscillating circuit are shown in Fig. 8, page 23, C, is a capacity, G, a spark gap, T, a Tesla transformer, E, the primary of the oscillator. This apparatus gives waves about 110 cm. in length. The manipulation is the same as in the other methods described except that no vacuum tubes need be used in a sufficiently dark room.

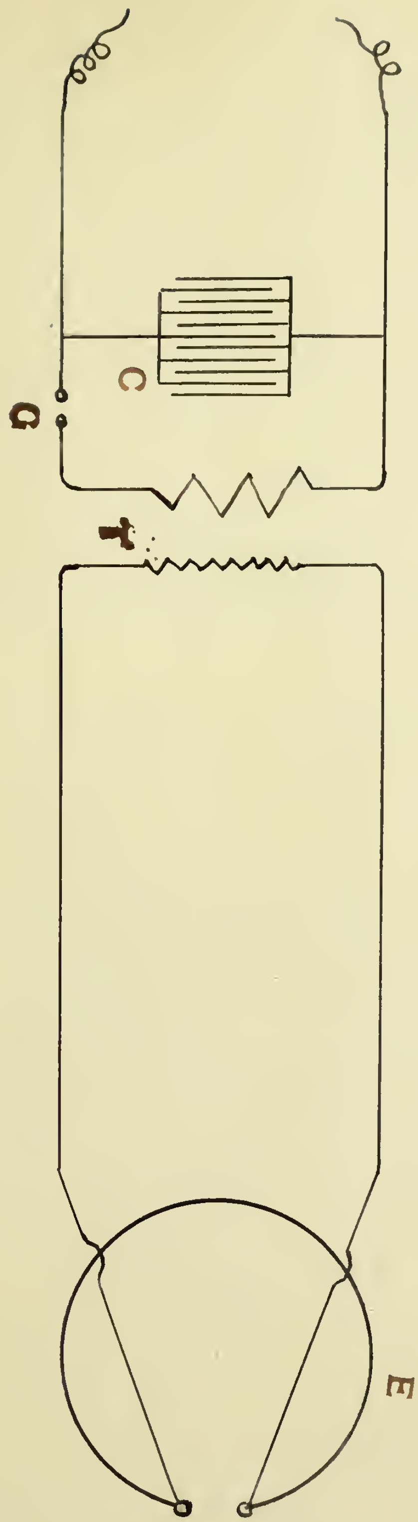


Fig. 3. Diagram showing connections of Coolidge apparatus.

E, oscillator, T. Tesla coil, G. Spark gap, C. Condenser.

Resonance.

One of the best methods for the demonstration of resonance of electric waves is by Prof. Braun. This arrangement makes it possible to see very distinctly the nodes and the anti-nodes of electric waves as they travel along wires, and it shows the change of wave length with the change of capacity and inductance of the oscillating circuit; or in other words, it shows the variations in resonance of the circuit with the variation of capacity or induction. The connections are as shown in Fig. 9, page **25** and Fig. 10, page **27**.

In Fig. 9, page **25** the oscillating circuit is the induction coil, leydenjars, the primary of the Tesla coil, and the spark gap and induction coil. The frequency of this circuit can be changed by varying the capacity since from the relation $N = \frac{1}{2\pi\sqrt{CL}}$ we see if the square root of the product of the capacity and inductance is decreased the frequency increases, and, if increased there will be a corresponding decrease in the frequency. In this circuit, however, nothing can be changed but the capacity, since the inductance will be practically constant. If the frequency of the circuit is made the same as the frequency of the resonance circuit, then streams of sparks will pour from the two outside parallel wires to the coil that is wound on the wood upright of the resonance circuit. The nodes and anti-nodes of the electric waves, when the capacity of the oscillating circuit is varied, travel along the coil and wires in a most beautiful manner.

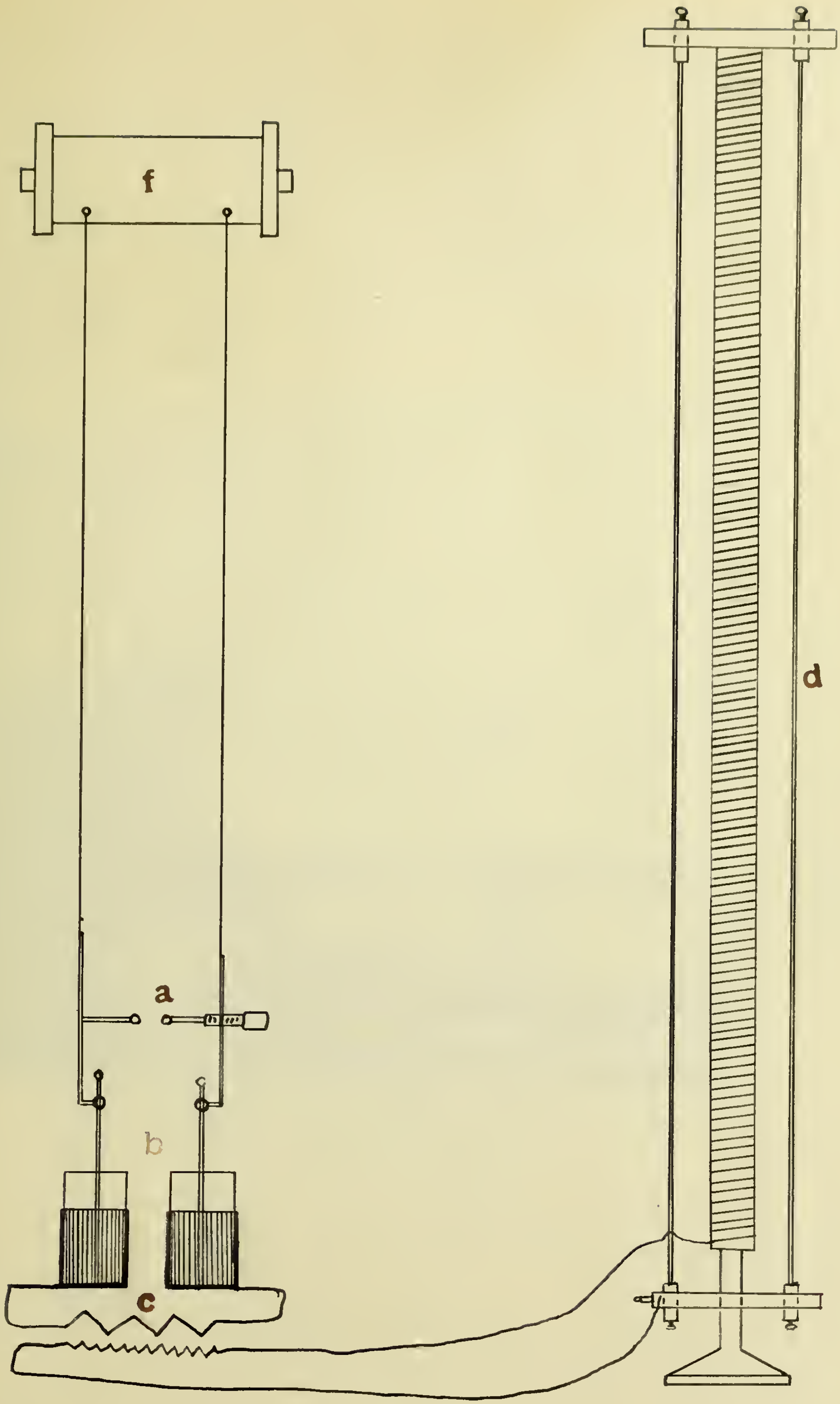
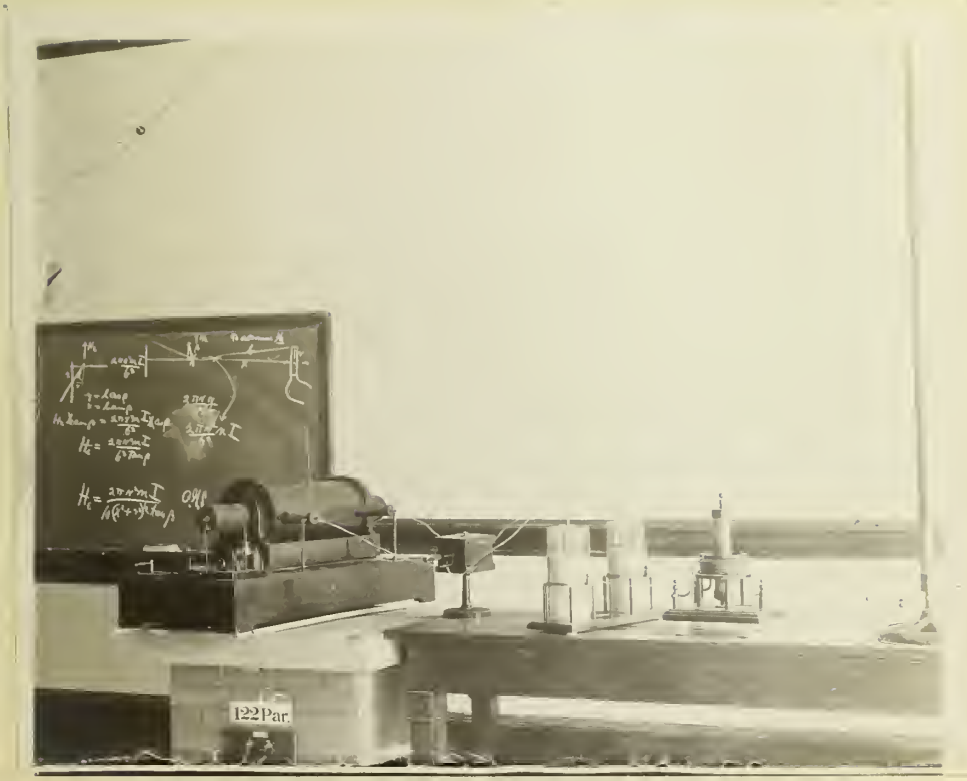


Fig. 9. Diagram showing connections of resonance apparatus.

a, spark gap, b. condensers, c. Tesla coil, d, resonance coil, f, induction coil.



Photograph showing apparatus when not in operation corresponding to Fig. **9** page **25**.

Photograph showing two nodes or one wave length

The photographs of this apparatus when not in operation and when in operation showing very distinctly the nodes and anti-nodes of the electric waves are given on page 25a, 25b.

In Fig. 10, page 27 the frequency can be changed by varying the inductance of the coil or resonator. In this arrangement both capacity, C, and inductance, L, may be varied. If the capacity is kept constant and the inductance be varied the nodes and anti-nodes will change accordingly for each corresponding change of inductance. Thus the nodes and anti-nodes will be seen to travel away from each other or toward each other with the change of inductance. That is, the length of the waves will increase or decrease according to the relation given by X=VT, where X is the wave length, V is the velocity of propagation, T is the period. But $T=2\pi\sqrt{LC}$ therefore $X=V(2\pi\sqrt{LC})$ since V is a constant determined by experiment to be approximately 2.998×10^{10} cm. per second, or 186,365 miles per second; there are then only two variables in the equation which gives their relation. Within the range of variation of capacity, C, and inductance, L many different wave lengths may be obtained and most beautifully shown. The accompanying photographs show the apparatus when not in operation and when in operation. From these some idea can be obtained of what can be done with this apparatus.

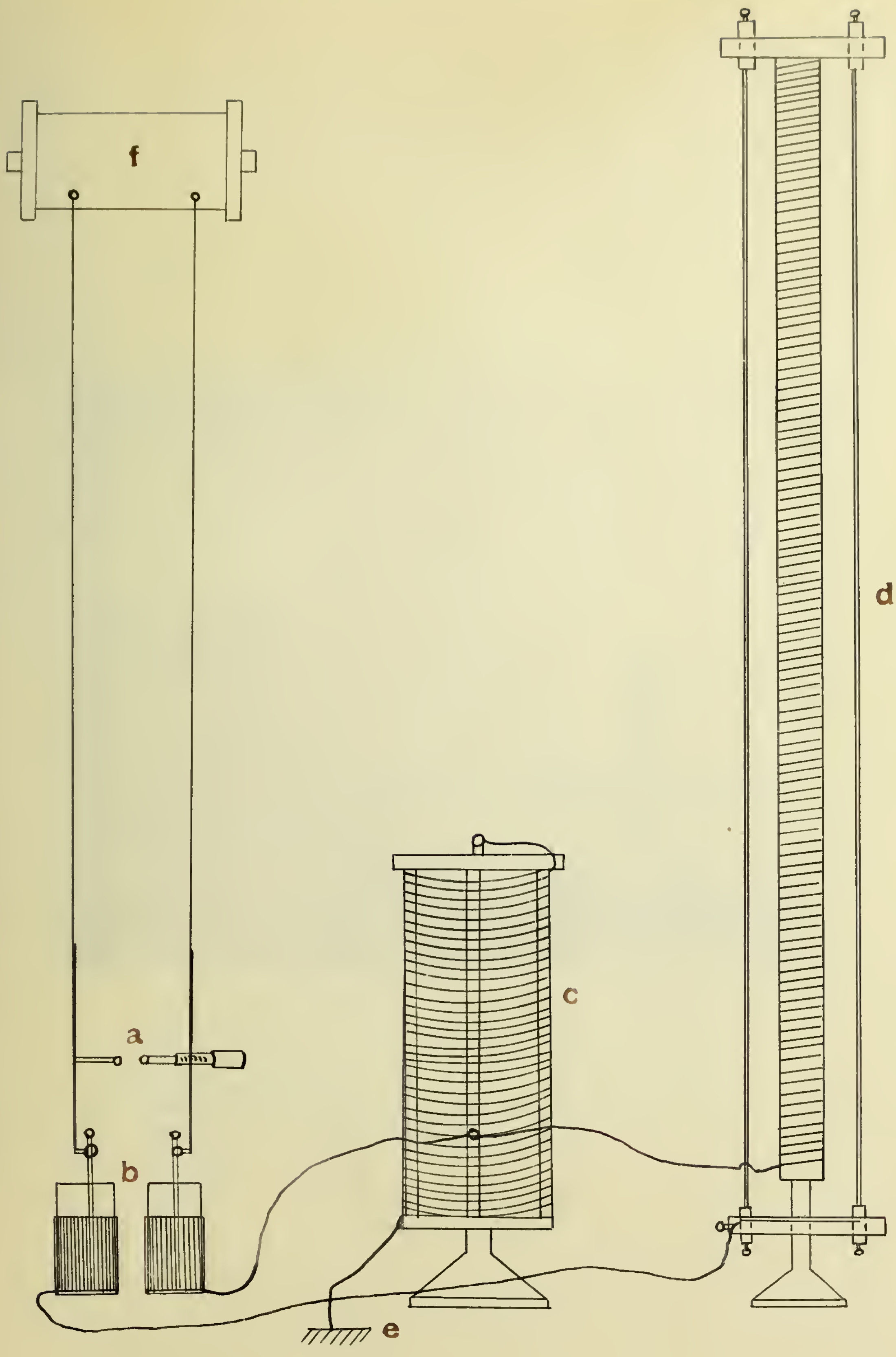
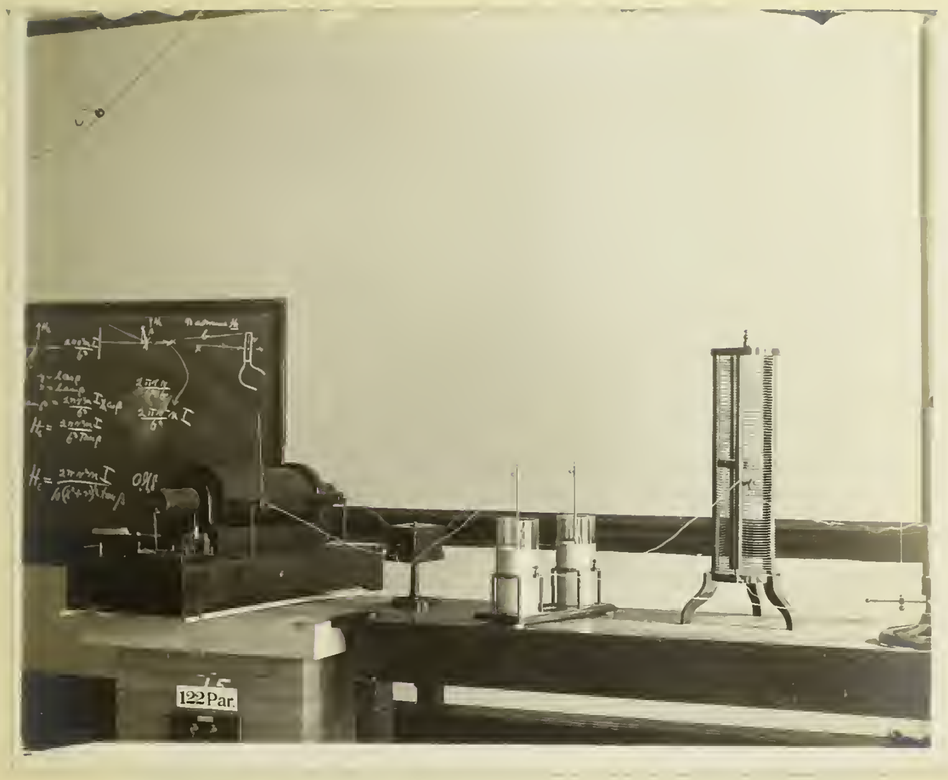
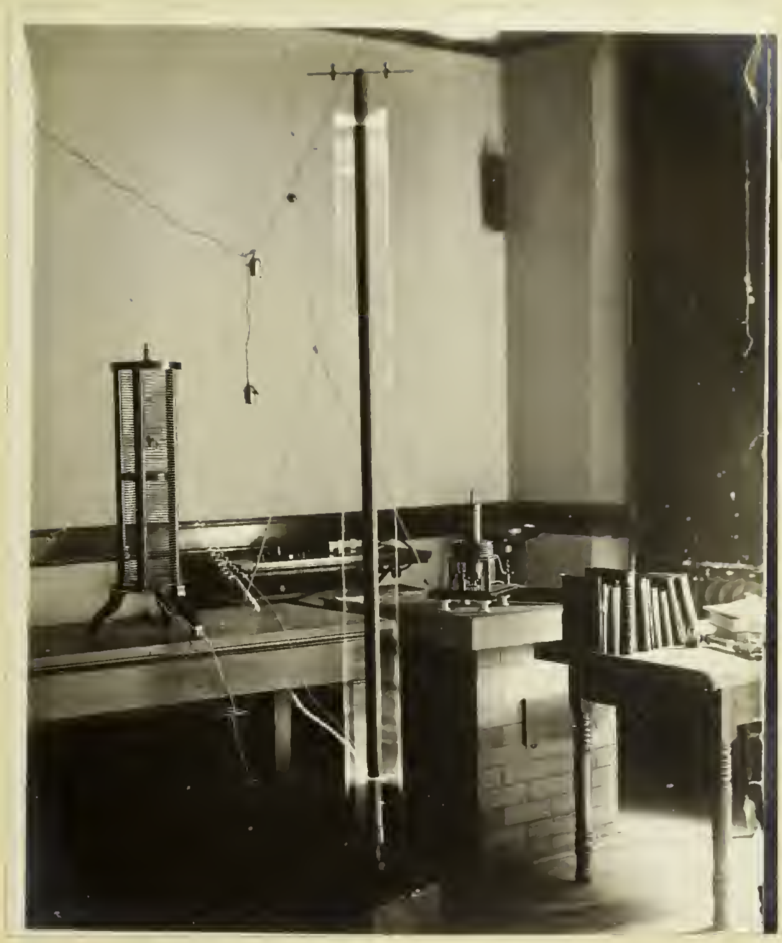


Fig. 10. Diagram showing connections for resonance apparatus, a, spark gap. b, condensers. c, inductance. d, resonance coil. c, to earth. f, induction coil.

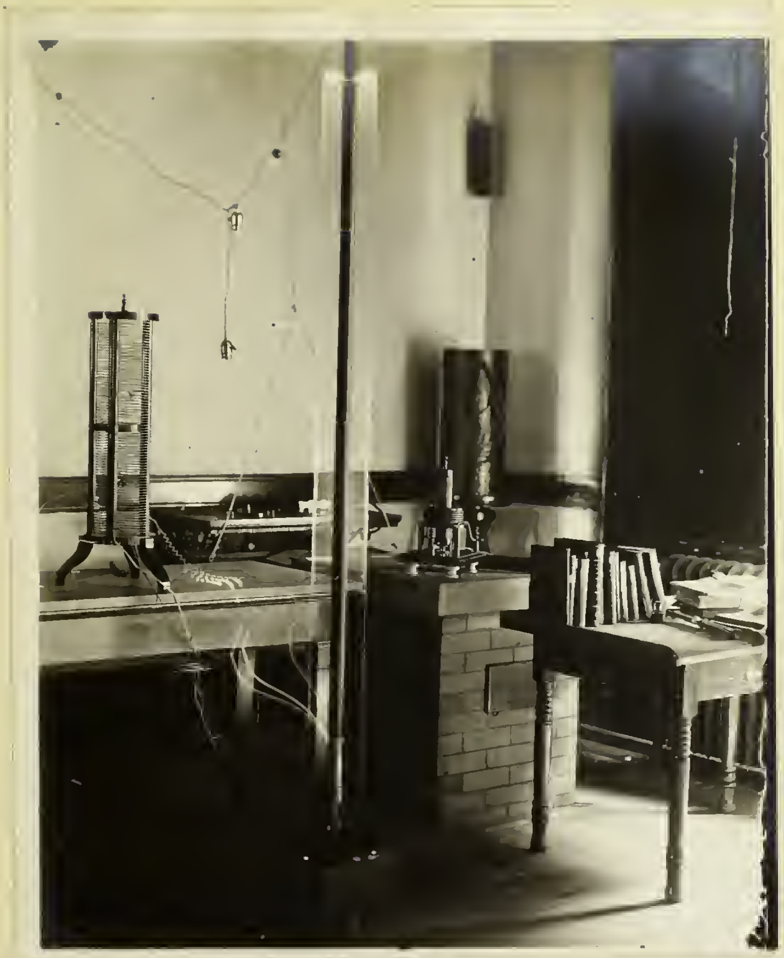


Photograph showing apparatus when not in operation corresponding to Fig. 10 page 27.

Photograph showing resonance circuit corresponding to Fig. 10 page 27.



Photograph showing one node or one half wave length.



Photograph showing one half wave length.

Photograph showing two nodes or one wave length.

Application of the Principle of Resonance to Wireless Telegraphy.

The fundamental principles of wireless telegraphy are based on resonance which was expounded to some extent in the previous pages of this thesis.

The Slaby-Arco system of wireless telegraphy is a good system to illustrate the principles of resonance; since in its transmitting station both capacity and inductance may be varied, while in the receiving circuit the inductance alone is variable. The connections of the transmitting circuit are shown in Fig. 11, page 29.

By varying the capacity and inductance of the transmitting station till it is in resonance with the receiving system, the inductance of which may also be varied, the antenna circuits are thus tuned to suit each other, or in other words brought into resonance with each other. Then as is designated below in the following pages on the receiving station the multiplier must be varied till it is of the proper length, then the coherer will respond and not till this has been adjusted. Very exact adjustment must also be made in the make and brake of the relay. The receiving station is quite a complicated arrangement as will be seen below.

Under the influence of electric waves the circuit in which lies the coherer and relay closes. The relay closes the

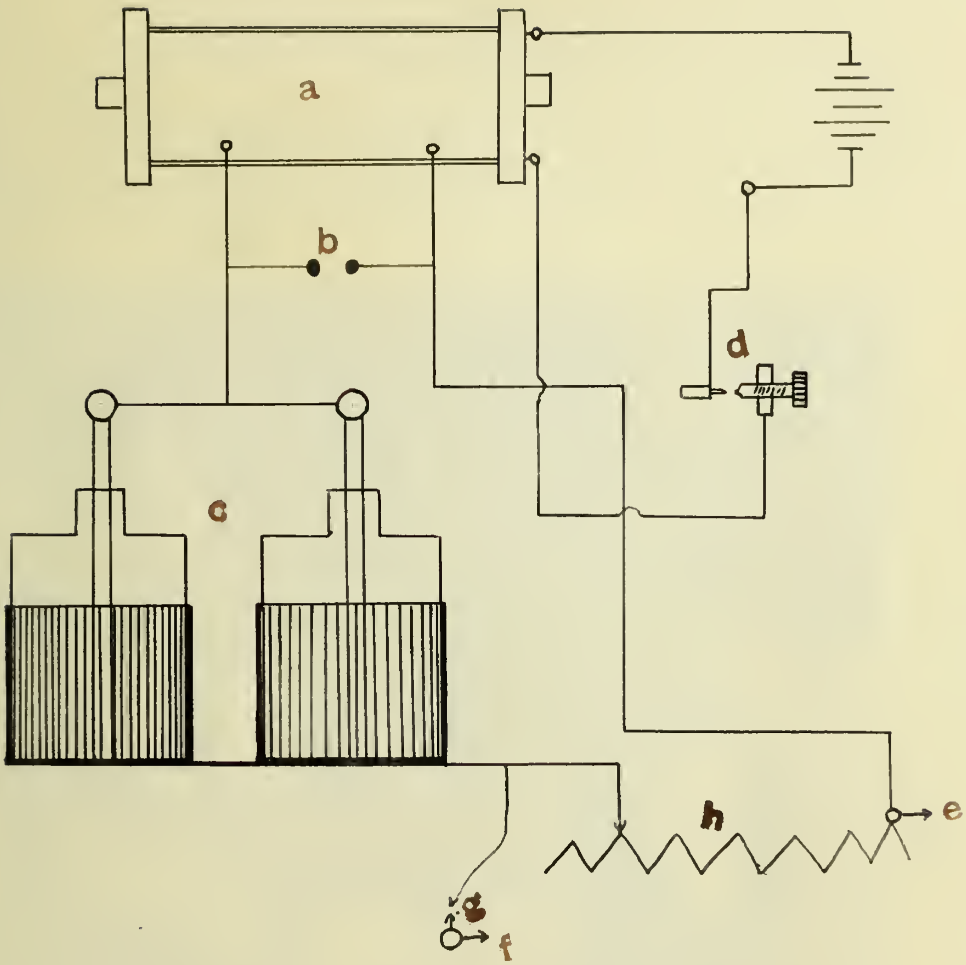
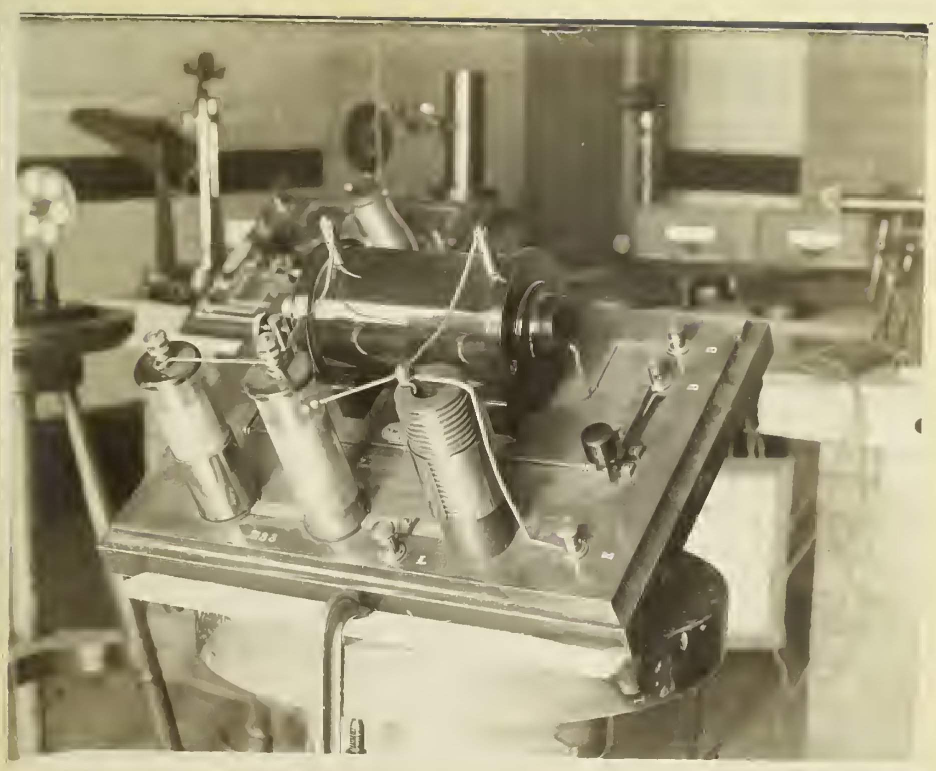


Fig. 11. Diagram showing connections of transmitting station. a, induction coil. b, spark gap. c, condensers. d, Morse Key. e, to earth. f, to antenna. g, spark gap of platinum. h, variable inductance.



Photograph showing transmitting station.

circuit of the tapper, the Morse recorder, and a local battery. There are three different circuits in the system which are given different colors so that they may be more easily traced as shown in Fig. 14, page 34.

1. The high frequency circuit (green) starts from the antenna, L, thru the upper end of the variable inductance coil to the coherer and a small condenser then to earth. Instead of to earth, as stated above, the waves may travel directly thru inductance to earth.

The inductance between antenna and coherer is called Slaby's multiplier.

The inductance in antenna and earth circuit determines its frequency, also acting as an auto-transformer in completing the two circuits; the part of coil in antenna, condenser-earth circuit is the Slaby multiplier whose function is as follows.

Open circuit detectors of the coherer type are characterized by the fact that a difference of potential between the terminals is necessary to operate them. In its normal sensitive condition no appreciable current flows thru the coherer, and it is not until the difference of potential reaches a certain critical value that the insulation breaks down and the particles cohere. It matters little whether this potential be oscillating, slowly alternating, or direct,-indeed the voltage of the local battery, if raised above a volt or so, will cause the apparatus to block and become inoperative.

This feature makes the coherer ill adapted to the ordinary connection in series, between the antenna and ground.

The base of the antenna is, as we know, a loop of the oscillation, where the current is a maximum, and the variation of potential is normally zero; hence a coherer located at this point works to very poor advantage.

Slaby used a method by which this disadvantage is overcome. If a straight wire of proper length be attached to the antenna near its foot, it will vibrate in unison with the latter, with a node at its outer end, and a coherer may be connected between this end and the ground. In order that the horizontal wire may be set in vibration, there must be some vibration of potential at its inner end, a, Fig. 12, page 32, so it is connected to the antenna at a little distance above the ground, or what is the equivalent, inserting a small self-inductance I in the ground wire. In practice there is no need of stretching the auxiliary wire out straight, for it may as well be wound into a coil of suitable length as shown in the fig. 13, page 33 where M is the multiplier. This multiplier is wound with fine wire of such a length that its own period of oscillations is the same as the antenna, and a node is produced at its outer end, where the coherer is connected, similar to that which occurs at the top of the antenna.

2. The coherer circuit, (*red*) goes from one pole of the dry cell, S, thru the relay coil, (which throws in the local batteries), to the spring of tapper back to the other pole of the dry cell, S.

3. The tapper circuit, (blue), runs from the binding post, B, on which are attached local batteries, thru the tapper coils to the base and vibrator of the relay back to the other pole

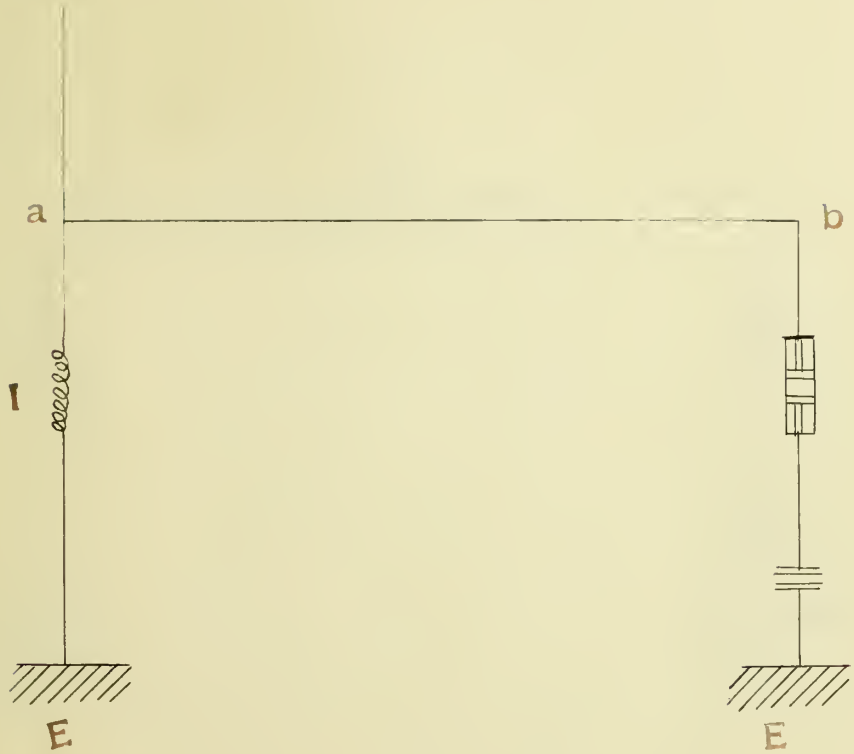


Fig. 12. Diagram showing coherer circuit.

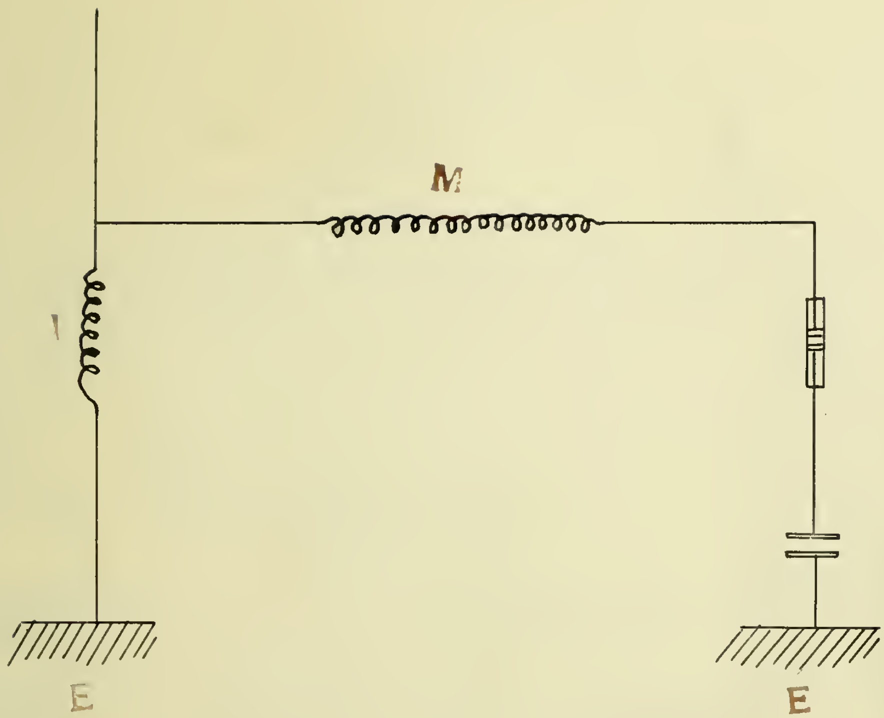


Fig. 13. Diagram showing Slaby Multiplier.

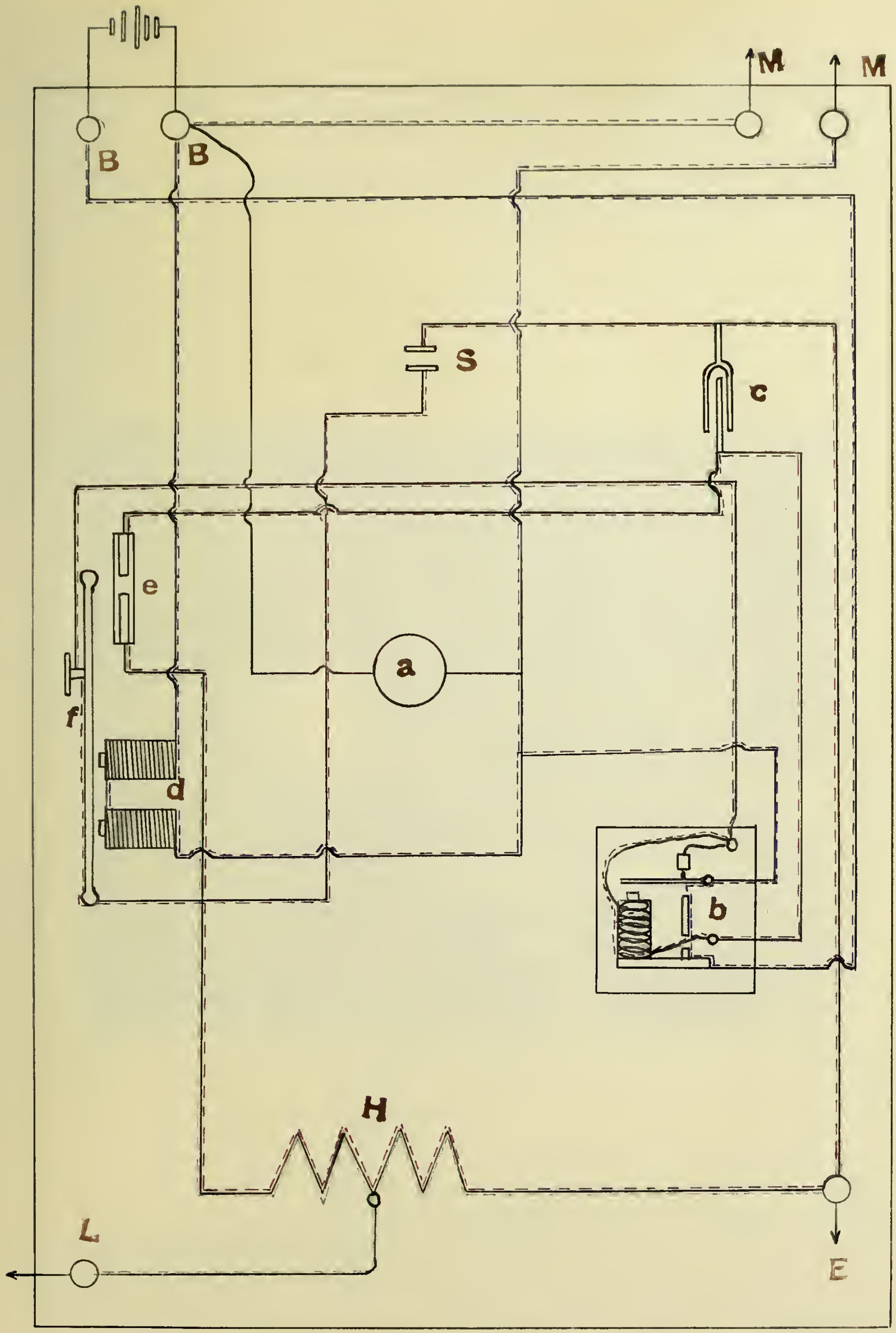


Fig. 14. Diagram of connections of receiving station, showing different circuits. Green, the high frequency circuit. Red, the coherer circuit. Blue, the tapper circuit.

Photograph showing receiving station to the right, to the left a Morse recorder.

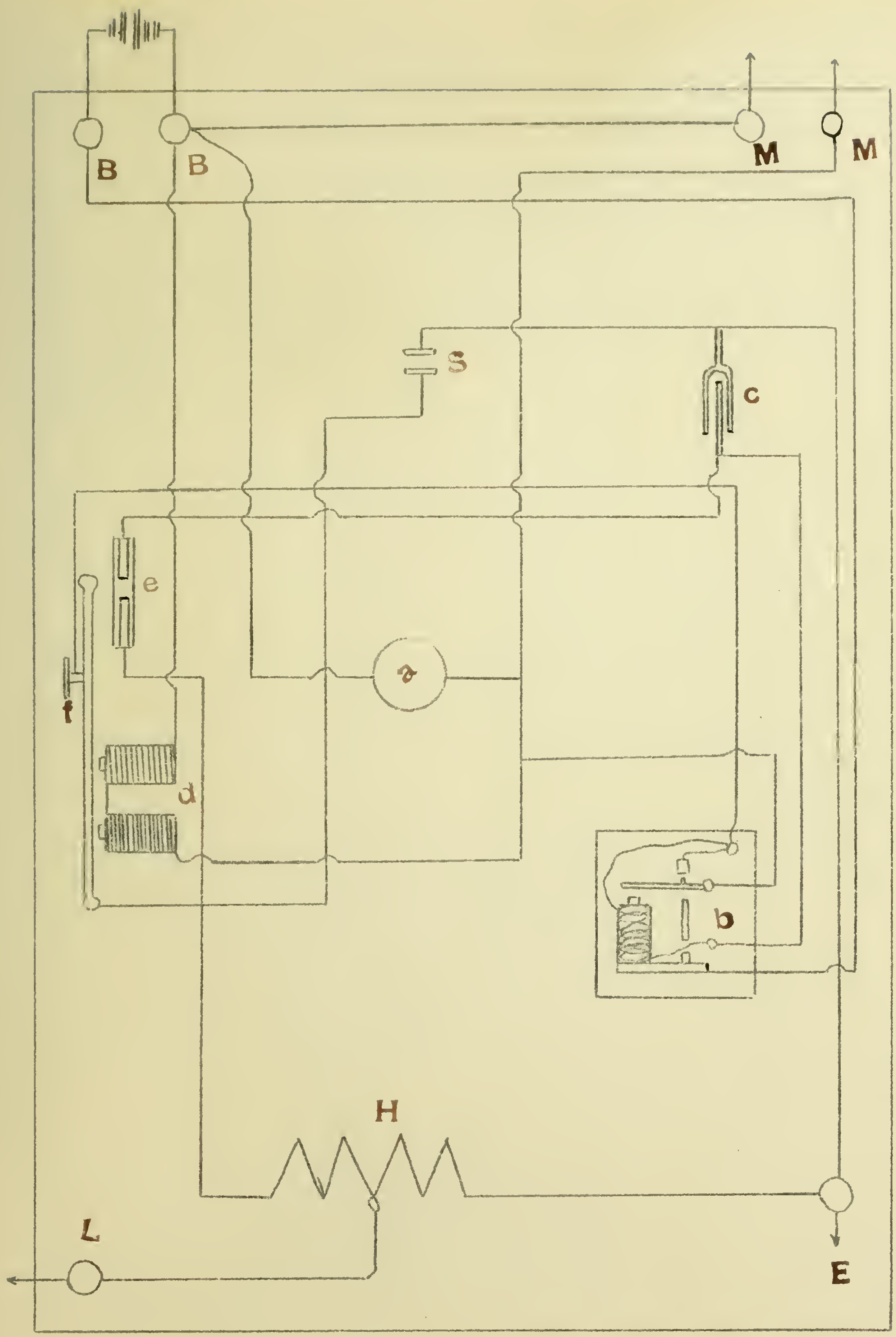


Fig. 15. Diagram showing receiving system. E, to earth. L. to antenna. M. to Mores recorder. S, dry cell. A, polarization cells b, relay. c, condenser. d, tapper coils. e, coherer. f. tapper spring.

of batteries at binding post, B. From this circuit the binding posts M.M. are connected in parallel, on which may be connected a Morse recorder. To the coils of the tapper are attached five polarization cells in parallel, which oppose the make and break spark of the relay, otherwise the resulting waves from these sparks would influence the coherer and produce false responses. The photographs on page 35 will give a fair idea of the proportions of the apparatus.

Ether Waves in General.

It is interesting to note the relation between the ether waves of different lengths. First of all the very shortest known are the Actinic, or ether waves which affect photographic plates.

Luminous, or ether waves which are known as light waves.

Infra-red or ether waves which are known as dark heat rays.

Next in wave length is a class between heat and electric waves, but as yet they have not been discovered. (?)

The longest waves are known as electric waves or ether waves sometimes called Hertz rays. The five classes are as follows:-

1. Actinic, or photographic rays.
2. Luminous, or light rays.
3. Infra-red, or dark heat rays.
4. Blank, unknown rays. (?)
5. Electric, or Hertz rays.

These five classes have definite wave lengths which may be compared in the following table.

Wave lengths	$\mu = \frac{1}{1000}$ of a millimeter
0.1 μ	Shortest ultra-violet wave.
0.2 " 0.4	Two octaves of ultra-violet waves called Actinic waves.
0.[illegible]3 μ to 0.75 μ	One octave of light waves.
0.8 μ 1.6 3.2 6.4 12.8 25.6 51.2	Seven octaves of dark-heat waves. Longest dark-heat wave measured = 67 μ.
102.4 204.8 409.6 819.2 1638.4 3276.8	Five octaves of unknown waves. Shortest electric wave measured = 4mm.
6553.6 μ 13 mm. 26 " 52 " 104 " 208 "	Twelve octaves of most frequently used electric waves. Longer waves up to 1000 feet or more are used in wireless telegraphy.

This gamut of ether waves shows most beautifully the relation between the different phenomena, actinic, light, heat, blank, and electrical. It seems rather provoking that this blank phenomenon does not reveal itself in some form that we can recognize.

Perhaps it would be interesting to speculate on a probably method of bridging over this blank in the gamut of ether vibrations.

Suppose we have a body that gives off heat radiations which have a frequency (n) per second, and that we have an ether wave detector arranged so that it is receding from the hot body, or that the hot body is receding from the detecting apparatus with a velocity, v, the velocity of the radiations being V. If the detector were at rest, it would receive, n. waves per second. If x is the wave length of the radiations, then in a space, v. there would be $\frac{v}{x}$ waves. Since the body moves thru a space, v, in one second, the detector will receive only $(n - \frac{v}{x})$ waves per second. So that $(n - \frac{v}{x})$ waves must occupy the space $V+v$. If x' is equal to the resultant wave length, $x' = \frac{V+v}{n - \frac{v}{x}} = x\frac{V+v}{nx - v}$ but $V = nx$ therefore $x' = x\frac{V+v}{V-v}$ and $v = V\frac{x'-x}{x'+x}$ . . . . (1)

But if the body and the detector are approaching each other, then the number of waves which the detector will receive is $(n + \frac{v}{x})$ per second. Then $(n + \frac{v}{x})$ waves must occupy a space $(V-v)$ in a second.

Then $x' = \frac{V-v}{n + \frac{v}{x}} = x\frac{V-v}{nx+v} = x\frac{V-v}{V+v}$

Then $$v = V\frac{x-x'}{x+x'} \qquad (2)$$

Now there are five octaves to be bridged over in the blank of the gamut. By using this principle, the Doppler principle as it is called, if we approach the blank from the heat side

the equation (1) page 40 must be used in order to calculate the velocity, v, with which it is necessary for the body or detector to be moved. The first three wave lengths of the blank may be obtained in this manner, while the remaining three may be developed by moving the detector with a velocity, v, toward an electrical oscillator which is giving the shortest electrical waves, then equation (2) page 40 must be used to calculate the velocity, v. The following tables will give the results of the calculations.

By means of the heat waves using equation $v = V\left(\frac{x' - x}{x' + x}\right)$ where x=67μ longest heat wave.

X'	v	v in miles per second.
102.4 μ	o.326 V	60,799.00
204.8 "	0.507 V	94,555.50
409.6	o.719 V	134,093.50

By means of the shortest electrical waves using $v = V\left(\frac{x - x'}{x + x'}\right)$ where x=4000 μ shortest electric wave.

X'	v	v in miles per second.
409.6 u	0.819 V	152,743.50
819.2	0.660 V	123,090.00
1638.4	0.418 V	77,957.00
3276.8	0.099 V	18,519.45

By means of the longest heat waves the shortest electric waves may be produced; then v is calculated from $v = V\left(\frac{x' - x}{x' + x}\right)$ where X=4000 μ, X=67 μ then v=.967 V.

By means of the shortest electric waves the longest heat waves may be produced; then v is calculated from $v = V\left(\frac{x - x'}{x + x'}\right)$ where X'=67 μ, X=4000 μ.

then v=.967 V.

These results show the impracticability of performing such an experiment in order to verify the calculations.

The smallest value of v would be 18,519.45 miles per second, an enormous velocity which is inconceivable in connection with any mechanical device. This would be approximately 100,000,000 feet per second while the fast express train makes about 90 feet per second.

Nevertheless the fact that we are unable to produce these ether waves by this means should inspire a more careful search of Nature and see if she does not produce them. The necessary conditions under which heat waves may be transformed in electric waves or vice versa surely exists in Nature; and our searching for the unknown intermediate waves is not without hope.