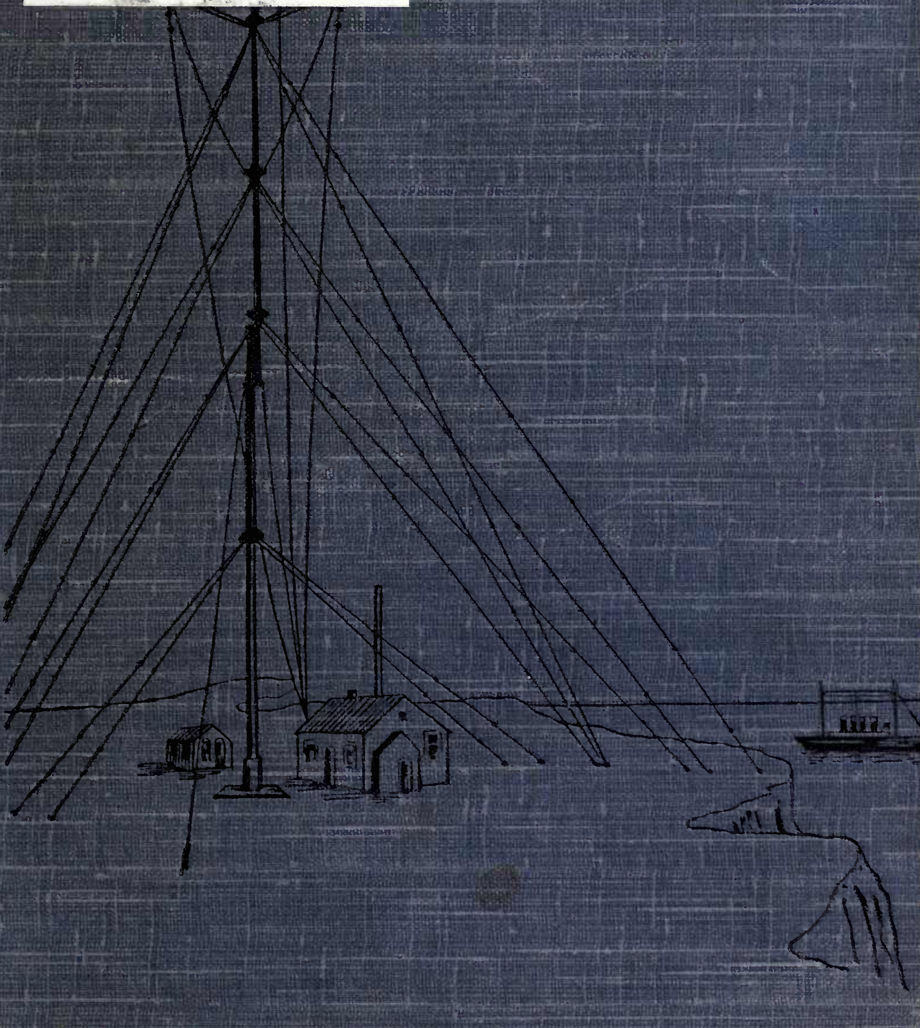
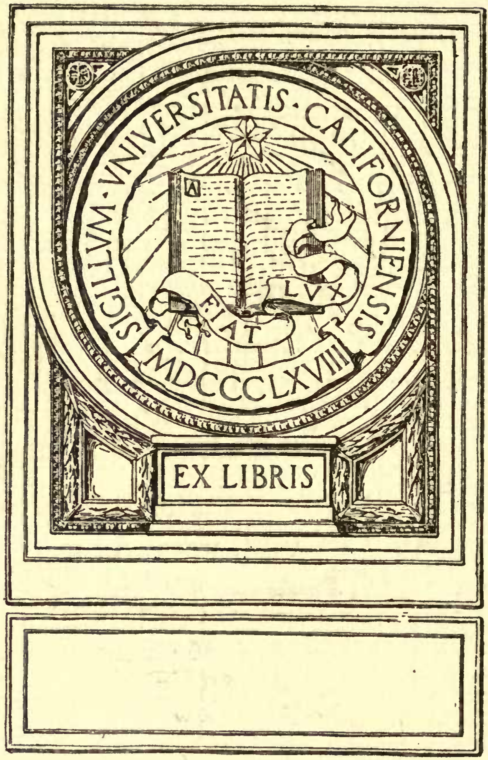
THE WONDERS OF WIRELESS TELEGRAPHY

J. A. FLEMING
D.Sc., F.R.S.





THE WONDERS OF
WIRELESS TELEGRAPHY

Works on Wireless Telegraphy and Allied Subjects

BY

DR. J. A. FLEMING, M.A., F.R.S.

ALL FULLY ILLUSTRATED

THE PRINCIPLES OF ELECTRIC WAVE TELEGRAPHY AND TELEPHONY. 2nd Edition. *28s.*

AN ELEMENTARY MANUAL OF RADIOTELEGRAPHY AND RADIOTELEPHONY. 2nd Edition. *7s. 6d.*

PUBLISHED BY

MESSRS. LONGMANS, GREEN, AND CO.

39, PATERNOSTER ROW, LONDON, E.C.

HERTZIAN WAVE TELEGRAPHY. A Course of Cantor Lectures delivered before the Royal Society of Arts. *3s. 6d.*

THE ELECTRONIC THEORY OF ELECTRICITY. A Lecture delivered before the Royal Institution of Great Britain. *1s. 6d.*

PUBLISHED BY

THE ELECTRICIAN PUBLISHING COMPANY, LTD.

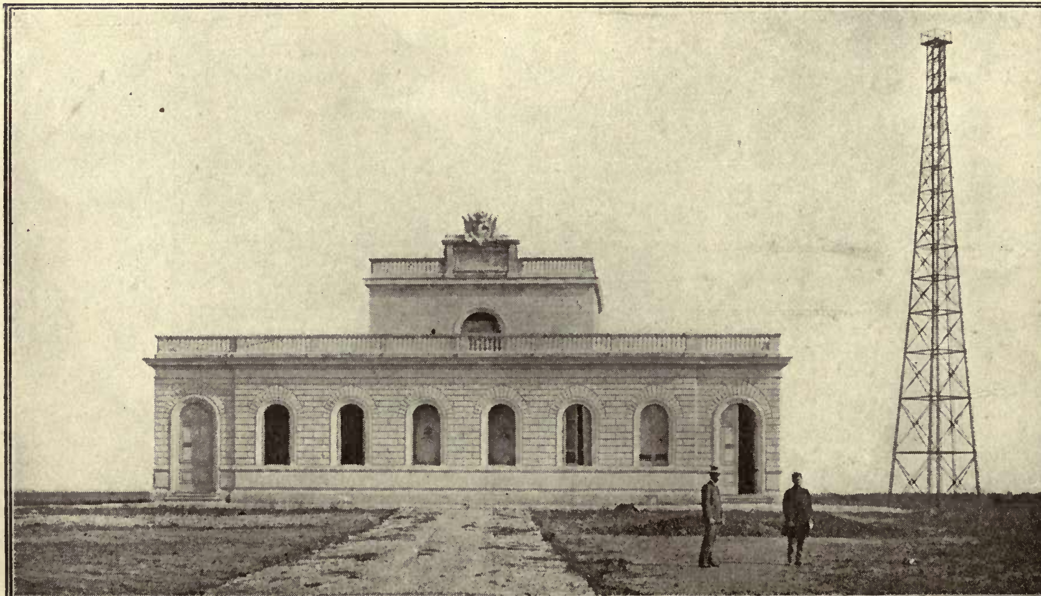
1, SALISBURY COURT, LONDON, E.C.

WAVES AND RIPPLES IN WATER, AIR, AND ÆTHER. A Course of Christmas Lectures delivered at the Royal Institution of Great Britain. 2nd Edition. *2s. 6d. net.*

PUBLISHED BY

THE SOCIETY FOR PROMOTING CHRISTIAN KNOWLEDGE

NORTHUMBERLAND AVENUE, LONDON, W.C.



By permission of Marconi's Wireless Telegraph Co., Ltd.

Elevation of the Marconi Wireless Telegraph Station at Coltano, near Pisa, Italy, showing also on the right one of the lattice Towers for supporting the Antenna wires.

THE WONDERS OF WIRELESS TELEGRAPHY

EXPLAINED IN SIMPLE TERMS
FOR THE NON-TECHNICAL READER

BY

J. A. FLEMING, M.A., D.Sc., F.R.S.,
ETC.

UNIVERSITY PROFESSOR OF ELECTRICAL ENGINEERING IN THE UNIVERSITY OF LONDON
MEMBER AND PAST VICE-PRESIDENT OF THE INSTITUTION OF ELECTRICAL ENGINEERS
FELLOW AND PAST VICE-PRESIDENT OF THE PHYSICAL SOCIETY OF LONDON
MEMBER OF THE ROYAL INSTITUTION OF GREAT BRITAIN, ETC., ETC.
AUTHOR OF "THE PRINCIPLES OF ELECTRIC WAVE TELEGRAPHY AND TELEPHONY"
"AN ELEMENTARY MANUAL OF RADIOTELEGRAPHY AND TELEPHONY"
"HERTZIAN WAVE TELEGRAPHY" "WAVES AND RIPPLES IN WATER,
AIR, AND ÆTHER," ETC., ETC.

WITH NUMEROUS DIAGRAMS

SECOND EDITION, REVISED

SOCIETY FOR PROMOTING CHRISTIAN KNOWLEDGE
LONDON: NORTHUMBERLAND AVENUE, W.C.
43, QUEEN VICTORIA STREET, E.C.
BRIGHTON: 129, NORTH STREET
NEW YORK: E. S. GORHAM
1914

Date of First Edition, October, 1913.

PREFACE.

The Preface of a book is the place in which the Author makes his excuses for writing it, or his explanations of its scope and purpose. Following this practice, it may be mentioned that the writer published in 1902 a little book entitled "Waves and Ripples in Water, Air, and Æther," through *The Society for Promoting Christian Knowledge*, which was a reprint, with some amplifications, of a Course of Christmas Lectures given at the Royal Institution, London. The last chapter of that book contains a brief reference to the then young art of radio-telegraphy. In the years that have since elapsed, this branch of telegraphy has developed with wonderful rapidity into a unique and most valuable means of communication. The importance of it is shown by the fact that three International Conventions and two Parliamentary Committees have deliberated at length on its regulation and condition within the short space of ten years. A large and highly technical literature has grown up around it, and an industry of considerable dimensions been created by it. Its astonishing achievements have raised a desire in the minds of the general public to know something of its mode of operation and possible future development, but in a form divested as far as possible of unexplained technicalities or abstruse formulæ. Many of the popular books written with this object seem to the writer to give insufficient explanations of the physical processes involved. When, therefore, the Author was asked to consider whether the final chapter of the book above mentioned should not be amplified to bring up the information on wireless telegraphy more to date, it seemed to him preferable to write a companion volume, which starting from the information on "Waves and Ripples" contained in the previous book should deal especially with the subject of modern wireless telegraphy. The present work is therefore not intended for technical students or practical wireless telegraphists, whose needs are sufficiently provided for in other books, but is put forward (with diffidence) as a little attempt to furnish the general reader with a fairly non-technical account of the underlying principles and practical achievements of wireless telegraphy, and of the wonders which it has rendered possible in the transmission of intelligence.

The reader who wishes to obtain more highly technical information on this fascinating subject has the choice of many books. The Author's two treatises, viz. "An Elementary Manual of Radiotelegraphy and Radiotelephony" and "The Principles of Electric Wave Telegraphy and Telephony" will provide this assistance for those possessed of some physical and mathematical knowledge.

In conclusion the Author desires to express his thanks to Marconi's Wireless Telegraph Company, and also to Mr. Duddell for their kindness in permitting the use of illustrations belonging to them.

The favourable reception given to this little book and consequent rapid exhaustion of the First Edition has enabled the Author to remove in this Second Edition a few little oversights in correcting the proofs of the First, and also to add to the final chapter one or two paragraphs bringing the general information on the subject up to date.

J. A. F.

UNIVERSITY COLLEGE,
LONDON, *March*, 1914.

CONTENTS.

CHAPTER I.

THE ÆTHER, ELECTRICITY AND ELECTRONS.

PAGE

The velocity of light, measured by the eclipses of Jupiter's satellites, by the aberration of stars, and experimentally—Corpuscular and wave theories of light—Interference of light demonstrating its wave propagation—The essential properties of a medium required for wave propagation—The æther and the electromagnetic medium—Chief electrical and magnetic phenomena compared — Relation of electricity, magnetism, and motion—Lines of electric and magnetic force—Maxwell's theory—Motion of an electric charge—Vibrations on lines of electric force—An electron—The effect of sudden stoppage on a moving electric charge—Röntgen rays—Possible æther structure—Structure of the atom—Radioactive atoms—Electrons, atoms, and theories of the æther 1

CHAPTER II.

ELECTRIC OSCILLATIONS AND ELECTRIC WAVES.

The discoveries of Volta, Ampère, and Faraday—The electric current as a movement of electrons—The invention of the Leyden jar—Discharge of the jar—An oscillatory discharge—Mechanical illustrations—Researches of Joseph Henry and Lord Kelvin—The oscillograph—Strongly damped and feebly damped oscillations—Definitions of electrical units—Frequency of an oscillation — Hertz's experiments — Hertz's oscillator and detector—His method for the production of Maxwell's electric waves — Interference of electric waves — Properties and nature of electric waves and the identity of electromagnetic waves and light waves 46

CHAPTER III.

WIRELESS TELEGRAPH TRANSMITTERS, AND THE SENDING OF WIRELESS MESSAGES.

PAGE

The telegraphic alphabet and signals—Telegraphy with wires and without—General structure of wireless telegraph transmitters —The antenna—Various types of antenna, umbrella, T-shaped, directive — The spark method of creating oscillations — Quenched sparks—Marconi high-speed disc dischargers—Ship transmitters—Mode of sending the signals—Poulsen arc transmitter—Explanation of the Duddell or musical arc—Persistent oscillations created by the arc—Resonance of circuits—High-frequency alternators—Alternators of Alexanderson and Goldschmidt—Multiplication of frequency by the polyphase or rotating field alternator—Difficulties of constructing such machines—Galletti method of creating rapid spark oscillations —Mr. Marconi's methods for the production of powerful feebly damped or continuous oscillations for long-distance work—Comparison of various oscillation producers—Requisite qualities in such appliances and relation of various forms to one another 83

CHAPTER IV.

WIRELESS TELEGRAPH RECEIVERS AND THE RECEPTION OF WIRELESS MESSAGES.

The receiving antenna—How it picks up wireless waves—The receiving circuit—Methods of reception, by ear and eye—Detectors for electric oscillations—Crystal detectors—Electric valve detector—Fleming oscillation valve or glow-lamp detector—Marconi magnetic detector—The frog's leg receiver —The coherer and Morse inker—The recording of messages photographically by the Einthoven galvanometer—Simultaneous reception of two or more messages—Marconi duplex transmission, sending and receiving simultaneously—Regulations as to wave-lengths—Wave-length measurement—The cymometer—Measurement of damping—Comparison of damped and undamped transmitters—Spark frequency—Efficiency of wireless telegraph apparatus—Various forms of tuner—Marconi's directive antenna—Bellini and Tosi apparatus for directive radiotelegraphy 139

CHAPTER V.

WIRELESS TELEGRAPHY OVER LAND AND SEA, AND THE TRANSMISSION OF WIRELESS WAVES ROUND THE WORLD.

PAGE

The propagation of wireless messages over land and sea—Reasons for the greater difficulty of transmission over land—Absorption of wave energy by the soil—Experiments in the United States —Advantage in using long wave-lengths—Law of decrease of wave amplitude with distance—Atmospheric absorption—Marconi's discovery of the influence of daylight on wireless transmission—Atmospheric electric discharges and stray waves —Variation of signal strength at different hours of day and night—The influence of earth curvature—How wireless waves travel round the earth—Not entirely due to diffraction—Sommerfeld's theory of surface waves—Surface and space waves—Ionisation of the air by ultra violet light—Its effect on the velocity of electric waves—Theory of ionic refraction —Theories of long-distance wireless telegraphy—How is it to be explained?—Its difficulties and problems 184

CHAPTER VI.

WIRELESS TELEGRAPHY AND TELEPHONY IN PRACTICE, AND THE UTILISATION OF ELECTROMAGNETIC WAVES.

Sketch of the history of electric wave telegraphy—Hughes' experiments—Invention of the coherer by Branly and Lodge—Marconi's early work in Italy and England—English Channel demonstrations, 1899—Marconi's improvements in 1900—Attempts at transatlantic wireless telegraphy—First station at Poldhu established—First signals sent across—Marconi Company's ship and coast stations—Services in case of shipwreck—Loss of the *S.S. Titanic*—New large power stations in Ireland and Nova Scotia—Marconi's inventions in connection with long-distance wireless telegraphy—The Clifden, Glace Bay, and Coltano stations—Success of his commercial transmission —The testimony of the Post Office Technical Committee—The Eiffel Tower station—Distribution of Time and Weather signals from various stations—The Telefunken station at Nauen, and other long-distance stations—Wireless telephony —Its principles and achievements—The future of wireless telegraphy and telephony—Conclusion 218

THE WONDERS OF WIRELESS TELEGRAPHY.

CHAPTER I.

THE ÆTHER, ELECTRICITY AND ELECTRONS.

IN the last quarter of a century (1888–1913) three great discoveries have strongly attracted popular attention, not only by their remarkable scientific interest, but perhaps more in consequence of the important practical applications which have followed.

One of these was the discovery of the X-rays by Röntgen; another that of the radio-active substances, particularly radium by M. and Mme. Curie; and the third the practical production of Maxwell's electric waves by Hertz and their utilisation by Marconi and others for radio or wireless telegraphy.

The first has proved to be of enormous value in surgery and medicine, giving to the physician as it were a new eye with which to look into the tissues of the living body. The second promises to become a remedial agent of the utmost utility in the treatment of certain diseases; and the third has enabled us to fling our messages across storm-tossed oceans without the aid of inter-connecting wires and provided ships with a far-reaching voice with which to call for help in the hour of need.

Owing to the new scientific problems it presents, no less than to the astonishing feats it has rendered possible, the study of radiotelegraphy has attracted the attention of the most eminent scientific investigators and there is no lack of highly technical literature bearing upon the subject.

The general public, however, are unable to follow advanced discussions and expositions, but ask for explanations in simple terms of these remarkable achievements.

It is not altogether an easy matter to satisfy this laudable curiosity, for it compels the inquirer to enter a region of thought far removed from the concepts of everyday life, and it also requires some little skill on the part of the expositor to avoid making long and strange words do duty for clear ideas in the mind of the reader.

Nevertheless the progress of scientific knowledge is to a considerable extent assisted by the intelligent sympathy of non-scientific persons, and it is therefore a work of utility to attempt to remove the difficulties which hinder the ordinary reader from understanding the principles of new discoveries or inventions.

An effort will therefore be made in this little book to convey in simple language a comprehension of the processes and appliances by which wireless telegraphy is conducted at the present time, and an indication will be given of its probable future development.

In the first place it is necessary to give a little information about modern views on electricity, atoms, electrons, and above all concerning the facts which support the assumption that space is filled with a medium called the Æther, not directly appreciable by our sense of touch, but through and by which all luminous and electrical effects are transmitted from place to place, and in addition may perhaps be the primordial basis of all that we call material substance.

Nearly 240 years ago, in 1676, Olaus Roemer (1644–1710), a Danish astronomer, read a paper before the Academy of Sciences in Paris in which he announced his conclusions drawn from observations on Jupiter's satellites, that light takes time to travel through space and is not transmitted instantaneously. The giant planet Jupiter revolves round the sun in a period of nearly 11 years and 315 days. In this stately march he is accompanied by a little Court of eight satellites or moons four of which were discovered by Galileo on January 7th, 1610, a year after he had constructed his first telescope, and four have been observed since. These four larger moons revolve round Jupiter in periods varying from two to twenty days, and in their revolution they pass through the shadow of the planet and disappear for a short time from view. The eclipses of Jupiter's major satellites can be observed with a telescope of very moderate size and are an endless source of interest to astronomical amateurs. The periodic time of revolution of the satellites being known and also certain irregularities due to the interaction of the moons, it is possible to predict a long time ahead the times when these eclipses will take place. In the course of its orbit round the sun Jupiter is sometimes in line with the earth and the sun, and on the same side of the sun as the earth. He is then said to be in opposition. When, however, the earth is on the opposite side of its orbit so that the sun stands as it were between Jupiter and the Earth, Jupiter is said to be in conjunction. When at exact conjunction he cannot, of course, be seen, as he is obliterated by the sun, but when not far from conjunction he is seen just after sunset or before sunrise as a brilliant evening or morning star.

Roemer noticed that when Jupiter is in opposition the eclipses of his satellites occur earlier than when he is in conjunction if reckoned from observations made when he is in a mean position.

The difference between the predicted time of eclipse of a given satellite when Jupiter is in opposition and when he is very near conjunction is about 1000 seconds, or roughly 15 minutes. It is easy to see that the difference between the distances of the earth from Jupiter in the two cases is approximately equal to the diameter of the Earth's orbit or, say, to 186 million miles roughly. Roemer correctly surmised that this difference between the observed and the calculated times of the eclipses must be due to the time taken by light to pass across the earth's orbit, and hence that light must travel with a speed of nearly 186,000 miles per second. This suggestion, like many other new ideas, was ridiculed at the time, and it was not until about 50 years later, when in 1728 Dr. James Bradley in England observed an astronomical effect called aberration, that Roemer's conclusions were accepted.

Bradley found that in the course of a year each so-called fixed star in the heavens appears to describe a small orbit in the sky. Those stars which lie on the ecliptic, that is, on the line in which the plane of the earth's orbit appears to cut the star sphere, are displaced parallel to the direction in which the earth is then moving by about 20·4 seconds in angular measurement. This is equal to about $\frac{1}{90}$th part of the apparent diameter of the sun and moon. Those stars situated near the pole of the ecliptic appear to move round in a small circle and those in regions intermediate in an oval curve called an ellipse.

This curious effect can be explained by the assumption that the velocity of light is not indefinitely large compared with that of the earth in its orbit. Imagine an astronomer looking at a star lying in the plane of the earth's orbit and in a direction exactly at right angles to the direction in which the earth is then moving in its orbit. The orbital velocity of the earth is about 18 or 19 miles a second. The star would then appear to the astronomer to be in advance of its true position. That is to say, he would have to point his telescope a little in front of the straight line joining the earth to the star in order to see it in the field of the telescope. The illustration usually given of this effect is as follows. If drops of rain are falling vertically downwards and we hold a tube open at both ends perfectly upright, a drop of rain entering at the centre of the top of the tube will fall out at the centre of the bottom. If, however, the tube is moving quickly in a horizontal direction, carried swiftly along, say, in a motor car, whilst still held nearly upright, then a rain drop entering at the centre of the top will not come out at the centre of the bottom unless the tube is held so that the top end slopes forward or is in advance of the bottom end. Substitute for the rain drops a ray of light, and for the tube a telescope and the earth for the motor car, and the same thing holds good. It should be remarked, however, that this analogy is not to be accepted as an explanation, but only as an illustration of the nature of the effect. The angle at which the telescope would have to rake or point forward to see the above-mentioned star is a very small one, only about $20{\cdot}4''$, or, as an engineer would say, a slope of about 1 in 10,000. This, however, clearly indicates that the speed of light is about 10,000 times greater than that of the earth in its orbit or somewhere near 186,000 miles per second. Hence the inference which can be drawn from the astronomical fact of aberration leads us to the same result as that which can be drawn from the accelerations or delays in the eclipses of Jupiter's satellites, viz., that light moves with a speed of nearly 186,000 miles a second through stellar space. But we can confirm this prodigious speed in another way by experiments made on the surface of the earth. Two such methods have been devised, both due to French physicists.

The first was suggested and tried by A. H. L. Fizeau, and the other by J. B. F. Foucault in 1862. As the latter method is the more accurate of the two we shall briefly describe it.

A ray of light emerging from a slit illuminated by the sun is allowed to fall upon the side of a cubical highly polished block of steel, which can be set in rapid rotation round a vertical axis. The ray is then reflected from this mirror to a second fixed mirror placed at a distance, and from this is reflected back again along its original path. A second time it strikes the revolving mirror and is reflected into a telescope. If, then, an observer looks through the telescope he sees four times, at certain positions in every revolution of the cubical mirror, an image of the slit. If the mirror revolves more than two or three times a second these intermittent images of the slit run together into a steady image of the slit. Supposing, however, the mirror is made to revolve several hundred times a second, then the ray of light returning on its own path finds the cubical mirror turned through a very small angle between the first and second reflections on it.

The image of the slit is therefore displaced by revolving the cubical mirror very quickly either in one direction or in the opposite direction, and by measuring the deflection of the image of the slit in each case and also the speed of the mirror it is possible to make a calculation of the time taken by the light to travel twice over the interval of space between the revolving and the fixed mirror. The most complete experiments with such an apparatus were made in the United States in 1885 by A. A. Michelson and by Simon Newcomb in 1883 and by Perrotin in France in 1902.

These observers agreed closely in determining the velocity of light in vacuo as 299,860 kilometres per second, or 186,326 miles per second. We see, therefore, that two quite independent astronomical observations and a totally different experimental method all combine to yield nearly the same value for the speed of light through empty space, and it is highly probable that the best experimental determination of its speed, viz., 186,326 miles per second does not differ by more than 20 miles from the true absolute value.

This velocity is such that a ray of light travels in about eight minutes from the sun to the earth. Astronomers are in the habit of expressing the inconceivably vast distances which separate us from the colossal masses of incandescent gases we call stars in *light-years,* that is, in multiples of the distance a ray of light would travel in a year. It is easy to show that a light-year is nearly equal to 6 million million miles, a number so great that its statement conveys little or no meaning to the mind. To travel this distance by an express train without stopping day or night would take more than 11 million years. Our nearest stellar neighbour is a star called Alpha Centauri, and its distance from us is 4 light-years. The brightest star in the heavens, viz., Sirius, is distant about

8 or 9 light years, the Pole-star 44 light-years, and the five middle stars of the constellation of the Great Bear or Plough are not less than 180 light-years.

In 1901 a star suddenly blazed out in the Constellation of Perseus and then soon faded away again. Observations of various kinds indicated that this star was at a distance of nearly 300 light-years, and the conflagration or eruption which caused this sudden outburst must therefore have taken place in the reign of James I. All the intervening years, however, the news had been travelling through space towards us and the intimation of its happening reached us not until about three centuries after its actual occurrence.

When we contemplate these appalling depths of space and the speed of this nimble-footed agent which brings us news of various ages from all portions of the visible universe we are at once led to ask the questions: What is the physical nature of the agent producing the sensation we call Light? Why does it take time to travel, and what explanation can be given of its mode of propagation? Sir Isaac Newton (1642–1727) asked himself these questions more than two hundred years ago in the course of his classical investigations in optics.

When any effect takes time to travel from one place to another it can only be one of two things. It must either be an article or object which travels bodily from one place to the other, like a letter by post, or a bullet from a gun, or else it must be a state in a medium which is handed on from place to place. Thus the written letter which you send to Australia arrives there, say, after one month and is identically the same article which left the hand of the writer. On the other hand, the spoken word, in its physical aspects, is merely a commotion in the air produced by the speaker's vocal organs. The word heard by a listener at a distance is due to a similar kind of disturbance made in the air near his ear. But that which travels from speaker to listener is not an object or article which preserves its identity during the journey but only a motion or state which is handed on successively from point to point in a medium (the air) otherwise at rest.

Newton supposed that light was due to the emission from luminous bodies of extremely small particles he called corpuscles which were shot out with immense velocity and had the power of passing through bodies we call transparent but not through those we call opaque. He supported this assumption by ingenious reasons, but it was found in many respects to be not in accord with facts. His contemporary, Christian Huyghens (1629–1695), and also a notable English philosopher, Dr. Thomas Young (1773–1829), gave scientific form to the idea that light is not a *thing* but a regularly repeated physical change of some kind in a universally diffused medium.

This change was first assumed to be a motion such that each particle of the medium lying on a straight line executed successively a to and fro motion, all particles in turn doing the same thing.

At certain equidistant intervals particles are moving in a similar manner at the same time. This interval is called a *wave length.* The reader who is not familiar with the ideas implied by the term *wave motion* and closely connected term *wave length* may be referred to the author's little book on "Waves and Ripples in Water, Air, and Æther," for full explanations.* Space will not permit us to repeat these here in detail.

* Published by the Society for Promoting Christian Knowledge, Northumberland Avenue, Charing Cross, London.

It is often possible to decide between two contending scientific hypotheses by a test called a crucial experiment. In the case of the above rival theories as to the nature of light such experiments were suggested by Grimaldi, Young, Fresnel, and by Foucault, which told heavily in favour of the undulatory or wave theory of light, and were equally decisive against the corpuscular or material theory.

Grimaldi's experiment as modified by Young was as follows. If sunlight is admitted to a dark room through two small holes placed very near together, and if at a distance a white screen is held so that the light from both holes can fall upon it, there will be seen on the screen a series of bright and dark bands which, however, vanish and leave the screen uniformly illuminated if one of the holes is covered up. Fresnel gave a more completely decisive form to the experiment as follows:—

If bright light of one colour only (mono-chromatic) is allowed to fall on a convex lens, such as the object glass of a telescope, it will be concentrated into a point or focus from which it will again diverge. If this beam is allowed to fall on two mirrors placed at a very slight angle to each other the rays after reflection will diverge as if they originated in two brilliant points of light very near to each other.

If this light is received on a screen a series of bright and dark bands will be seen called interference bands which, however, vanish if the mirrors are placed truly in one plane or level with each other.

Let us consider the rays diverging from a common source through two small holes made very near together in a screen and let the light fall on another parallel screen placed at a little distance. Then draw a line through a point half-way between the small holes and perpendicular to the screens. It is clear that the point where this line meets the second screen is equidistant from the two sources.

If, however, we choose a point a little on one side of this central point then the lines drawn from it to the two sources will differ in length, and the point may be so chosen that this difference is equal to half the length of a wave of the light or to a few multiples of half a wave length. At such a point there would be found a dark band, but if the difference of wave length is a whole wave length or a few multiples of it then at that point there will be a bright band.

Hence it is clear that light proceeding from one source which reaches a distant point by two paths, one differing slightly in length from the other, can under some conditions produce darkness, since the dark bands seen in the above described experiment which vanish when one luminous point is covered up, can only be due to the superposition of the luminous effects due to each source separately. This effect is called interference. If light is a substance or consists of small particles shot out from luminous bodies it is impossible to explain how light added to light can produce darkness. If, however, light is a motion and particularly a wave motion, then it is quite easy to see that oppositely directed motions may annul each other or that the crests of one set of waves may fill up the hollows or dumps of another set of waves and so destroy the wave effect. An experiment by Fizeau and Foucault is equally opposed to deductions from the corpuscular theory. It is a well-known fact that when light passes from one transparent medium to another the rays are refracted or bent. The bent appearance of an oar or stick half immersed in clear water is a proof of this.

If we hold a plumb line perpendicular to the surface of clear water, and allow a ray of light to fall slantingly on the water striking it at the point where the plumb line touches it, the angle between the plumb line and the ray is called the angle of incidence. When the ray enters the water it is bent so that the angle between the ray in water and the vertical line continued downwards, called the angle of refraction, is less than the angle of incidence.

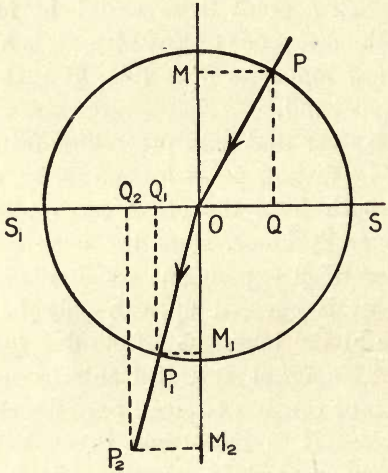


FIG. 1.

Suppose then that we draw a circle with centre O (see Fig. 1), and let the line PO represent the incident ray, and the angle POM the angle of incidence. If light consists in the movement of a material particle it is clear that the relative velocities parallel and perpendicular to the surface SS_1 separating the two media would be represented by the lines OQ and OM. On entering the denser medium, which we shall suppose lies below SS_1 the ray is bent into a position OP_1 and it is also evident that the relative velocities parallel and perpendicular to the surface are represented by the lines OQ_1, OM_1.

If we produce the direction of the refracted ray and take a point Q_2 such that $OQ_2 = OQ$, and drop a perpendicular through Q_2 to meet OP_1 produced to P_2 then it is easy to see that if light consists in the movement of a material particle, and if the ray is bent in the manner which we find it is bent, the component of the velocity of light perpendicular to the refracting surface in the denser or lower medium must be to the velocity in the upper or rarer medium as OM_2 is to OM. In other words the vertical component of the velocity must be increased when the light passes into a denser medium.

Newton accounted for this by assuming that the denser medium exerts an attraction on the corpuscles which quickens their speed and so increases the vertical component of the velocity, but does not alter the horizontal component parallel to the bounding surface. Hence, according to this view, light should move faster in water than it does in air or in empty space.

With the apparatus consisting of a revolving and fixed mirror above described, Foucault and Fizeau were able to measure experimentally the velocity of light through water by interposing a long tube with plane glass ends, which was filled with water in the path of the ray between the fixed and revolving mirror.

They at once found that light travels more slowly in water than in air in about the ratio of 3 to 4. Hence, if the velocity in empty space is 186,326 miles per second, then in water it is only 139,465 miles per second.

This experimental fact, administered a fatal blow to Newton's corpuscular theory and showed that the refraction of light could not be accounted for by an increased velocity imparted to the luminous particles. On the other hand, starting from the observed fact that light moves more slowly in water than in air we can deduce at once on the undulatory theory the ordinary laws of refraction.

For let the line AB in Fig. 2 represent the wave front or line of crest of a plane wave of light advancing at an oblique angle into a denser medium, the boundary being denoted by the line SS_1. If, then, the wave moves more slowly in the denser medium, it is clear that as soon as the end B of the wave touches the surface SS_1 it will

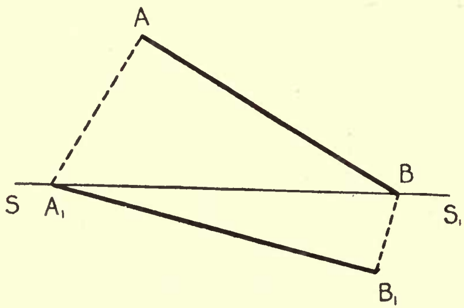


FIG. 2.

begin to be propagated less fast than the end A which still remains in the rarer medium, and after a time when the wave front has wholly passed into the denser medium it will be slewed round into the direction A_1B_1. The direction of the ray of light is the direction at right-angles to the wave front. A little consideration of the diagram in Fig. 2 will show that the angle of incidence is the angle ABS, and the angle of refraction is the angle $S_1A_1B_1$. In the case of a right-angled triangle the ratio of the vertical side to the long slant side or hypotheneuse is called the Sine of the angle of slope. The velocity of a wave is the distance the line of crest advances perpendicularly to itself per second. Hence in the above case the velocity in the rarer medium is to its velocity in the denser medium as the length AA_1 is to the length BB_1. But the ratio of AA_1 to A_1B is the Sine of the angle of incidence, and the ratio BB_1 to A_1B is the Sine of the angle of refraction.

Therefore the velocity of the wave in the rarer medium is to its velocity in the denser medium as the Sine of the angle of incidence to the Sine of the angle of refraction. But it was proved by Willebrord Snell in 1621 that this ratio is a constant ratio, and is greater than unity for a ray passing from air to water, and nearly equal to 4 to 3.

Hence the facts discovered by Foucault and Fizeau are consistent with Snell's law of refraction, and both are explicable on the wave theory of light.

There are also countless other experimental observations which go to prove that a ray of light must involve an undulation or wave of some kind, and this means that at any one point in the path of a ray there are periodic changes of some description repeated very rapidly. Also at equidistant intervals along the path of a ray similar changes are taking place at the same instant.

If then light consists in an undulation the question arises, What is it that undulates? Before we can answer this question we must refer to two numerical laws which hold good for undulations or wave motions of all kinds. The first is a rule connecting the velocity of propagation or speed of the wave with the wave length and the frequency or number of movements or changes at any one place per second.

It is thus stated: *The numerical product of the wave length and wave frequency is the wave velocity.*

Thus in the case of sound, which is a wave motion propagated through the air, the aerial or sound waves travel with a speed of 1100 feet per second at ordinary temperatures. If, then, we create a musical sound by the aid of a piano or violin string which makes, say 275 vibrations per second, the length of the corresponding wave will be 4 feet since $4 \times 275 = 1100$. In the case of light waves it is possible to measure by several different methods the length of the waves.

The simplest of these is the interference experiment of Young, already described. If we measure the distance between the two small holes from which light falls on the screen, and if we measure also the distance of the screen from the plane of the two holes and the distance between the two first dark bands on either side of the central points, then it is quite easy to prove that the wave length of the light employed is to the distance between the small holes as the distance between the two first dark bands on either side of the middle line is to the distance between the holes and the screen.

Operating in this manner with yellow light obtained by placing some common table salt in the flame of a Bunsen gas burner we can prove that the wave length of such yellow light is about one fifty-thousandth part of an inch.

Since the velocity of light is nearly 1000 million feet a second, or 12,000 million inches per second, it follows that the number of vibrations per second which give rise to the sensation of yellow light is obtained by dividing 12,000 million by $\frac{1}{50000}$ or multiplying 12,000 million by 50,000.

This product gives us the enormous number 600 million million, or 600 billion. All these ætherial vibrations take place in one second of time, and must enter the eye to produce the sensation of yellow light.

Hence the longer the wave length the less the frequency, but the above rule enables us to connect the two when we know the velocity of the wave.

The next important rule in connection with wave motion is this: *The speed of a wave in any medium is numerically equal to the quotient of the square root of the elasticity by the square root of the density of that medium.* The elasticity of a substance is defined as the quality in virtue of which a force of a certain kind causes a change of size or shape, which change disappears when the applied force is removed.

It is measured by the ratio of the force or pressure applied, to the corresponding change of shape or size. The substances we call solid resist more or less elastically changes both of size and form or shape. The bodies we call liquid or gaseous resist change of size, but not change of shape. There is therefore only one kind of elasticity in liquids and gases, viz. compressional or bulk elasticity. This is measured by the ratio of the increase of pressure per square inch applied to them or exerted by them on the walls of the containing vessel to the corresponding diminution in volume.

This diminution must be expressed as a fraction of the original volume.

In the case of solids there are three principal kinds of elasticity, viz. bulk or compressional elasticity, torsional elasticity and linear or longitudinal elasticity.

The first kind is that in virtue of which the solid resists diminution in volume when pressure is applied to it all round. The second is that which resists change of form or distortion, and the third is that type of elasticity which is brought into play when a wire or rod of the material is stretched or compressed. The number defining the last kind of elasticity is generally called Young's Modulus for the particular substance. Suppose for instance we take a bar of steel 100 feet in length, and having a square section of $\frac{1}{4}$ of an inch on each side. The cross section is then $\frac{1}{16}$ of a square inch. If a stretching force of 2 tons were applied to this 100 foot bar it would be stretched about 3 inches or $\frac{1}{4}$ foot, and when the stretching force was removed it would return nearly to its original length. Hence the stretching force per square inch of cross section is $2 \times 16 \times 2240 = 71680$ lbs., and the elongation is 1 part in 400. Therefore the Young's Modulus for this steel is the ratio of 71,680 to $\frac{1}{400}$, or is $400 \times 71{,}680 = 29$ million nearly.

This Modulus must be determined subject to the proviso that the bar is not stretched beyond that point at which it will return to its original length when released.

Over and above a certain amount of stretching the elastic limit is passed and the bar takes a permanent set.

It can be proved, as above stated, although the proof requires some use of mathematics, that the velocity of a wave in any medium depends on the square root of the ratio of the elasticity to the density. Hence there are different kinds of waves connected with the three varieties of elasticity.

Suppose a very long wire suspended horizontally in the air and a sharp pull given to one end. This pull would not make itself felt instantly at the distant end, but would be propagated along the wire as a wave of compression and extension. The elasticity with which we are here concerned is the longitudinal elasticity measured by Young's Modulus for that substance. Imagine the wire to be of steel, then we have just seen the

Young's Modulus when using pounds and inches as units of mass and length is represented by the number 29,000,000. If, however, we take the foot as our unit of length the Modulus will be 144 times greater. In the formula for the velocity of a wave we have, however, to express the elasticity in certain units called absolute units which in the case of the pound and foot as units of mass and length involves multiplying the Modulus number above given also by thirty-two. Therefore, on this scale of measurement the longitudinal elasticity of steel is represented by the number 134,000 million.

On the above system of units the density of steel or the mass of a cubic foot is 550 lbs. Hence the ratio of elasticity to density for steel is the ratio of 134,000 million to 550. This is nearly 240 million.

If we take the square root of this last number we have 15,500 as a result. Hence the velocity of a longitudinal wave of "pull" in a steel wire is 15,500 feet per second or nearly 3 miles per second. This is, therefore, the velocity of sound along a steel wire. Suppose we had a steel wire 3 miles in length suspended like a telegraph wire. If a bell were attached to one end and a sharp pull given to the other end, it would take one second for the "pull" to travel along the wire and actuate the bell. If the wire stretched from the earth to the moon it would take nearly twenty-two hours for a pull at one end to travel to the other end and ring the bell.

If the steel wire stretched from the earth to the sun and a pull were given to it at the sun end, it would be just one year before that pull was felt at the earth. We have seen that a ray of light travels the same distance in about eight minutes. On the other hand a twist given to one end of a steel wire would be propagated along it with a different speed to a pull because it would bring into play a different type of elasticity.

We have another illustration of this in the case of earthquake waves. When a shock or blow is administered at some internal point on an elastic solid like the earth it gives rise to two waves, one due to the compressional elasticity and the other to the distortional elasticity. In the case of the earth the wave due to compressional elasticity travels at the rate of 10 kilometres per second or 6¼ miles per second. The wave due to distortional elasticity with about half the speed, viz. 3⅛ miles per second. The corresponding elasticities are considerably greater than that of steel, and show that the earth as a whole is more rigid than if it were a ball of steel. But in no instance do the velocities of any kind of wave created in elastic solids at all approach the velocity of light in empty or stellar space. Hence if light is an undulation of some kind, as it is convincingly proved to be, the medium in which it is propagated through space must have properties very different from those of ordinary matter. Either its elasticity must be vastly greater or its density must be very much less than that of any material substance in order that the wave velocity may be as great as it is.

Before, however, we can discuss the special properties of the luminiferous æther, one other quality of a ray of light must be explained.

In the case of sound waves in air or of the longitudinal waves in metallic wires the vibratory motion of the particles whether air or metal is in the direction of propagation of the wave. The air particles in a sound wave move to and fro in the direction in which the wave is travelling. In a ray of light the undulations must take place transversely or across the direction of propagation.

This is proved by many curious effects. For instance, if a ray of light is passed through a thin slice of crystal called tourmaline cut in a particular way it is found that it can pass through a second slice of the crystal cut in a similar way if the slices are placed in the same relative position they occupied in the uncut crystal, but cannot pass if one of the slices is turned half-way round so that they lie over each other but with axes crossed. Also if a ray of light is reflected at a certain angle from a glass plate it is only partially reflected from another glass plate at the same angle when the planes of reflection are at right-angles to each other. These and many other optical facts prove that a ray of light may possess different properties on different sides. It is impossible to explain this if the undulations in a ray of light are longitudinal, that is, take place along the direction of the ray, because then everything would be symmetrical with respect to this direction. This is the case with a sound wave.

The motion of the particles of air which constitutes a sound wave takes place along the line in which the sound is being propagated. On the other hand the phenomena connected with the passage of light through crystals or after reflection at surfaces is only capable of being explained on the assumption that the vibrations of light take place at right-angles to the direction in which the light is travelling. In an ordinary ray of light these transverse undulations are directed indiscriminately in all directions perpendicular to the ray, but in the case of light which has passed through a crystal of tourmaline as above described the direction of the vibrations is confined to one plane, and the light is said to be plane polarized.

We are now able to gather together the above-mentioned statements concerning a ray of light, and consider the very important question—What kind of elasticity must the æther possess in order that undulations in it may be propagated with the speed, and have the qualities we find them to possess in the case of light?

We have seen that the medium must have very great elastic resistance to deformation of some kind, and also that the properties of a ray of light unquestionably show that the vibrations must take place across and not along the direction of the ray. It follows from this that the elasticity with which we are concerned cannot resemble the elasticity of a gas or of a liquid since these exhibit only compressional elasticity, and can only propagate longitudinal waves like waves of sound.

Physicists were, therefore, thrown back on the idea that the æther must have properties resembling a highly elastic solid.

In the middle part of the nineteenth century much scientific work was done in explaining optical effects by the aid of this elastic-solid theory of the æther.

It was early realised, however, that there were many unexplained difficulties. It was, for instance, remarkable that a distortional wave could be propagated through the elastic-solid æther, and yet not involve the production of any compressional or longitudinal wave.

No discoveries in optics have given any indication of the existence of such a compressional or longitudinal wave in the æther. Another difficulty which presented itself was to reconcile the presence of a highly elastic-solid æther filling all space with the entire absence of any evidence of resistance to the motions of the earth and planets through it.

The earth flies along in its orbit with a speed of nearly 20 miles per second, or 1200 times that of a fast express train. Every day between one sunrise and another we all travel about one and three-quarter million miles through space, being carried along on the earth without any appreciation of our rapid movement.

In one year we travel about 600 million miles in the same way. If there were the very slightest resistance to the earth in forging its way through the æther it would soon begin to tell, and by reducing the earth's speed would cause it ultimately to fall into the sun. There is clear evidence that the length of the year has not altered by even a few seconds within historic times, and therefore that there is no sensible resistance to the earth in its passage through the æther. Hence Fresnel and Young were driven to the conclusion that the æther must pass quite freely through the earth like wind through a forest of trees. Here, however, we are led to consider a fundamental question which has exercised the minds of some of the greatest scientific thinkers.

It is as follows: When a material body such as the earth is in motion does it carry the æther within it and around it along with it or does the æther remain at rest whilst the atoms of the body march through it, the æther so to speak filtering through the interstices like water through a bed of sand?

We know that the velocity of light in transparent bodies such as glass is far greater than can be accounted for by the mere distortional elasticity of the glass itself. Light is therefore propagated through it by the æther contained within the glass modified no doubt by the atoms of the glass, but still essentially a wave motion in the internal æther within the glass. If then the glass moves forward through space we immediately ask: Is it always the same æther which remains within the glass or does the stationary universal æther slip through the glass as the latter moves? To the ordinary man of the world such an inquiry no doubt seems about as profitable and useful as the discussions of the school-men in the middle ages on the question: How many angels can stand upon the point of a needle? Nevertheless these questions concerning matter and æther lie at the very root of any intelligent comprehension of natural operations, and, moreover, they are capable of being brought to the test of experiment, which the question about the angels is not. In this case we are able to apply a particularly delicate test by observing a far distant star through a prism of glass and noting whether any difference in the refraction or bending of the ray of light takes place when the prism is so held that it is being carried by the earth in or against the direction in which the ray of light from the star to the earth is travelling. A very careful experiment of this kind was tried by the French philosopher Arago (1786–1853), and again in 1867 by James Clerk Maxwell. The result was that no difference was found. Another extremely sensitive arrangement was devised by A. A. Michelson in the United States and put in operation by him and by Morley in 1887 for testing whether a ray of light shows any apparent difference in velocity when the ray is travelling in a direction with or against the direction in which the earth is moving. Not the slightest appreciable difference could be found. Numerous other careful experiments have shown that all optical effects take place on the earth just as if the earth were at rest with respect to the æther. On the other hand, careful experiments have been made by Sir

Oliver Lodge, to ascertain, by rapidly whirling steel discs, whether the æther in the neighbourhood of solid bodies moving at a very great speed is at all disturbed. The results showed that it was not disturbed. Fresnel pointed out in a letter to Arago that the astronomical effect called aberration or the apparent displacement of stars due to the earth's motion, could not be explained on any wave theory of light except by the assumption that the æther is not carried along by the earth in its motion. Hence we are faced by an apparent contradiction. On the one hand certain very delicate optical experiments appear to prove that the æther near the earth's surface is carried along by it or is at rest with respect to the earth. In antagonism to these results we have the phenomena of aberration already described which necessitates the hypothesis that the æther does not move with the earth. Also we have such experiments as those of Lodge proving that by no rapidly moving bodies can we set the æther in motion. Deferring for a time the recent explanations of the negative results obtained by Arago and Michelson and Morley we may say that present-day opinion is in favour of the view that the æther itself does not partake of the movement of the earth. A highly ingenious theory was elaborated by Sir George Stokes to explain aberration without assuming that the æther passes freely through the earth.

Before we can profitably discuss these questions at greater length it will be advisable to refer briefly to certain electrical and magnetic phenomena, and to explain how modern researches have compelled us to seek in the properties of the æther an explanation of them as well as of those of light.

From very ancient times it has been known that substances such as amber when warmed and rubbed with fur could attract small objects and repel other similarly rubbed bodies. Substances in this state are said to be electrified or to have an electric charge. Every electrified substance exerts what is called electric force, which means to say that a small ball also charged with electricity would experience a force tending to move it to or from the electrified body if held near it.

In 1733 Charles François Dufay made a discovery which fixed a new starting-point. He proved that electricity was of two kinds, and that the electricity excited by rubbing glass with silk was different from that produced by rubbing sealing wax with flannel.

Henceforth we had to distinguish vitreous or positive electricity from resinous or negative.

Philosophers during the eighteenth century gathered in a copious store of knowledge concerning the laws and effects due to electricity at rest.

On the last year of that century Volta gave to the world his epoch-making discovery of the Voltaic battery or pile. Piling up a column of discs of copper, moist cloth, and zinc one on the other repeated in this order for scores of times, he constructed the *pile,* which ever since has borne his name.

Then he demonstrated that one end of this pile, if built of a sufficiently large number of discs, exhibited all the properties of vitreous electricity and the other of resinous electricity, as shown by their powers of repelling and attracting other small electrified objects. But more, if the two ends of the pile were joined by a wire this wire was found to become hot, and if severed and the ends placed in acidulated water they were able to decompose the liquid into gaseous oxygen and hydrogen. This wire was then said to be traversed by an electric current, which was soon recognised to be electricity in motion.

Long previously to this date mankind were acquainted with the curious properties of the lodestone, its power of attracting bits of iron, and when floated or freely suspended setting itself in a nearly fixed direction with regard to the north and south line—at that place. Also the power of transferring these properties to iron or steel was known. Dr. Gilbert, of Colchester, had laid the foundations of magnetic science strong and sure as far back as the Elizabethan age, but no one had been able to connect the properties of the lodestone or of magnetised steel with those of the rubbed or electrified glass or amber. Then in 1820 Hans Christian Oersted (1777–1851) discovered the bridge which unites the two sets of phenomena. He found that the space round the wire joining the ends of Volta's pile possessed properties similar to those of the region round the lodestone. It was in short, a magnetic field, a place in which magnetic force was exhibited, meaning by that term a region in which a force acts upon one end or pole of a long magnetised steel wire there held.

Two other interconnecting links, however, remained to be discovered between the lodestone and the rubbed amber. One of these was supplied by Faraday in 1831 by his historic discovery that an electric current can be created in a metallic circuit or closed loop of wire by merely moving a magnet to or from it. Hence a lodestone or natural magnet produces Volta's electric current in conducting wires merely by being moved rapidly in their neighbourhood.

Finally, in 1876, Professor H. A. Rowland proved experimentally that when an electrified substance is set in rapid movement along any line it creates in all surrounding space a magnetic force just as if that line were occupied by a wire carrying a Voltaic electric current. For example, if an ebonite disc has pieces of tin foil attached to it, and if these are charged with electricity and the disc set in very rapid rotation like a wheel, a small magnet held near the edge of the disc would be affected just as it would be if held near a wire bent into a circle which is traversed by an electric current created by a Voltaic pile. There is, therefore, a magnetic field created round a moving electrified body.

We can then summarise all this information in two simple statements as follows :—

1. Electrified bodies in rapid motion produce around themselves magnetic fields.
2. A magnet when in rapid motion creates electric currents or sets electricity in motion in neighbouring conductors.

There is, therefore, a very intimate relation between electricity, magnetism, and motion. From the time when this connection began to be appreciated it became evident that the action of electrified bodies and magnets in producing effects at a distance could not be explained with satisfaction to the human mind without assuming that there must be an *electromagnetic medium* in space through or by which these effects at a distance are produced.

The question soon presented itself whether this electromagnetic medium was not identical with the æther which we have seen has to be postulated to explain the phenomena of light. This suggestion remained merely a working hypothesis in the hands of Faraday, Ampère, and Henry and the great philosophers of the early nineteenth century.

On that fortunate day, however, when Professor James

Clerk Maxwell, stimulated by the advice of Lord Kelvin, began to direct his attention to the electrical discoveries of Faraday, the foundations were laid of a vast superstructure of exact thought and discovery which forms one of the most remarkable achievements of the human mind. Maxwell gave to Faraday's clear ideas about electric and magnetic fields mathematical expression and he stated in symbolic language the two fundamental laws founded on the discoveries of Oersted and Ampère regarding the magnetic force round an electric current or electricity in motion, and the discovery of Faraday concerning the electric force produced by a magnet in motion.

Starting from this basis he was able to show that electromagnetic effects must take time to travel through space and from the data at his disposal he proved that their velocity must be that of light.

To give a simple illustration. Suppose we have a wire connecting the ends of a Volta pile and that an electric current is flowing through it. Then, as Oersted proved, there is a magnetic force around this wire. It will attract iron filings and deflect a compass needle. The magnetic force at every point has direction as well as magnitude, and it is arranged in circular lines which embrace the wire like rings threaded on it. These rings of magnetic force extend far out into space. If the electric current is reversed in direction in the wire by changing about the connection to the two poles of the Volta pile, then the magnetic force is everywhere around it reversed in direction also.

Suppose that we could instantly reverse the current, the magnetic force at distant places due to it would not instantly be reversed at the same moment. The reversal would take place immediately at points near the wire but would only take effect at points more and more distant after a progressively increasing delay. In other words, the reversal would travel outwards from the wire with a certain speed and that speed Maxwell showed must be the speed of a ray of light.

Now this coincidence cannot be a matter of accident. It gives a strong indication that the medium concerned in the propagation of light and that involved in electromagnetic phenomena must be one and the same.

We shall now consider another typical and very important case which will enable us to understand more perfectly the nature of an electric wave or electromagnetic wave as it is more properly called.

Suppose a sphere or ball of metal to be charged with electricity, say, with positive electricity. Then around the sphere there is a distribution of electric force along lines which are directed straight away from the centre of the sphere, all round it or in radial directions. These lines of electric force are not merely imaginary lines like lines of latitude and longitude.

There are some reasons for believing that they have a physical existence outside of the electrified body and involve a certain state of strain in the electromagnetic medium all along each radial line. Moreover, these lines of electric force exhibit three qualities which seem to furnish additional arguments for regarding them as objective realities and not as mere mathematical abstraction. Faraday and Maxwell pointed out that they behave as if in a state of tension like elastic threads which are stretched and also they exert a lateral pressure upon each other.

Every line of electric force must start from the surface of some body charged with positive electricity and terminate on some body charged with negative electricity. When we remember that such oppositely charged bodies attract each other, the suggestion at once arises that this attraction may be merely the visible result of the tension of these lines of force endeavouring to make themselves as short as possible.

Then again, these lines of electric force possess a property which is identical with, and perhaps the explanation of, the inertia of matter. It is our every-day experience that heavy bodies, *e.g.* railway trains and motor cars cannot be started into motion instantly, and when in motion cannot be stopped instantly. They tend to persist in their state of rest or motion and require something we call energy to be given to them to make them move and taken from them to bring them to rest again.

This quality is usually called the inertia of matter. The word inertia, strictly speaking, means inactivity. It is not therefore a very suitable term by which to describe this persistence of material bodies in continuing to do what they happen to be doing, viz.; remain at rest or continue in motion. Nevertheless it has become sanctified by use. Newton's First Law of Motion is merely the exact expression of this property of inertia. Lines of electric force exhibit exactly the same quality. It is a fact well known to electricians that an electric current cannot be started instantly in a conductor and when started cannot be stopped instantly. Bearing in mind that an electrified body in motion is in fact, an electric current in one form, it is easily seen that this well-known quality of the electric current which might be called electric inertia, is possibly only the inertia of the system of lines of electric force carried about by, and attached to, the electric charges the motion of which constitutes the electric current.

But this inertia of the lines of force can be nothing but the inertia of the electromagnetic medium, or, say, the æther in which they are formed.

We have already seen that the notion that light is a wave motion or undulation implies that there must be some medium which undulates and must possess density, and this involves the possession of mass or inertia.

Also we have proved that the existence of a wave motion requires some kind of elasticity to be present in the medium. But we now find from a study of electrical phenomena that we have to assume the same qualities, viz., an elastic resistance to stretching in the lines of electric force and also an inertia or density in these lines which would bestow upon them the power of conveying vibrations along them.

If we stretch an elastic string like a violin string between two points then, as well known, we can set up a vibration in it by twitching and pulling on one side a part of the string. This vibration runs along the string at a speed depending on the elasticity or tension and the density per unit of length.

It is not, therefore, surprising to find that Faraday, in his "Thoughts of Ray Vibrations" ("Experimental Researches in Electricity," Vol. III., p. 451), throws out the suggestion that radiation of light and heat may be only a "high species of vibration in the lines of forces which are known to connect particles and also masses of matter together." A consideration of the context shows that Faraday was not limiting himself to lines of electric force, but seemed to hold in view vibrations on lines of gravitational force as well. Before, however, we can dwell on this point, we must return for a moment to our charged electrified sphere set in rapid motion.

We have seen that experiment proves that a moving electrified body creates magnetic force round itself which is distributed in circular lines embracing the direction of motion. Since this magnetism is only present whilst the electrified body is moving and disappears when it stops, we are led to the conception that the lines of magnetic force are created in the medium by the sideways or lateral motion of the lines of electric force proceeding from the electrified moving sphere.

This idea, which is confirmed by many experimental facts and mathematical arguments, is a very important one, and we shall therefore endeavour to make it quite clear.

Let us suppose a very long wire to be charged uniformly with electricity. At every point near the wire the electric force would be in a direction perpendicular to the wire, and the lines of electric force might therefore be imagined as sticking straight out from the wire like hairs upon the body of a very long thin hairy caterpillar.

Suppose the wire to move lengthways with great speed. It would then become an electric current and would create magnetic force distributed round it in circles threaded on the wire like rings. A careful consideration of the state of affairs close to the wire will then show that we have (1) electric force acting straight away from the wire; (2) magnetic force at that point acting across the wire, and (3) motion of the two parallel to the wire.

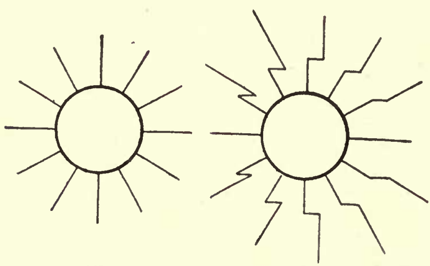
We can sum up the relation between moving lines of electric force and moving lines of magnetic force as follows :—

(i.) Lines of electric force moving sideways or in a direction more or less perpendicular to their own length create lines of magnetic force which run in a direction perpendicular to the lines of electric force and also to that of the motion.

(ii.) Lines of magnetic force when moving sideways in a direction more or less perpendicular to their own direction create electric force and this electric force is in a direction perpendicular to the lines of magnetic force and to the motion.

The exact expression of these laws would require the use of mathematical symbols, but the above statements are enough for our purpose.

Returning, then, to the case of our electrified ball in motion. We must picture it to ourselves as the centre of



a *b*

FIG. 3.

a sort of spider's web of lines of force; lines of electric force running straight away from it in all directions and lines of magnetic force embracing it in circles, and this web of interlacing lines it carries about with it as it travels (see Fig. 3*a*).

We have then to ask: What will happen if the electrified ball is suddenly stopped? The answer to this question is that the inertia of the lines of electric force will cause them to continue to move on for a little in advance of the ball and hence a sort of kink will be produced in the lines of force (see Fig. 3*b*). The lines remain attached to the electrified body by one end, but the jerk or sudden stoppage causes the rest of the line to lurch forward, just as when a vehicle suddenly stops the passengers inside are jerked onwards. This kink in the line of force cannot, however, remain stationary. In virtue of the elasticity of the line and its endeavour therefore to straighten itself, the kinked or bent portion flies outwards, and as part of the moving kink travels laterally it will, as above stated, create a magnetic force at right-angles to itself and to its direction of motion. If, then, our scientific imagination is vivid enough to picture to ourselves the state of affairs when the moving electrified ball is suddenly stopped, we should find the rays of electric force streaming out from it in all directions will immediately have a kink or bend produced in them near the ball, and these kinks at once move outwards with the speed of light; each little bend in the line of electric force as it moves being accompanied by a transverse magnetic force, and the general effect is to produce an expanding shell of force which grows in size and has at all points on its surface electric force and magnetic force in directions perpendicular to each other and both perpendicular to the radius of the shell at that point. This shell is called an electric pulse. The pulse expands outwards with the velocity of light which is nearly 1000 million feet per second.

The same kind of thing happens if the electrified sphere is suddenly started from rest into motion or if it suddenly changes its speed.

If the electrified sphere were to jump backwards and forwards between two extreme positions or to vibrate, then electric pulse would succeed pulse and the repeated emission of electric pulses would constitute what is called electric radiation.

Every electrified body or particle thus radiates when it changes its velocity, whether that change is in magnitude or direction.

This electric radiation involves the removal of energy from the electrified body. Professor Poynting gave, many years ago, a proof of an important theorem now known as Poynting's theorem, which tells us that when electric and magnetic force occur at any point in space at right-angles to each other, then energy is being transferred through the medium at that point in a direction at right-angles to both the forces. The expanding shell of force or the electric pulse thus conveys energy away from the electrified body into space.

The practically minded reader may then ask for some proof that these things are actualities and not mere fictions or cobwebs of the brain. We can find a strong confirmation by carefully considering the production of Röntgen rays and noting how consistently all the above statements fit in with the observed phenomena.

Long years before Röntgen's discovery, electricians had become convinced that electricity, whatever may be its nature, is not capable of being obtained in indefinitely small quantities. All the electricity which exists is in multiples of a certain minimum quantity which cannot be divided and may therefore be called the atom of electricity, or, as Dr. Johnstone Stoney named it, an *electron.*

Electricity, in fact, resembles certain articles of commerce, such as cigars, which may be obtained in multiples only of an unit. We can buy 10, 100 or 1000 cigars, but we cannot purchase half or quarter of a cigar.

The minimum quantity of electricity, called an *electron,* is that which is carried by or attached to an atom of hydrogen. It is Nature's unit of electricity.

More than forty years ago Sir William Crookes began his remarkable researches on electrical discharges in high vacua. If a glass tube has two platinum wires sealed into the ends and if a partial vacuum is made in the tube, then if the air or residual gas exists in the tube under a small pressure, this rarified gas is found to be a conductor of electricity. The tube becomes full of a pinkish or bluish glow when connected to an electrical machine, and the device is popularly known as a vacuum tube. If, however, the air is very completely exhausted, new and striking effects present themselves. When the two metal wires, called the electrodes, by which the electric current enters and leaves the tube, known respectively as the *anode* and *cathode,* are joined to the terminals of an electrical machine yielding positive and negative electricity, it is found that inside the tube a torrent of small particles is given off from the negative electrode, which makes itself evident by raising to incandescence pieces of metal, or by producing vivid phosphorescence in various substances, such as diamonds, rubies, and sulphides of lime, when placed in the tube, and also when properly directed can cause rapid rotation in small paddle wheels or vanes placed in its path. Sir William Crookes originally and very aptly called this "radiant matter," and proved that each particle was charged with negative electricity so that the whole collection of them moving rapidly in one direction constitutes an electric current. Moreover, these so-called cathode particles or radiant matter produce a green fluorescence on the glass when they fall upon it. They are called cathode particles because there is evidence to show that they are produced at the cathode or negative electrode.

So much was known up to the year 1895, when Professor W. K. Röntgen, of Würzburg, discovered that certain peculiar radiations were given off from the outside of the glass tube at the place where the cathode particles struck it on the inside, and these rays he called X-rays. They have the power of passing through many substances opaque to light, and can affect a photographic plate like light. By their agency he was able to photograph and to render visible the bones inside a living hand, since the bones are partly opaque to these rays whilst the skin and muscles are transparent.

These X-rays have the power of producing a brilliant green phosphorescence in certain substances such as platinocyanide of barium and in a mineral called willemite which is a native silicate of zinc.

This property was at once taken advantage of to enable the X-rays to be used in surgery for locating the position of bullets in the flesh or fractures of the bones.

Three or four years later Sir J. J. Thomson carried out at Cambridge a series of most remarkable experiments which enabled him to determine the magnitude of the negative electric charge carried by these cathode particles and also their mass of weight and size. He found that the electric charge carried on each of them was exactly one electron or equal to the electric charge of an atom of hydrogen, but that the mass of the particle was only $\frac{1}{1700}$ of that of the hydrogen atom, whilst the diameter of the particle was about $\frac{1}{100000}$ of that of the atom.

Moreover, Thomson proved that the charge and mass of the cathode particle is quite independent of the nature of the residual gas in the vacuum tube and of the material used for making the electrodes. Thus a new and wonderful field of research was laid open.

It was proved that the same kind of negatively electrified small particle, which Thomson called a corpuscle, was given off from hot bodies and from certain metals under the action of light, and that in whatever way these corpuscles were obtained they had the same mass and the same electric charge.

The mode of production of Röntgen's X-rays now became clear. We have seen that when an electrified sphere is suddenly stopped the shock communicates a tremor to the system of lines of electric force carried by it and this shock travels outwards in all directions as an electric pulse propagated through the electromagnetic medium.

In the case of the Crookes' tube the electrified particles are the corpuscles which are shot off from the cathode or negative electrode with a velocity of about 20,000 miles per second, or somewhere about one-tenth of that of light. When these flying electrified particles strike the glass wall of the tube, or better still, a screen of very hard metal placed to receive them, called an anti-cathode, they are suddenly stopped. The shock or jerk thus communicated to their attached spider web-like system of radiating lines of electric force creates, as explained above, an electric pulse which travels on as a vibration in the electromagnetic medium or æther and constitutes the X-rays.

Thomson also proved mathematically that when an electrified sphere moves, its apparent mass is increased by a certain amount due to its electrification. We find a very similar effect when a ball is made to move through a perfect or non-viscous liquid. The ball would drag some of the liquid along with it and in effect increase its own mass by an amount depending on its speed.

By certain very delicate experiments Kaufmann has shown that the apparent mass of a corpuscle depends on its velocity and that therefore part at least of its mass must originate and depend upon the system of electrical lines of force it carries, in other words, upon its electric charge. The moving electron therefore drags some æther along with it in its motion.

Thomson has given good reasons for believing that the whole of the mass of the cathode particle or corpuscle is electrical and that the corpuscle may therefore be regarded simply as an atom of negative electricity and nothing else. To emphasise this view the corpuscle is now simply called an electron—using the term originally applied to denote a natural unit of electricity to designate the corpuscle itself, which is, so to speak, an incarnated unit of negative electricity.

We have thus come to the conclusion that what is commonly called negative electricity is, in fact, a fluid composed of electric atoms or electrons which are mutually repulsive and vastly smaller than the atoms of even the lightest known material substance, viz., hydrogen gas.

The electron is as much smaller than an atom of hydrogen as a very small pin's head is smaller than a sphere 80 or 90 feet in diameter, say the size of the dome of a cathedral or an exceedingly large balloon.

So far we have been standing on the solid ground of experimental research. The human mind seeks, however, inter-connecting links between facts and especially the means of visualizing the unseen machinery of Nature. Hence attempts have been made to picture a structure of the electron which will enable us to deduce from it logically the results of observation. We are indebted to Lord Kelvin and to Sir Joseph Larmor for assistance in this attempt.

It has been suggested by the latter that an electron or corpuscle is merely a strain centre in the æther. Imagine a long wire bent round into the form of a ring. Let the two ends be given twists in opposite directions and then be welded together. There would then be a twist in the wire forming an endless ring. This twist could be displaced so as to appear at any part of the ring. In this same manner Sir Joseph Larmor has supposed that an electron may be a small spherical portion of the æther towards which lines of æther twist converge and to which they are permanently attached. It would therefore be capable of being displaced in the stagnant æther without resistance. To justify the hypothesis another assumption has to be made, viz., that the elasticity of the æther is of such a kind that each smallest portion of it resists twisting. It does not resist compression, or rather the æther must be supposed to be perfectly incompressible. Neither does it resist shearing, that is the sliding of one small part over any adjacent part. Its elasticity is therefore not like that of a gas or of an elastic solid, but something peculiar to itself. From such an hypothesis as to the structure of the æther, an Irish mathematician, James MacCullagh, many years ago deduced consistently the chief phenomena of light. Larmor has now advanced farther and proved that an æther structure of this kind would permit the production in it of permanent strain centres which we may conceive these electrons or atoms of negative electricity therefore to be.

The nature of the atoms of positive electricity is not yet quite so clearly demonstrated. It has been shown that they are much larger than the electrons, and in fact comparable in size with chemical atoms.

In a high vacuum tube the positive units of electricity or as they are called, the positive ions (*i.e.* wanderers), move much more slowly than the negative electrons or corpuscles.

The wonderful element radium and the other radio-active bodies have been proved to give off continually three kinds of radiation, called respectively the Alpha, Beta, and Gamma rays. The Beta rays are negatively charged electrons and are projected with enormous speed and have all the properties of the negative corpuscles in a Crookes' vacuum tube. The Alpha rays are positively electrified particles comparable in size with a chemical atom, and on losing their electric charge are probably transformed into the element Helium. The Gamma rays are not atomic matter of any kind but are æther pulses of the same nature as Röntgen or X-rays.

The researches of numerous physicists, and in particular of Professors Rutherford, Soddy and M. and Mme. Curie, Sir J. J. Thomson and many others, have shown that atoms of radium, thorium, and the other radio-active elements are in a continual state of disruption. One by one they break up or explode and send out Alpha and Beta particles. At each projection the remaining atomic structure forms a different substance in a gaseous or solid state, and thus gives rise to a whole series of derivation products.

If an atom of radium loses an Alpha particle then the remainder forms an atom of Radium Emanation which is an inert gas, and if this again loses one Alpha particle it becomes converted into a second derived substance, and so on for a long series of substances called Radium A, B, C, D, etc.

Radium itself is probably a disintegration product of the metal Uranium and as a final product possibly yields the metal Lead after the loss of eight Alpha particles or Helium atoms. Thus the dreams of the Alchemists have, in a sense, come true by the transmutation of so-called elements into one another.

The hypothesis that has been suggested to explain these wonderful discoveries is that a chemical atom, for example an atom of hydrogen, is a complicated structure, somewhat resembling a solar system in miniature, in which negative electrons revolve round or in a sphere of positive electricity like planets round the sun. In the case of the so-called radio-active atoms, like Radium, these rapid internal motions result in the occasional expulsion of an electron from its atomic home. The result is to transform the remainder into a different structure and therefore a different kind of atom.

The electrons themselves are possibly strain centres in the æther, and the lines of force which connect them to the positive electricity are therefore lines of twist in the æther. According to this hypothesis there is nothing involved in the material Universe but æther and energy. The material substances or so-called Matter which seem to us so real and substantial are only patterns or textures so to speak woven out of the intangible æther, and everything that has form and tangibility to us is only æther animated by energy under different forms.

Our various chemical atoms are but congeries of strain centres in the æther in rapid motion. The æther itself is supposed to be stationary or stagnant, and offers no resistance to the displacements of the strain-forms through it from one place to another. Hence in this theory we find at once an explanation of the astronomical aberration of light, and also an answer to the question: How comes it to pass that the earth in its orbital motion does not displace the æther, but moves freely through it? Since from every such strain-form or so-called electron, lines of æther twist radiate in all directions, the æther as a whole may be said to have a fibrous structure and owing to the inertia or density of the æther these lines of force or æther twist behave exactly as if they had inertia themselves. Hence, vibrations can be propagated along them, and whenever a strain centre or electron starts moving or is stopped or changes its speed, vibrations are propagated out along its attached system of lines of twist and are evident to us as radiation of some kind either as light or heat, or the longer electric waves we have especially to discuss.

We shall now have to consider more in detail how this radiation is produced and what is the exact nature of the vibrations which create electric waves in space.

Having outlined briefly the constitution and structure which is attributed to this assumed universal space-filling æther, and the manner in which electricity and atoms may be supposed to be built up out of it, we shall be able to proceed a step further and discuss the operations which give rise to the effects we call respectively electric oscillations and Hertzian waves. In so doing we shall make use of the hypothesis or supposition of an æther in which lines of strain called lines of force can exist, and strain-forms or centres from which twist starts, called electrons; and this will furnish us with a language in which to express ideas or connect together observed facts. It is not to be assumed that this is the only possible mode of explanation or theory of the phenomena. The careful student should always endeavour to distinguish clearly between the observed and well-ascertained truths of science and the suppositions or guesses which we make as to the possible nature of the hidden machinery by which the observed effects are brought about. The facts themselves remain; but the mere collection of isolated facts does not constitute scientific knowledge. We seek to inter-connect them, to pierce below the surface and lay bare unseen things, or to reach broad generalisations concerning them. Our scientific hypotheses are therefore in a continual state of flux, but nevertheless they are necessary to provide us with a terminology or language in which we may describe the relation between observed facts as far as we know them and enable us to place them consistently and connectedly before our minds. From time to time our hypotheses have to be modified, extended or abandoned, but the truths arrived at by observation or experiment remain, and constitute the solid fabric of science though theories and speculations may have to be cast aside.

CHAPTER II.

ELECTRIC OSCILLATIONS AND ELECTRIC WAVES.

THE progress of scientific knowledge is marked by periods of activity and repose. At intervals startling discoveries or inventions are made by men of exceptional genius which open up unsuspected fields of investigation. These are then diligently explored by the rank and file of the scientific army.

As soon as Volta had given to the world in 1799 the means of producing an electric current it was very soon noticed that it had the astonishing power of effecting the chemical decomposition of certain liquids; in other words, it could liberate from these liquids certain elements or constituents which are combined together in them.

Within a year after Volta's invention of the galvanic battery, Nicolson and Carlisle had discovered that the ends of two gold wires attached to the terminal plates of the pile if dipped in water evolved from their immersed ends bubbles which proved to be oxygen and hydrogen gas. They thus electrically analysed water, and set free from it the two gaseous constituents which the eminent Henry Cavendish had proved sixteen years previously formed water by their combination.

This power of the electric current was applied soon after in numerous classical researches by Sir Humphry

Davy, resulting in such great discoveries as that of the isolation of metallic potassium from caustic potash in 1807, and also in the decomposition of the other alkalies and alkaline earths, marking a new era in Chemistry.

The next property of the electric current which was noticed was its power of producing heat and even incandescence in the conductor conveying it. In 1808, or perhaps earlier, Sir Humphry Davy provided the terminal wires of a large voltaic battery erected in the Royal Institution, London, with rods of carbon and bringing their ends in contact, obtained for the first time a brilliant display of the electric arc, the progenitor of all modern electric lighting.

It was not until 1820, however, that Oersted discovered that the connecting wire of the pile possessed also magnetic properties. On October 2nd, 1820, Ampère presented to the French Academy of Sciences a memoir in which he summed up the result of his joint researches with Arago on the subject, and made known his own discoveries in the nascent science of electromagnetism. Ampère, who has been called the Newton of electricity, laid so securely the foundations of this new branch of knowledge that no one has been able subsequently to disturb them. His crowning discovery was the proof he gave that if the connecting wire of a voltaic pile is coiled into a helix or spiral, it then possesses when it is traversed by an electric current exactly the qualities of a magnetised iron bar.

Eleven years later Faraday, then in the prime of his powers, began those celebrated researches in electricity and magnetism which opened still wider fields of conquest for himself and others, and formed the platform on which has since been erected the vast edifice of modern electro technics.

Faraday's most notable achievement was his discovery of the relation between magnetism and electricity, which is the converse of that discovered by Oerstedt, Arago and Ampère. They found that the electric current or electricity in motion could produce magnetism. Faraday discovered that magnets in motion could create an electric current.

Moving a magnet to or from a copper wire helix, the ends of which were joined to complete the circuit, created a current in that helix.

That current flows one way when the magnet is approaching the circuit and the reverse way when it is receding from it.

We are therefore acquainted with two kinds of electric current, one, called a direct current, is a current the direction of which does not vary, as shown by the embracing magnetic field produced by it maintaining always the same direction in space. The other kind of electric current generated by moving a magnet rapidly to and from a closed circuit of wire is called an alternating current.

The direct current is a uniform motion of electricity in one direction in the wire, the alternating current is an ebb and flow, or frequently reversed flow. We may liken the two forms of electric current to the movement of the water in a tidal river, say the river Thames, above and below the places where the tide ceases to be felt. Up at Oxford the water in the river flows always in one direction, viz. down towards the sea. At London the water flows sometimes up the river when the tide is rising and sometimes down when it is falling. At about Teddington this reversal of the flow ceases to be noticed.

We have seen that resinous or negative electricity probably consists of ultra-atomic particles called electrons, and that a current of electricity must, therefore, involve a movement of these electrons. According to the electronic theory of electricity every metal or conductor must contain some free electrons which have been set free from the atoms composing it. These free electrons may be thought of as passing from atom to atom in every possible direction. They cannot escape from the metal, because if they did try to do so it would leave behind a preponderance of electrons of the opposite sign, and this escape would be resisted by the powerful attraction thereby exerted on the escaping electrons. Nevertheless, if any external electric force acts in the metal in any direction, it will cause these free electrons to move in that direction, and this constitutes what we call an electric current.

In the case of an alternating current we must assume that after the electrons have more or less migrated in one direction for a little distance, the driving force reverses its direction and they migrate in the opposite direction. Any agency which creates a general migration of the free electrons in a conductor in one direction is called an electromotive force, briefly denoted by the letters E.M.F. If the speed with which the electrons are moved is, relatively speaking, a slow one, or rather if it changes their direction very gradually, the system of lines of electric force carried out by each electron will not receive any rough shock tending to produce vibrations along these lines as already explained. Hence, the energy of motion associated with each electron, and its system of radiating lines of force or other twist will remain close to the nucleus or centre. On the other hand, if the E.M.F. is of such a kind as to cause the electrons to jump backwards and forwards very rapidly between two

E

positions, then it will set up vibrations in the lines of force, and energy will be carried right away into distant space.

These very rapid movements of electrons are called electric oscillations. We have, therefore, to study their mode of production. To comprehend the manner in which these oscillations are produced we must return to the earlier history of electrical discovery.

One of the electrical inventions of the middle of the eighteenth century, which excited popular interest at that time, almost as much as the discovery of Radium has done in our day, was that of the electrical appliance known as the Leyden Jar.

In 1745 Dean Von Kleist, of the Cathedral of Camin in Pomerania, was endeavouring to electrify water contained in a bottle which he held in his hand. The bottle had a nail stuck through the cork and passing down into the water. Applying the nail to a frictional electrical machine he gave, as he thought, a charge to the water, but when the bottle was removed, still being held in one hand, he received a shock on touching the nail with the other. The experiment appears to have been independently tried by Peter Van Musschenbroeck, a Professor in the University of Leyden in Holland, and he communicated his observations in a letter to Reaumur. Very exaggerated descriptions were given by these independent discoverers of the violence of the shock so experienced, and some little difficulty appears to have arisen before the conditions of success were determined. Finally, in 1746, Dr. Bevis, a Fellow of Royal Society of England, gave to the appliance, now called a Leyden jar, its familiar form of a glass bottle having its sides coated within and without part of the way up with tin foil and a wire ending in a ball connected to the inner tin foil coating (see Fig. 4).

When a charge, say, of positive electricity is given to the inner coating it induces an equal charge of negative electricity on the outer coating, and when the two coatings are connected by a wire or through the human body by touching them with the two hands simultaneously the charges unite and produce a brief but energetic electric current. This, at any rate, was the view of the older electricians who held to the two fluid theory of electricity.

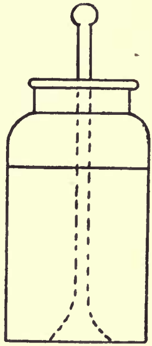


Fig. 4.

The celebrated Benjamin Franklin (1706–1790) originated the hypothesis in which positive electricity is regarded as an excess and negative as a deficit of a single electric fluid, and from this point of view the discharge of a Leyden jar consists in the passage of the excess through the wire or the body from one coating of the jar to the other. Whichever theory was held, it appears to have been thought that the nature of the discharge consisted in a movement of electricity in one direction through the wire.

At a later period, when Faraday discovered the true function of the glass in the Leyden jar, it became clear that the so-called electric charge of the jar, at least in part, consisted in a peculiar state of strain in the glass, and to emphasise these functions, Faraday called the glass or other substance between the metal coatings *the dielectric.* To bring these conceptions into line with modern ideas, we must now explain what is considered to be the true difference between so-called conductors and non-conductors of electricity. As soon as careful experiments began to be made with electrified substances, such as a warm glass rod rubbed with silk, it was found that whilst some bodies, such as rods of glass, resin and amber could easily be electrified by friction, and then could attract light objects, such as feathers and straws, other things like metal rods could not be electrified if held in the hand. As far back as the middle of the seventeenth century, Otto von Guericke, the ingenious and many-sided Burgomaster of Magdeburg, had noticed that electricity could travel along a linen thread, but it was not until a century later that Stephen Gray, a pensioner of the Charterhouse, in experimenting by himself and with his friend, Granville Wheeler, clearly proved that whilst electricity could diffuse itself over great lengths of linen thread or hemp string, it refused to pass at all over a silk one. Then it became clear that the inability to electrify a metal rod was merely due to the immediate dispersion of the electrification over the rod and the hand and body of the experimenter, and not to any other difference between metals and glass or resin. Stephen Gray and his brilliant contemporary in France, Charles François de Cisternay Dufay, were ardent experimentalists and accumulated large stores of observations, which soon led to a more precise statement of the facts concerning the power of electricity to pass over or through certain substances, but not others.

The terms conductor and non-conductor seem to have been used first by Dr. Desaguiliers in their modern sense. If, then, we regard negative electricity as the collective name for the ultra atomic particles or electrons, we have to consider that in metals and other substances which conduct there must be free electrons which can pass easily from atom to atom in the metal. We can deduce from certain effects that these free electrons are about as numerous as the atoms themselves, but being vastly smaller, they lurk, as it were, in the interstices between them or leap from atom to atom with amazing agility. It is highly probable that what we call the temperature of a substance depends entirely on the energy of motion of these little electrons, and that temperature is increased by everything which increases their activity.

Since an electric current consists in a movement of these inter-atomic electrons in one common direction; the substances, which are conductors, must be such as permit a passage of these free electrons from atom to atom, and they may be considered to resemble busy commercial travellers running about from town to town. The speed of these electrons in their short but hurried journeys is, however, about 60 miles per second, or 3600 times greater than that of an express train.

In their ordinary condition these little travellers run to and fro in every conceivable direction, and, therefore, there is no greater crowd of them in one part of a metal than in another. But if an electromotive force acts on the metal it causes them to travel more or less in the same direction, and this common movement creates what we call an electric current. The heat produced by the current in the conductor is due to the increased energy of motion given to the electrons, and since the electrons are constantly having their velocity changed by collision with the atoms, there is a continual communication of energy to the æther in the form of vibrations, sent out along the lines of force radiating from each electron.

Turning now to the class of substances called non-conductors, such as glass or resin, we have to assume that certain electrons are capable of being displaced, but are restrained from moving very far from one position. They are, so to speak, tethered by an elastic leash which permits a little movement in every direction, but drags them back to their place when the displacing force is removed. In other words, they are not like commercial travellers journeying from town to town, but like errand boys sent out on a message but compelled to return to the shop the moment their business is over. If then, as in the Leyden jar, we place a sheet of glass between two sheets of tin foil or other metal we have three regions to consider. In the outer or metal portions the electrons are free to move in any direction. In the inner or glass portion the electrons can be displaced from their mean position, but fly back like a spring released when the stretching force is removed.

From this point of view it follows that when a substance is negatively electrified there are more than the normal number of electrons on it, and their mutual repulsion keeps them all on the surface.

When it is positively electrified there are less than the normal number of electrons. Faraday proved conclusively that it is impossible to create any quantity of one kind of electricity without creating somewhere else an equal quantity of the opposite kind. When a glass rod is rubbed with a piece of silk some of the electrons are transferred from the glass to the silk. The silk therefore becomes negatively electrified and the glass positively. If a rod of sealing wax is rubbed with flannel then some electrons pass from the flannel to the wax. The latter becomes negatively electrified and the flannel positively. It will naturally be asked why there should be this difference between glass and resin. The answer to that is difficult to give in any form, except that experience shows that molecules of some kinds more readily take up than part with electrons, and others more readily part with them than take them up.

Returning then to our Leyden jar, let us suppose that the inside coating of the jar is negatively electrified by bringing it in contact with a rod of ebonite which has been rubbed with flannel. Then this metal coating has on it an excess of electrons. Corresponding to this, there will be a deficit of electrons on the outer coating. The electrons in the glass, therefore, are displaced elastically from their positions of rest, but cannot move freely enough to supply the deficiency on the outer metal coating. In this state the jar can remain for any time. If, however, the two coatings are connected by a wire or any conductor, even the human body, then there is nothing to prevent the excess of electrons on the inner coating finding their way round to make up the deficiency in the other coating. Simultaneously the strained electrons in the glass are allowed to return to their normal position because the repulsive force due to the excess of electrons on the inner coating is then removed. There are two ways in which they may return to rest, which are best illustrated by a simple experiment. Suppose we take a thin strip of steel, like that used to stiffen a lady's corset, and fix one end in a vice. Then let us displace the top end and strain the elastic steel. On releasing the steel strip it will return to its vertical position, but as it possesses mass as well as elasticity, and has stored up energy on being bent it will overshoot the mark and continue to vibrate for some time like a pendulum.

These vibrations die away because the energy stored up on displacement is gradually frittered away in creating movement in the surrounding air or heat in the bending steel. It is easily seen that the existence of these vibrations depends upon the steel strip possessing mass or inertia which enables it to acquire energy of motion, and elastic pliability which enables it to acquire energy of strain or distortion. The greater its mass and the greater its flexibility or pliability the slower it will vibrate. We can make a stiff steel strip vibrate more slowly by affixing a piece of lead to the top and so increasing the mass. We can make a strip thus weighted vibrate more quickly if the steel is made thicker and thus less pliable or more elastic. A similar effect can be exhibited by the elastically displaced electrons in the glass of our Leyden jar. If the wire which connects the two coatings is short and thick it will offer very little obstruction or resistance to the equalisation of the difference in the numbers of electrons on the two coatings. The strained electrons in the glass will then be released very suddenly from their strained position, and will return to rest only after executing a number of vibrations exactly as in the case of our strip of steel. These vibrations of the electrons are called electrical oscillations or vibrations. It will be evident that in order that the strained electrons in the glass may vibrate on returning to rest the free electrons in the connecting wire must vibrate also. The reason for this is that if they did not execute accompanying vibrations those in the glass could not move either. The movement of the electrons in the glass constitutes an electric current, but Maxwell called it a dielectric current, or displacement current, to distinguish it from the current in the wire which is called a conduction current.

Thus it will be seen that the dielectric current is necessary to complete or permit the conduction current and *vice versâ.* Hence, if we charge a Leyden jar, and then discharge it through a short thick wire, or one of low resistance, the discharge will not consist in a single movement of electricity in one direction, but in an oscillatory movement which gradually dies away. That this must be so was evident to the mental eyes of mathematical physicists long before it was rendered visible to the eyes of the body by experiment.

It was suspected and announced in 1842 by Joseph Henry in the United States, a contemporary of Faraday, and it was more explicitly stated in 1847 by von Helmholtz, the great German physicist.

In 1853 Lord Kelvin published a classical paper in which he discussed the whole question mathematically and with full insight into the problem. After that date the conditions under which the oscillatory discharge of a Leyden jar could take place were well understood. It was not, however, until 1858 or 1859 that B. W. Fedderson showed that these oscillations could be rendered visible to the eye by examining the spark discharge of a Leyden jar in a rapidly revolving mirror. If the spark were an absolutely instantaneous discharge its appearance, when seen by reflection in a spinning mirror, would merely be a single flash of light. If it were a steady persistent light it would be seen drawn out into a luminous band. As, however, the oscillatory spark is really a series of rapidly succeeding discharges in opposite directions, what we see on looking at the reflected image of the spark in a mirror revolving rapidly is a series of bright images separated by dark intervals.

To obtain a permanent record by photography of this oscillatory spark we may proceed as follows. If a strip of photographic film is attached to the edge or front of a disc which can be caused to spin very rapidly in a light-tight box, and if through a hole in the box we allow the light from the spark of a discharging Leyden jar to fall on the film then, when the latter is developed and fixed, we shall find on it an image such as that shown in Fig. 5. This clearly indicates that the light of the spark is not continuous, but is interrupted, and consists of separate discharges which are superposed.

A more convincing proof of the existence of these

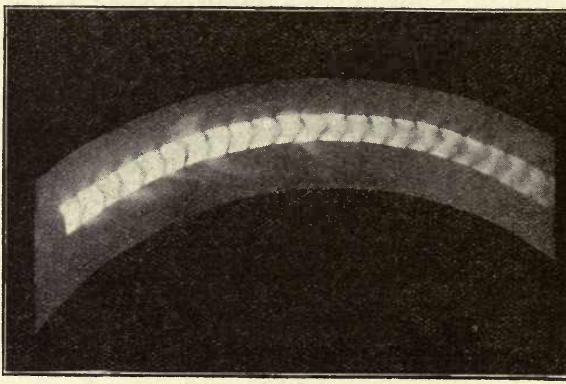


FIG. 5.—Photograph of an oscillatory electric spark.

electric oscillations can be obtained by the use of an instrument called an oscillograph. We have seen that when a current of electricity traverses a wire it creates round it magnetic force in circular lines. If a fine wire is doubled on itself so as to form a narrow loop, and the bottom ends fixed whilst the top is strained by a spring P (see Fig. 6), the passage of a current through this loop will give it all the properties of a very short magnet. If these wires are fixed between the poles of a very strong permanent magnet NS then the flow of current up one wire and down the other will cause these wires to try to move across the lines of magnetic force of the magnet, one wire being pulled forward and the other pushed back. If a little mirror *m* is fixed across the two wires then when an alternating current of electricity flows through the wires, it will cause the mirror to twist backwards and forwards in step with the current, being deflected one way when the current flows in one direction, and the opposite way when the current reverses. If, then, a powerful beam of light from an electric arc L (see Fig. 7) is allowed to fall on the small mirror *m* it can be reflected on to a screen or photographic plate, and will simply register a mark or spot of light when no current flows through the wire. If an alternating current flows through it, then the rapid wagging to and fro of the mirror will cause the spot of light to move backwards and forwards, and trace out a bright line of light upon the screen.

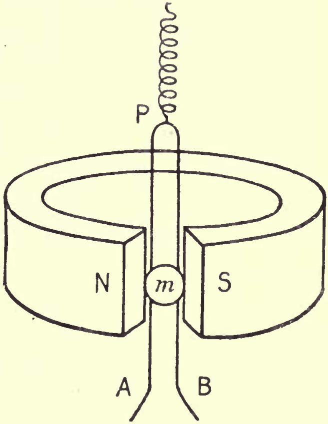


Fig. 6.—Diagrammatic sketch of a Duddell oscillograph.

If instead of receiving the ray directly on the screen it is allowed to fall on a long mirror M which is made to vibrate by a little motor about an axis perpendicular to the direction of the ray of light coming from the other small mirror and then reflected on to a screen, we can give the resulting spot of light on the screen two motions, viz. one, a movement up and down which corresponds exactly to changes in the strength and direction of the current in the two fine wires stretched in the field of the magnet, and the other a horizontal movement to and fro, which results from the rocking motion of the long mirror. The arrangements will be understood from the diagram in Fig. 7. It only remains to be added that the long rocking mirror M must make its excursion to and fro, in just the same time that the variable current in the fine wires A, B takes to pass through one complete cycle of its changes, and also keep in step with it. This, however, is easily

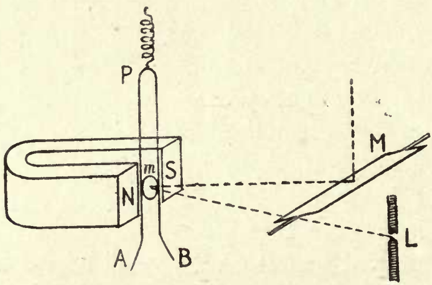


FIG. 7.—Mode of using an oscillograph.

arranged. We have then a device which enables us to see or to photograph the changes of current in a wire when that wire is traversed by an electrical oscillation. If we examine such an image or photograph taken in an oscillograph we shall be able to notice that the interval between two complete swings backwards and forwards remains the same, even although the extent or amplitude, as it is called, of each swing diminishes. The oscillations, therefore, each occupy a constant time whether they be large or small, as long as we employ the same Leyden jar and the same piece of discharging wire. At the same time the swings or oscillations rapidly die away (see Fig. 8.).

We must now introduce a few technical words which, although they may sound strange to the inexperienced, are necessary to define these phenomena or effects properly.

The gradual dying away of the oscillations is called their *damping*, and when an oscillation dies away quickly it is said to be *highly damped* (see Fig. 8*b*). When it dies away slowly it is said to be *feebly damped* (see Fig. 8*a*). If it does not die away at all, but remains always of the same amplitude, it is said to be *undamped*.

a *b*

FIG. 8.—Oscillograph records of feebly damped (*a*) and highly damped (*b*) oscillations.

This damping is measured by the proportion or percentage which one oscillation bears to the one in front of it, and the ratio remains the same during the complete set of swings.

Again the *time period* of an oscillation is the time which elapses between the beginning of one oscillation and that of the next succeeding one in the same direction. The reciprocal of the time period is called the *frequency*. Thus, if the time period were one-thousandth of a second, the frequency would be said to be 1000. This time period or frequency is determined by the size of the Leyden jar and the length and shape of the piece of wire through which it is discharged.

Every Leyden jar, or, as it is called, condenser, has a certain electrical *capacity*. This means that it requires a certain quantity of electricity to be put into it to raise the electrical pressure in it or potential to a certain amount called a unit potential. It is, as if we measured the bulk or volume of a motor wheel tyre or elastic bag, by stating the quantity of air which must be pumped into it to raise the pressure just to 1 lb. on the square inch. This electrical capacity is measured in a unit called a *farad,* just as ordinary volumes are measured in cubic feet or cubic inches. The farad is, however, a very large capacity, and so in measuring small capacities, like Leyden jars, we employ one-millionth part of it called a *microfarad.*

It may be well to explain here that electrical units are required for electrical measurements just as units of length, weight and bulk are required for common things in life. We have the yard, the mile, the pound, the ton, the pint, the gallon, and so on, in terms of which we express the amount of certain things we use. The electrical units with which we are concerned are as follows :

1. The unit of electric current called an *ampère* after Andre Marie Ampère (1775–1836), the eminent French physicist.

2. The unit of electric pressure or potential called a *volt* after Alessandro Volta (1745–1827), the Italian philosopher who invented the pile.

3. The unit of electrical resistance called the *ohm* after Georg Simon Ohm (1787–1884), a German physicist who first enunciated the law governing the relation of electric current, electric pressure, and resistance.

4. The unit of electrical capacity called a *farad* after Michael Faraday (1791–1867), greatest of English electricians.

5. The unit of electrical inertia or inductance called the *henry* after Joseph Henry (1797–1878), an American physicist and contemporary of Faraday.

6. The unit of electrical power called a *watt* after James Watt (1736–1819), the inventor of the steam engine with separate condenser.

7. The unit of electric quantity sometimes called a *coulomb* after Charles Augustin Coulomb (1736–1806), a French electrical investigator.

8. The unit of electric work called a *joule* after James Prescott Joule (1818–1889), an English physicist renowned for his determination of the mechanical equivalent of heat.

With the object of adapting these units to the measurement of all amounts, large and small, it is usual to employ certain decimal multiples or fractions of them just as we have inches, yards, and miles for length units. This is done by the use of prefixes as follows: the prefix *kilo* means 1000 times. Thus kilowatt is a thousand watts. The prefix *meg* or *mega* means a million times. Thus a megohm is a million ohms. The prefix *milli* means one-thousandth part of, thus a milliampère is one-thousandth of an ampère. Lastly, the prefix *micro-* means one-millionth part of. Thus a microfarad is one-millionth of a farad, and so on.

We are now able to state a rule for determining the speed with which these electrical oscillations or swings take place when a Leyden jar is discharging through an electrical circuit consisting of a coil of wire.

It will be evident that as the electrons rush backwards and forwards the energy stored up in connection with the jar and coil of wire is at one moment wholly electrical, or, as it is called, static. This occurs at the moment before the charged jar begins to discharge. At another instant the energy is wholly magnetic or dynamic, and this occurs when the discharge current is at its maximum value, and the jar itself is for the moment destitute of charge. A little thought will make it clear that the energy passes from a static form to a dynamic form in one quarter of the complete double swing or, as it is called, periodic time. The strength of an electric current is defined by stating the quantity of electricity which passes across any section of a conductor in a second, assuming the current to remain constant. Therefore, the total quantity of electricity stored up in the jar reckoned in coulombs, divided by a quarter of the time period of swing, must be the average discharge current reckoned in ampères. The actual current, however, varies from instant to instant, but it can be shown that the average current during a period is very nearly 7-11ths of the maximum value. Therefore, the ratio between the numbers representing the maximum charge of the undischarged jar and the maximum current of the discharging jar is very nearly represented by 7-44ths of the complete time period of oscillation. Again, the maximum energy stored up in the jar in a static charge is measured by the number obtained if we multiply by itself or square the number representing the charge of the jar, and then divide it by twice the number denoting the capacity of the jar. Also a number representing the energy of the maximum discharge current is obtained by squaring the current strength and multiplying it by half the electric inertia or inductance of the discharge circuit. These energies must be equal numerically, because if the energy disappears from the jar it must reappear in some other form in the circuit. In fact, the energy is continually transformed backwards and forwards from energy of strain in the dielectric or glass to energy of motion in the electrons in the wire of the discharge circuit.

It will then be evident that the ratio of the static charge of the fully-charged Leyden jar to the strength of the maximum discharge current must be numerically equal to the square root of the product of the capacity and inductance. Since this ratio is also equal to 7-44ths of the time period, we see at once that the time period of oscillation of the discharging jar must be equal to 44-7ths of the square root of the product of the jar capacity and the circuit inductance.

The reciprocal of this gives us the frequency of oscillation or number representing the total oscillations which would take place in a second if the electric charge continued oscillating at the same rate.

A numerical example will make all the above clearer.

Suppose we have a Leyden jar made with a glass bottle of about one gallon size as regards its liquid holding capacity. Then, when coated inside and out with tinfoil, its electrical capacity or capacity for electrical charge would be about 1-400th of a microfarad. If this jar were charged and discharged through a copper wire about 1-25th of an inch in diameter, and a couple of yards long, the time of one complete electrical oscillation would be about 3-8ths of one-millionth of a second. Each oscillation would occupy the same time, even although the magnitude of the discharge current would die gradually away.

We sometimes find it convenient to calculate the frequency instead of the periodic time, and this gives us the number of oscillations which would take place per second if they continued for one second.

The rule for calculating this frequency is as follows: Multiply together the capacity of the condenser reckoned in microfarads, and the inductance of the circuit reckoned in microhenrys, and take the square root of this product. Then divide the result into 159000, and the quotient will be the frequency of the oscillations.

It is quite possible that the reader will find these rules easier to remember if they are put in symbolical form. Let the letter C stand for the capacity of the condenser, and Q for the maximum quantity of electricity stored up in it. Then $\frac{Q^2}{2C}$, or half the square of the quantity divided by the capacity, measures the energy stored up in the condenser. If I stands for the maximum discharge current, and L for the inductance or electric inertia of the circuit, then half the square of the current multiplied by the inductance or $\frac{1}{2}LI^2$ measures the energy associated with the circuit in the form of magnetic force when discharge takes place. Now these two quantities of energy are equal, that is $\frac{\frac{1}{2}Q^2}{C}=\frac{1}{2}LI^2$. Hence, $\frac{Q}{I}=\sqrt{CL}$, or the ratio of quantity of charge to maximum current is represented by the square root of the product of capacity and inductance. Again, the mean value of the discharge current is measured by $\frac{Q}{\frac{1}{4}T}$, where T is the complete time period of an oscillation, and it can be shown that this is equal to $\frac{2I}{\pi}$ where π stands for 3·1415, or nearly $\frac{22}{7}$, Hence, $\frac{T}{2\pi}=\sqrt{CL}$ or $T=2\pi\sqrt{CL}$, which is the rule given above.

So much was known up to the year 1887, but at that time Heinrich Rudolf Hertz began at Karlsruhe to make a series of famous researches which marked a fresh epoch in electrical discovery.

In all cases up to that time Leyden jars or condensers had been made with the metal plates very near together and separated by a thin sheet of glass or other insulator. Hertz devised a form of condenser in which two metal plates A and B were as far apart as possible with planes coincident, and each provided with a long rod terminating in a ball, the rods being placed in one line with the balls near together (see Fig. 9). When these plates are charged with electricities of opposite sign they become, in fact, the coatings of a sort of Leyden jar, in which the surrounding air takes the place of glass as the insulator. If they are charged to the pressure at which a spark takes place between the balls S (Fig. 9), this condenser discharges with oscillations through the rod. In other words, the electric charge rushes backwards and forwards along the rod.

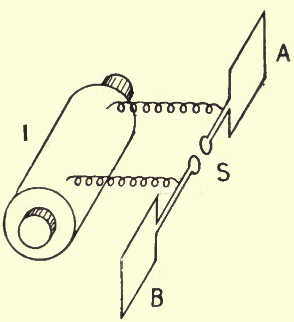


FIG. 9.—A Hertzian oscillator (AB) charged by an induction coil I.

We may regard this as due to the rapid vibrations of the free electrons in the metal rod.

We have already seen that when an electron vibrates or moves quickly to and fro the result is to propagate outward vibrations along the lines of electric force which stretch out from it like tentacles into space. We may picture an electron to ourselves as something like those tiny flower seeds which are provided with radiating hairs with which children amuse themselves by blowing off the hairs by successive puffs of breath. The seed represents the electron proper or nucleus, and the diverging hairs the associated lines of electric force.

Any sudden to and fro movement of the electron causes little thrills or vibrations to run outwards along the attached lines of force, and these constitute an electric pulse or electric wave. Hence, when a Hertzian oscillator, as it is called, is rapidly charged and discharged, each little electron in the wire dispatches its vibrations outwards along the lines of force, and the whole of them doing it together cause a powerful electric radiation or emission of electric waves to take place from the oscillator.

If all the electrons move backwards and forwards absolutely in step, then all the little electric ripples they each send out will be added together so as to make one considerable wave.

Hertz was able to demonstrate this radiation in a very ingenious manner. He employed a wire bent into a circle, but having its completeness interrupted at one point by a pair of balls with a very small air gap between them (see Fig. 10). Such a ring is called a Hertzian resonator. The balls act like the coatings of a very small Leyden jar, and this circuit, interrupted at one place, may be considered to consist of a very small condenser in series with a thick wire having small resistance and inductance. In any case, the circuit has a natural electrical time period, in which electricity in it will vibrate if disturbed. It resembles the string of a violin which vibrates in a certain period and gives out a particular note if it is plucked or bowed.

Hertz erected an oscillator in a large room with the rods in a horizontal position, and the balls in the middle separated by about half an inch. He then connected each rod to one pole of an electrical machine, so that the plates were charged one with positive and the other with negative electricity to a gradually increasing pressure. At a certain pressure a spark passes and makes the air between the balls conductive. The two plates are then connected together suddenly. The charges in them, therefore, begin to oscillate. The charge of that plate, which was positive, rushes over to the opposite plate, and the same for the negative charge. This is repeated again and again for several swings. If we translate this statement into the language of the electron theory it is as follows: The plate which is negatively electrified has more than its normal amount of electrons, and the plate which is positively electrified has less. The superfluity of electrons on one plate try to get over to the other plate. As long as the air in the gap between the two balls remains a non-conductor they cannot force their way through it. If, however, the pressure exceeds a certain amount, the air atoms are ionised or broken up, and it then becomes a conductor. The excess of electrons then rushes over to the opposite plate. Since, however, these electrons possess inertia they can no more be stopped instantly than a railway train. Hence, they overdo it, and too many pass over. The state of affairs as regards electronic population is now reversed. That plate which at first

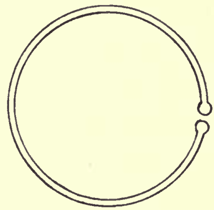


FIG. 10.—A Hertzian ring resonator.

had too many has now too few, and *vice versâ*. Hence, there is a rebound, but at each rush across the gap some energy is frittered away as heat in the air gap, but most of all by radiation or vibrations sent out along the lines of force. Accordingly, the electronic rushes die down at each reversal, and end by leaving the plates in a state of equilibrium and discharged. Such a set of die-away rushes of electrons backwards and forwards is called a train of oscillations, which are said to be damped out by loss of energy. Accompanying the train of oscillations there is the emission of a train of electric waves from the oscillator.

The particular experiment which Hertz performed which gave a convincing proof of the actual existence of such radiation was as follows: He set up his oscillator with the rods horizontal in a large room, the end wall of which was covered with a plate of zinc. He then held his ring resonator with its plane parallel to the oscillator rods and vertical, and the spark gap, say, at the top. He found that when the oscillator was set in action, and the resonator moved to or from the wall, that there were certain distances from the wall at which little sparks occurred between the balls of the resonator, thus showing that there were oscillations in it. Also certain intermediate positions at which there were no sparks. On measuring these distances they were found to be equal. On considering this effect it irresistibly suggested a comparison with the phenomenon of the interference of light we have already discussed. Just as the waves of light coming from the two small holes in Young's experiment produce bands of light and darkness at regular intervals on the screen, so here in Hertz's experiment we have a sort of interference produced, viz. positions in the room of sparking and non-sparking in the resonator. When this Hertzian experiment came to be critically examined it was found to be best explained as follows: The electric wave which is sent out from the oscillator at each vibration consists of a movement through space of lines of electric force accompanied by magnetic force at right-angles to them. If we call the line joining the centre or spark gap of the oscillator with the centre of the resonator the axis line, then if the oscillator rods are horizontal the electric force at all points along the axis is at right-angles to the axis and parallel to the oscillator rods.

The magnetic force is everywhere along the axis at right angles to the axis, and also at right-angles to the electric force.

As the electric pulse sweeps past the resonator the lines of electric force pass between the spark balls of the resonator and create for an instant an electrical difference between them just as if one ball had been charged positively and the other negatively.

The electric pulse then passes on, and is reflected at the end wall of the room just as a wave in water would be reflected at the closed end of a canal, and returns again on its original path. As it passes back between the balls of the resonator it again creates a difference of electrical state between the resonator spark balls as if they had been electrified. If the resonator is at an appropriate distance from the end wall of the room these two effects on the resonator, viz. on the passage of the electric pulse forwards, and on its return journey will each act so as to give the resonator a couple of properly timed sudden electrical impulses, which will set the electrons in it vibrating, and also cause a small spark at the balls of the nearly closed circuit. We have thus electrical oscillations set up in the resonator. If the resonator is at an appropriate distance from the wall the electrical impulse given to the resonator on the forward passage of the electrical pulse will conspire with or be added to the effect produced on the return journey, but at other distances they will neutralise each other. The action may be illustrated as follows: Suppose we hang up a ball by a string a yard or two long so as to form a simple pendulum. With a bit of wood give the ball a little tap. It will at once commence to swing. If we let it make one complete swing to and fro and then give a second little tap just at the right moment the two blows will conspire or assist each other so as to greatly increase the swing of the ball. If, however, the second tap is administered just as the ball returns to its original place after half a complete swing then the second blow will just suffice to bring the ball to rest and will neutralise the effect of the first blow.

The distance of these resonator-sparking points from the wall in Hertz's experiment depends, therefore, upon a relation between the natural or free time of electrical oscillation of the resonator and the time taken for the electrical pulse sent out from the oscillator to pass twice over the distance between the resonator and the end wall.

The resonator consists of a pair of small balls very close together, which may be compared, as already explained, to the two metal coatings of a Leyden jar, the air between them taking the place of the glass. Also these are connected by a wire in the form of a ring. The resonator possesses, therefore, the two qualities of capacity and inductance or electric inertia. It has, therefore, a certain definite time period in which the electrons in the wire vibrate if disturbed just as every pendulum has its own natural time-period of oscillation.

We can start a pendulum swinging and keep it swinging by giving to it little taps or blows provided these blows come at intervals of time which exactly agree with the natural time period of oscillation. If, however, the blows fall at irregular intervals they will not increase or keep up the swing of the pendulum.

Even a couple of taps administered exactly at intervals equal to the proper time period will create a good swing, but if not at right intervals will probably entirely neutralise each other's effect.

The principle here involved, viz. that large vibrations can be produced by very small impulses acting on a pendulum or any form of elastic rod having a natural time period of oscillation, provided that these impulses are exactly timed to that natural frequency, is of enormous importance in wireless telegraphy. Hence, no excuse is needed for explaining it more at length.

We may give another instance of the action in common life. For crossing a brook a plank is sometimes laid as a bridge. If any one stands on the plank it bends very slightly. If he jumps up and down irregularly it will probably not endanger the bridge. If, however, he should jump at regular intervals corresponding to the natural time period of oscillation of the plank, he will soon accumulate such large deflections or swings in it that it will be in danger of breaking.

In like manner the safety of a suspension bridge may be risked by a large body of soldiers walking over it in step if it should happen that the interval between their tread agrees closely with the time of swing of the bridge itself.

Now, in the case of the Hertzian resonator, when the electric wave or pulse sweeps over the resonator it creates a sudden electromotive force in the ring which gives an impulse or push to all the free electrons in the metal. The wave then travels on, is reflected at the back wall like a water wave at the closed end of a canal and returns on its path. Passing over the resonator a second time it will again give a push to the electrons. If it so happens that the natural time period of vibration of these electrons agrees exactly with the interval between the passage of the direct and reflected wave, then these two impulses will conspire greatly to increase the swing of the electrons and may cause sufficient displacement to break down the insulating quality of the air in the very small air gap and form a spark.

It can be proved by a mathematical calculation, not however suited to an elementary book, that in such a Hertzian resonator consisting of a ring of wire with a very small spark gap in it, the natural time of vibration of the electrons in the wire is a fraction of a second expressed by dividing eight times the diameter of the ring measured in centimetres by the number 30,000 million.

Thus, supposing the ring was 50 centimetres in diameter or about 20 inches, then the time period of complete oscillation would be 1-75th of one-millionth of a second, and the time of a semi-oscillation would be 1-150th of one-millionth of a second.

It may be well to note that we are here dealing with small fractions of a second of time, which are as much less than one second as a second is than a fortnight, nevertheless they can be accurately measured. If, then, a Hertzian resonator is set up as described in a room with a metal sheet on the end wall and if we measure the distances between the places on the axis line at which the resonator sparks when the oscillator is in action it is not difficult to see that these lengths are equal to the distances over which the electrical impulse or wave travels in the time of one semi-oscillation of the electrons in the resonator. The speed of the wave is then found by dividing this distance by the time of half a complete oscillation of the resonator.

The most careful experiments of this kind were made in 1891 by MM. Sarasin and de la Rive in a large hall at Geneva, and they employed resonators of various sizes. For instance, using a ring resonator 400 centimetres in diameter, the distance between adjacent sparking points was 406 centimetres. Now the half period of oscillation of this resonator as a fraction of a second is equal to 1600 divided by 30,000 million. Hence, the electric wave travels a distance of 406 centimetres in 1600 ÷ 30,000,000,000ths of a second. Therefore the velocity is nearly 30,000 million centimetres per second, or 300,000 kilometres per second. But this velocity is identical with that of light. Innumerable experiments of the same kind have established beyond a doubt that the electric impulses sent out from a Hertzian oscillator travel through space with the same speed as light, and are, therefore, unquestionably disturbances propagated through the æther.

Hertz proved by a series of brilliant experiments that the electric waves or impulses given off from his oscillator could be reflected by sheets of metal and refracted by large prisms of pitch just as rays of light are by mirrors or glass prisms. By using a small Hertzian resonator it is possible to imitate all the ordinary optical experiments with this invisible radiation, and detailed accounts of the apparatus and experiments used for this purpose will be found in the author's little book, *Waves and Ripples in Water, Air and Æther,* Chapter VI.* For our present purpose we shall, however, consider the subject from the point of view of wireless telegraphy rather than of optics, and, therefore, must examine a little more closely into the mechanism of this effect called an electric wave.

Let us, then, suppose we have a rod of metal of a certain length, and that we are able to set in vibratory motion the free electrons in the metal by methods which will be explained later. These electrons in the interatomic spaces in the rod lurk between the atoms or spring from one atom to another. In their ordinary condition these electrons are leaping about irregularly, that is, in every possible direction. At each start and stop or change of velocity the gossamer garment of lines of electric force which converge on to the nucleus of the electron has a rude shock given to it, and the result is to send out in every direction a vibration or thrill along these lines of force. As already explained, this consists in a sort of kink or bend which travels outwards along the line, and as the kinks on each line move with the same velocity the effect is to produce an expanding shell within which the electric force is parallel to the surface of the shell or perpendicular to the radius. Also this outward moving kink in the line of force generates a magnetic force, which is at right-angles to the direction of the bent portion of the lines of electric force and to the direction in which it is moving. Within this shell or spherical layer we have, therefore, intense electric and magnetic force directed at right-angles to each other,

* Published by the Society for Promoting Christian Knowledge, Northumberland Avenue, Charing Cross, London.

and also to the radial line from that point to the electron nucleus. Moreover, these portions of the line of forces are being moved outwards with the speed of light. This process constitutes the electric radiation of an electron.

When we drop a stone on to still water, and make a splash at one point we see a circular ripple of water move outwards from that point on the surface of the water, and this ripple consists in a kink or corrugation or bend in the level surface of the water, which changes its place on the level surface of the stationary water.

In a similar manner when we give an electron a sudden jerk starting or stopping it we cause a sort of splash in the æther and propagate outwards a spherical ripple which consists in a kink or bend in the direction of the otherwise straight lines of electric force radiating from it.

If, then, we consider a straight wire, and suppose the free electrons in it all swinging backwards and forwards in the direction of the length of the wire with great rapidity, each electron will send out its own spherical ripple, and they will all do it together, so that their effects will be added together. The result is to send out what may be called a cylindrical æther ripple from the wire. At all parts of this wave surface, which is in form like a cylinder with the wire in its axis, the electric force is directed parallel to the wire, and the magnetic force is directed in circular lines, which are circles described round the wire with centres on it.

This may be seen in another way. Let us suppose that in the diagram in Fig. 11 the small circles stand for the electrons, and the thin black lines for the lines of electric force diverging straight away from the wire.

Then when the electrons make one jump backwards and forwards suddenly the result is to produce a kink on these lines just as if we were to give a sudden jerk to one end of a long rope fastened at the far end. For the sake of simplicity, we shall consider the kink produced on the line of force to be a square shouldered kink. It will easily be seen that if all these kinks are produced together, and travel outwards together, the result is as if we superimposed on the stationary radiating lines of force a pair of moving transverse lines of electric force which are parallel to the wire, and move outwards parallel to themselves. In one of these moving lines the electric force is directed in one direction, and in the other in the opposite direction.

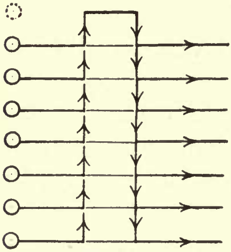


FIG. 11.

Since moving electric lines give rise to magnetic lines at right-angles to themselves, it is clear that the wire is embraced by a pair of circular expanding lines of magnetic force which accompany the expanding lines of electric force. If we could see these magnetic lines, and if we were to look endways at the wire, we should see these circular lines of magnetic force moving outwards by becoming perpetually larger in size just as do the water ripples on a pond when a stone is thrown into it. If the wire we are considering is not very long, then, when electric oscillations take place in it the lines of electric force which fly out from it will take the form of closed loops, as shown in Fig. 12. Also the magnetic lines will be circles, the planes of which are at right-angles to those of the electric loops. At each oscillation of the electrons a loop of electric force is produced near the wire, and this moves outwards with the speed of light. If the vibrations of the electrons continue then other loops are generated, and these flit away outwards in all directions from the wire.

A case of particular importance for our purpose is that of a wire, the bottom end of which is connected to a plate of metal sunk in the earth. Such a rod or wire is called an *antenna* or *aerial* wire, and it can have powerful electric oscillations set up in it by means which will be described in the next chapter. If we consider the earth's surface to be a fairly good conductor, which is the case over sea water, then such an earthed antenna is equivalent to one-half of the completely insulated rod or Hertzian oscillator. When electrical oscillations are set up in the rod there is in effect a high frequently alternating current in the rod which current has its maximum value at the base or earthed end, and is zero or nearly zero at the summit or upper end. In accordance with the principles above explained we have, therefore, an emission from the rod of lines of electric force which take the form of semi-loops resting on the ground. The accompanying lines of magnetic force are expanding circles.

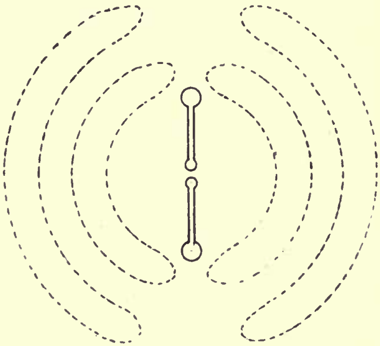


FIG. 12.—Lines (dotted) of electric force surrounding a Hertzian oscillator when in operation.

We have made an attempt to represent in Fig. 13 the distribution of this electric and magnetic force at any one instant round the rod, represented by the thick black vertical line in the diagram. It must, however, be understood that nothing short of a "Cinematograph" or "Living Picture" could represent what actually exists. For these looped or arched lines of electric force represented by dotted lines are not stationary, but are flitting outwards from the rod in every direction with the speed

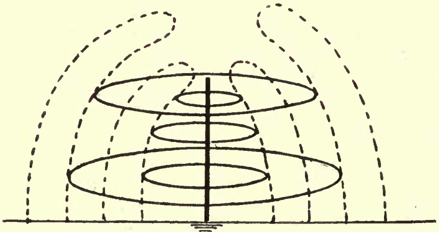


FIG. 13.—Lines of electric force (dotted) and lines of magnetic force (firm) surrounding an antenna (vertical thick line) when in operation.

of light. Also the circular lines of magnetic force (represented by the firm black lines) are expanding at the same rate.

It should be noticed that at certain regular intervals of space and time the directions of these electric and magnetic forces are reversed. If, then, we possessed the kind of eye which would enable us to see these lines of force as they rush through the air we should see that at certain regular intervals of space the direction of the electric force near the earth was upwards, and at intermediate positions it was downwards. The interval between two adjacent positions of electric force in the same direction and phase as it is called is said to be one wave length.

The relation between wave length and frequency of oscillation in the antenna is expressed by the formula :—

Wave length in feet = 984 million divided by the *frequency* of the oscillations ; or,

wave length in metres = 300 million divided by the *frequency* of the oscillations.

Hence, if the frequency is one million the wave length would be 984 feet, or 300 metres.

We have to distinguish two kinds of electric waves.

First those which are created by a single oscillation or by a group of oscillations, each of which is less in amplitude or extent than the previous one. This is technically termed a *damped* or decadent train of oscillation, and the resulting waves of the same kind are called damped wave trains. Of this nature are the electric waves produced by charging and discharging a Hertzian oscillator by an electrical machine, or an ordinary sparking coil, such as is used in petrol engine ignition. Each wave train consists of a series of waves following each other closely, but the amplitude, or what we should call the height of the wave in speaking of water waves, continually decreases down to nothing. There may, however, be a wide interval between the wave trains so that the time occupied by the whole group of waves in one train in passing a given point may be small compared to the time interval between the wave trains. This may be represented by the diagram in Fig. 14*a*. A very important matter is the rate at which the amplitude of the waves in each train decays. The rate of decay can be measured by stating the number of waves of one train which pass a given point before the wave amplitude is reduced, say, to 1 per cent. of that of the initial wave of the train.

It can be shown that if we take a number equal to one less than the number of waves which pass before the amplitude dies away to 1 per cent. of the initial amplitude, then this number divided into 4·6 will give us an important constant called the *decrement* of the waves.

A wave train consisting of a large number of waves which decrease in amplitude slowly is said to have a small decrement and to be feebly damped. A wave train having a small number of waves in a train rapidly decreasing is said to be highly damped (see Fig 14*a*) and to have

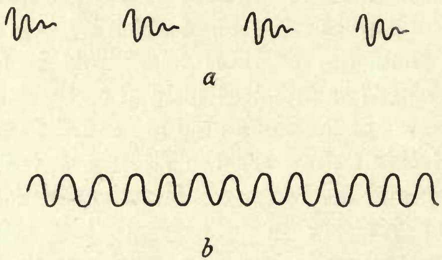


Fig. 14.—Diagram representing damped intermittent oscillations (*a*) and undamped oscillations (*b*).

a large decrement. We shall see that these ideas are of the utmost importance in connection with transmitters and receivers in wireless telegraphy.

We have also to consider cases in which the decadent wave trains are so closely adjacent that there is no idle or unoccupied time between the trains. These are called closely sequent wave trains. Again, in some cases, the oscillations employed continue without decay or are persistent as indicated by the wavy line in Fig. 14*b*. We shall proceed to discuss the application of these facts to wireless telegraphy in the next chapter.

CHAPTER III.

WIRELESS TELEGRAPH TRANSMITTERS, AND THE SENDING OF WIRELESS MESSAGES.

WITH the aid of the information given in the two previous Chapters the reader will now be prepared to advance a stage farther and to follow without difficulty an explanation of the means and methods by which wireless telegraphic messages are sent.

The apparatus for sending messages collectively considered is called the Transmitter, and that used for reception the Receiver.

It will probably be desirable to explain in the first place that all telegraphy involving the communication of information to a distance makes use of certain visible or audible signs each of which stands either for a letter of the alphabet or for a word or phrase. Thus in the case of Flag signalling as practised in the Army or by every Boy Scout, the letters of the alphabet are denoted by groups of long and short, or else right and left, dips of a flag attached to a stick held in the two hands in a particular manner, or the letters may be signalled by long or short flashes of light made with a shielded lantern, or with sunlight reflected from a mirror as in heliographic army signalling. In any case a code of signals has to be adopted. In naval or military signalling some codes are used which are secret, but for ordinary telegraphy and especially for wireless telegraphy the code employed is called the International Morse Code in which the letters of the alphabet and the numerals are each denoted by a short group of long or short sounds, marks, or flashes which are technically called *dashes* and *dots*. Thus the letter A is signified by a dot followed by a dash thus, · — and the letter C by — · — ·. The complete Morse Code is given below :—

THE INTERNATIONAL MORSE CODE OF SIGNALS.

A	· —	N	— ·	1	· — — — —
B	— · · ·	O	— — —	2	· · — — —
C	— · — ·	P	· — — ·	3	· · · — —
D	— · ·	Q	— — · —	4	· · · · —
E	·	R	· — ·	5	· · · · ·
F	· · — ·	S	· · ·	6	— · · · ·
G	— — ·	T	—	7	— — · · ·
H	· · · ·	U	· · —	8	— — — · ·
I	· ·	V	· · · —	9	— — — — ·
J	· — — —	W	· — —	0	— — — — —
K	— · —	X	— · · —	Full stop	· · · · · ·
L	· — · ·	Y	— · — —		
M	— —	Z	— — · ·		

In the case of Continental languages there are additional signals for accented vowels and for diphthongs.

In accordance with the regulations of the International Radiotelegraphic Convention certain signals are also decreed to indicate the beginning and end of messages, and above all an especially important signal for ships in distress calling for aid, viz. the S, O, S, signal, thus · · · — — — · · · repeated at short intervals which signifies great danger, and is a ship's call for immediate help.

These signals may be made either to the eye or the ear by the signs printed on paper tape or else by long or short sounds made as a telephone in a manner to be described later on.

The sending of a telegraphic message involves, therefore, means for producing at a distance some audible or visible effect which can be more or less prolonged to give a dash or dot signal, and repeated as required to build up the necessary alphabetic signals.

In the case of non-alphabetic languages such as Chinese, the ideographs or signs for ideas or words have to be numbered and the numbers are transmitted.

As an illustration of the manner in which intelligence may be thus transmitted let us consider the very simplest case of telegraphy *with* wires.

Suppose a pair of wires stretched on insulators between two places. At one end let there be a voltaic battery the poles of which can be connected as required to the ends of the pair of long line wires by a contrivance called a *key*. At the other end let the wires be connected to a spiral wire of copper covered with silk wound round a bar of iron. On connecting the battery to the line wires by the key an electric current will flow along them, and passing round the spiral wire will cause the iron bar to become a magnet. This can then be caused to attract a piece of iron, called an armature, and this in turn to move a lever which will bring a metal pen in contact with a slip of paper moved along by clockwork. If the key at the sending end is depressed for a very short time the pen at the receiving end will make a short mark or dot upon the paper, and if it is depressed for a longer time it will make a long mark on the paper indicating a dash. Hence, by proper manipulation of the key the person at the sending end can write down on the moving slip of paper at the receiving end any message he pleases in the Morse Code.

In this case the wire connecting the two places forms the means of guiding the electric energy from the sending station to the receiving station. In the case of wireless telegraphy we have no such guide. The process of sending wireless signals consists in creating at some place a rapid series of unguided electric waves diffusing out into space which are cut up or interrupted by means of a key or interrupter so as to form short or long trains of waves in accordance with the signals of the Morse alphabet. It is as if we had a horn or hooter continually being blown but provided with some tap or interrupter in the air pipe to intermit the continuous sound into short or long blasts following one another in accordance with the Morse code. Or to use another simile it is like a lighthouse, the light from which is interrupted by a screen so as to produce long or short flashes of light. This is what is in fact actually done to enable the lighthouse to inform the mariner of its name and position.

These audible or luminous signals can be heard or seen by any one within a certain range. In the same manner the wireless signals made as below described can be picked up and interpreted by any one within a certain range possessing the necessary appliances. The wireless transmitting station must then be considered as a sort of lighthouse sending out flashing signals not made with visible light, but with invisible electromagnetic radiation of much greater wave length, or it may be regarded as a sort of hooter sending out Morse code sound signals consisting not of air waves, but of Hertzian or Maxwellian electric waves affecting only special appliances.

We proceed then to describe more in detail the appliances used. Every wireless telegraph transmitter consists of three parts.

(i) Some appliance for creating a high or very high electromotive force (E.M.F.).

(ii) Means for using this high E.M.F. to create electric oscillations in a certain circuit.

(iii) A part called the antenna or aerial wire or radiator by means of which the energy of these electric oscillations is in part transformed into electromagnetic waves in the surrounding æther, and radiated as wave energy in the form of long electromagnetic waves.

Beginning with the last-mentioned element we find at every radiotelephic station some kind of long elevated air wire or wires called the aerial or antenna. In erecting this antenna the first step is to set up one or more tall masts or towers.

In most cases for small land stations a single ordinary timber ship's mast 150 to 180 feet in height will serve. This mast is carefully stayed, as it is generally erected in a very exposed position on the sea coast or on a cliff or hill. In the case of large land stations lattice towers of wood or steel are built, or else steel tubular masts are erected and strongly stayed.

The simplest form of antenna consists of a length of about 150 feet of stranded copper wire cable suspended from the top of the mast by an insulator of ebonite or porcelain and connected at the bottom to one end of a coil of wire the other end of the coil being attached to a plate or network of wires laid in the earth or to a large metal conductor which may be in some cases insulated from the earth (See Fig. 15*a*). In other cases more elaborate forms of antenna are employed. Thus, for instance, a number of such wires may be elevated and attached at their upper ends to an insulated cross stay which is stretched between two masts. We then have a *fan antenna* (see Fig. 15*b*). Or the wires may be led up the side of the mast and then bent down radially in all directions like the ribs of an umbrella forming an *umbrella antenna* (see Fig. 15*c*).

In the case of ships it is usual to stretch a number of widely separated wires between the masts in a horizontal direction, and lead them downwards towards the bow and stem. Other vertical wires leading to the signalling

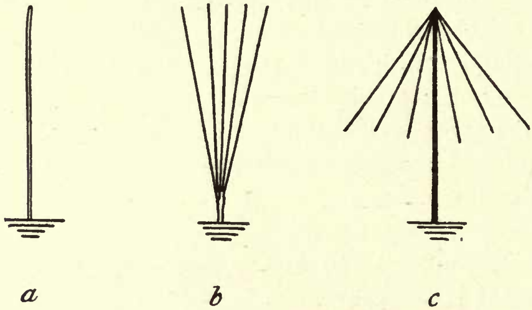


FIG. 15.—Various types of antenna or aerial used in wireless telegraphy.

cabin are connected to the middle of the horizontal ones, and then we have a *T-shaped antenna.*

The Marconi Company mostly make use of a *directive aerial* or *antenna,* invented by Mr. Marconi, which has a certain length of the wires nearly vertical, and a much greater length horizontal, as shown in Fig. 16. These wires are supported on masts represented by the vertical double lines in the diagram.

This directive antenna possesses the valuable property that it sends out the most powerful radiation in a direction opposite to that in which the upper horizontal portion points. Again, a number of nearly vertical wires may be arranged in cone shape, being suspended from a number of masts arranged in a circle. In some cases the supporting mast itself, if of metal, forms part of the antenna. In this case the foot is not buried in the earth, but rests upon a block of glass or marble.

Whatever form it takes the antenna essentially consists of a wire or wires the upper or outer ends of which are insulated, and the lower ends connected with a plate in the earth or with another conductor called the balance or counterpoise, the antenna and earth plate or

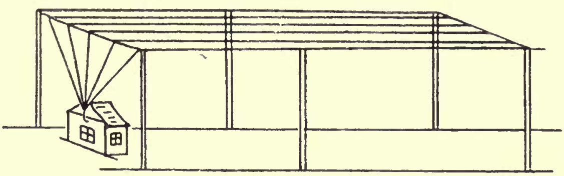


FIG. 16.—Marconi directive antennæ.

counterpoise being connected through a coil of wire which forms part of the circuit.

If in this antenna we set up very high frequency electrical oscillations consisting in an electric current which runs up and down the antenna, we have as a result electromagnetic waves of great wave length radiated from it. There are several methods by which these oscillations can be generated. One method, generally called the *spark* method, for creating the oscillations in the antenna is as follows. As above stated the antenna A (see Fig. 17) is connected in series with a coil of wire P which is wound on a wooden frame. On this frame, or on another near to it, a second coil of wire S is wound, and this last coil has one of its ends connected to the inner coating of a Leyden jar L or number of Leyden jars, and the other end to one of a pair of balls B called spark balls, the second ball being connected to the outer coating of the Leyden jar. The reader will easily understand the arrangement from the diagrammatic sketch in Fig. 17. These spark balls are

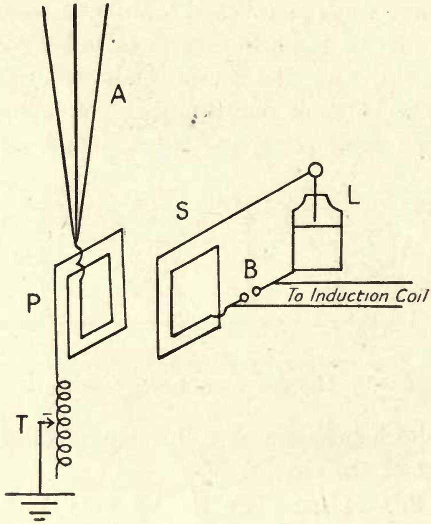


FIG. 17.

also connected to some appliance, such as an induction coil, for giving a high-pressure current of electricity.

Now it has already been explained that if a Leyden jar or condenser is charged, and then suddenly discharged through a circuit or wire of small resistance, the discharge of the jar is not a single movement of electricity in one direction, but consists in a series of backwards and forwards movements or flow of electricity first in one direction and then in the opposite, thus setting up what are called electrical oscillations in the discharge circuit.

When this rapid to and fro rush of electricity in the discharge wires takes place it generates another similar movement of electricity in the adjacent coil of wire to which the antenna is attached. It was one of Faraday's most notable discoveries that if an alternating or interrupted current of electricity exists in one wire then it creates a similar current in a closely adjacent wire. This induction of electric currents, as it is termed, is the principle involved in the construction of every sparking coil or induction coil as used in motor engine ignition. In the case we are considering, the oscillations set up in the wire which is in circuit with the Leyden jar give rise to other induced oscillations in the coil in series with the antenna. Hence, rapidly reversed electric currents run up and down the antenna. It therefore becomes equivalent to a very large Hertzian oscillator set up with its axis vertical to the earth.

The high frequency currents in the antenna are, in accordance with modern views, only very rapid oscillations of the free electrons in the wire. As already explained these electronic vibrations cause vibrations in the lines of electric force radiating from the electrons, and therefore electric waves are sent out into the æther or surrounding space.

The antenna is, as it were, a very large electrical organ pipe in which oscillations of the electrons in the wire take the place of oscillations of air particles in the pipe and ætherial or electric waves radiated from the wire take the place of air or sound waves sent out from the organ pipe. We have then to complete our description by explaining how the condenser or Leyden jar is charged to a high pressure. The usual method on board ship is to employ a large induction or spark coil. A bundle of fine iron wires is wound over with a spiral of thick cotton covered copper wire. Over this is placed an ebonite tube, and on this is wound in sections an enormous length (8 or 10 miles) of fine silk covered copper wire (see Fig. 18).

The ends of the thick wire or primary circuit are connected to a storage battery of eight or ten cells supplying an electric current through a device which continually

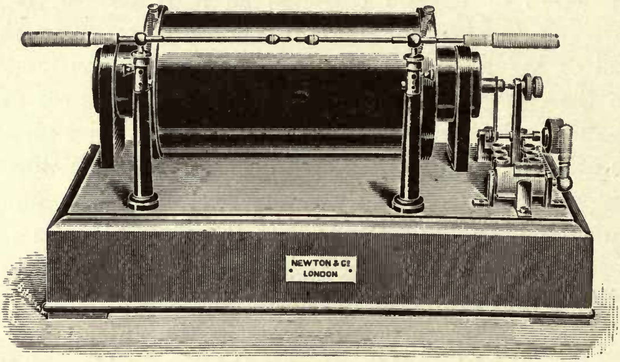


Fig. 18.—A 10-inch spark induction coil for wireless telegraphy.

interrupts the current. The primary circuit is therefore traversed by an electric current which is continually being started and stopped.

The result is to produce in the long secondary wire or circuit a very high electromotive force of many thousand volts. This would give rise to a spark several inches long between the terminals of the secondary circuit if no Leyden jar were connected to it. These ends are, however, connected to the spark balls in series with the Leyden jar in the transmitter. This high electromotive force therefore charges the jar with electricity, and when the pressure is sufficiently high the jar discharges in the form of a short bright spark across the spark gap, and produces by this discharge electric oscillations in the discharge circuit.

On board ship the spark coil is generally supplied with current from a dynamo machine in the ship's engine-room. In order to make provision against accidents and the flooding of the engine-room, it is usual to provide storage batteries in the wireless telegraph cabin which hold enough electricity to work the spark coil for several hours.

To make the signals, a hand key or interrupter is placed in the primary circuit of the induction coil, and by pressing down this key the operator completes the primary circuit of the spark coil, and immediately a torrent of brilliant sparks leap across between the spark balls to which the ends of the secondary circuit of the spark coil are attached. These sparks are due to the rapidly repeated discharge of the Leyden jar or condenser. To secure the right kind of discharge the spark balls must not be too near or too far apart, but have an interval between them of about ½ or ⅜ths of an inch. The operator can judge by the sharp crackling sound of the spark whether the Leyden jar is producing the kind of oscillatory discharges which are required, or whether the spark is merely due to the secondary current of the spark coil alone. The number of sparks per second depends upon the nature of the interrupter used in the primary circuit of the induction coil, but it is generally 100 or 200 per second.

If, then, the operator gives one sharp tap on the sending key in the primary circuit of the spark coil the result is to permit, say, half-a-dozen discharges of the Leyden jar to take place through the coil of wire in series with it and across the spark gap. These run together into a single brilliant spark lasting, say, for about one-tenth of a second. If he presses the sending key for a longer time then about twenty to thirty discharges would take place, and the spark would seem to endure longer. A single short tap on the key produces therefore a *dot* signal, and a pressure for about three times as long a *dash* signal. Each of these discharges consists of a rapid movement to and fro of the electrons in the above-said coil. This alternating current creates another similar alternating current in the other adjacent coil of wire in series with the antenna. These two coils of wire taken together are called an "oscillation transformer," or in slang terms a "jigger." The alternating currents set up in the antenna come in groups corresponding to each spark discharge.

The reader must then understand clearly that corresponding to each such group of oscillatory currents in the antenna we have corresponding trains of electric waves radiated, each train consisting of a series of waves following each other, but every wave a little less in amplitude than the one preceding it.

Each train of waves may be likened to a short blast made on a trumpet, the sound dying away more or less slowly during each blast. Each individual discharge of the Leyden jar produces a train of electric oscillations in the antenna, and each train of oscillations in the antenna produces a similar train of electric waves.

Hence, since the dot signal may comprise a few say, half-a-dozen jar discharges, the dot signal is in effect equivalent to the emission from the antenna of half-a-dozen groups of electric waves, each group being composed of a train of waves, say ten to twenty, gradually decreasing in amplitude.

The dash signal comprises a group containing many more such trains of waves, and these may be represented graphically by the diagrams in Fig. 19.

Supposing that the operator wishes to call up a ship and ask the question, " What ship are you ? " he would tap the key as follows: *dot-dash-dash, dot-dot-dot-dot, dot-dash, dash ; dot-dot-dot, dot-dot-dot-dot, dot-dot, dot-dash-dash-dot ; dot-dash, dot-dash-dot, dot ; dash-dot-dash-dash, dash-dash-dash, dot-dot-dash.* As a matter of fact, the

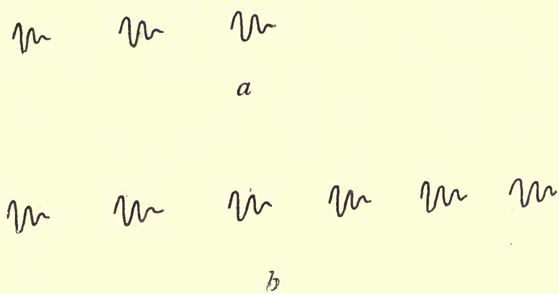


FIG. 19.—Groups of oscillations forming a dot signal (*a*) or a dash signal (*b*).

operators are in the habit of using many contractions and abbreviations, the word " are " would probably be denoted by the single letter " r " or by the signal *dot-dash-dot,* and the word " you " by the single letter " u " or by the signal *dot-dot-dash,* so that to save time the whole message might be abbreviated into *dot-dash-dash, dash, dot-dot-dot, dot-dash-dash-dot, dot-dash-dot, dot-dot-dash.*

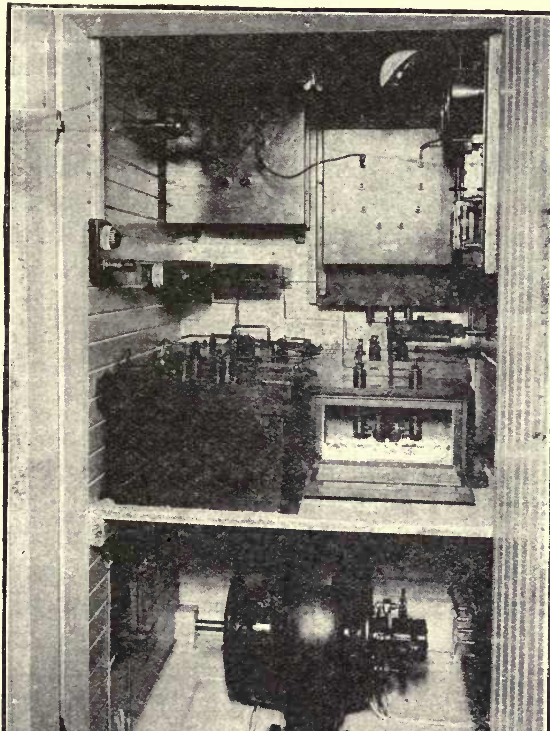
In any case the message, whether in plain English or abbreviated or in code, is tapped out in *dot* and *dash* signals, and each of these short or long taps on the key sends out from the antenna a brief or prolonged group of trains of electric waves, each train tailing off in strength, but comprising perhaps ten to thirty waves, as the case may be.

It will be seen, therefore, that the whole apparatus is very compact and simple, and is capable of being contained on a small table in a ship's cabin. In ships provided with wireless telegraphy a cabin on deck is set apart for it and into this the lower end of the antenna is brought through a tubular insulator.

The main spark coil is generally screwed up against a bulk head. The exciting current is brought up by insulated wires from the dynamo in the engine-room, and the oscillation transformer and the necessary Leyden jars are contained in boxes which can be fixed to the bulk head or on the cabin table. The operator has then only to turn on the current, adjust the spark gap and tap the sending key (see Fig. 20).

The above is the simple practical form of ship transmitter invented by Marconi and employed by Marconi's Wireless Telegraph Company in all their extensive ship work. In the case of large ships a special form of alternating current dynamo is used which supplies to the spark coil an alternating electric current, having a frequency of 300 or 400. That means to say the current is reversed in direction some 600 to 800 times a second. The reason for this will be more fully explained after we have dealt with the construction of the receiver.

It may be noted that instead of using two separate coils of wire on the jigger or oscillation transformer, one in series with the antenna, and the other in series with the Leyden jar, we can employ a single coil of wire divided into two sections. We insert a spiral coil of wire in between the base or lower end of the antenna and the earth plate or balancing capacity. Two points on this coil not very far apart have movable clips or contacts on



By permission of Marconi's Wireless Telegraph Company.

FIG. 20.—Arrangement of Transmitting apparatus in the "Wireless Cabin" of a ship. The dynamo shown in the lower part of the illustration is usually placed in the engine-room.

them, and one of these is connected to the interior coating of the Leyden jar or jars, and the other to one of the pair of spark balls. The other spark ball is connected to the outer coating of the Leyden jar. In this manner we make part of the coil of wire the discharge path for the Leyden jar, and the rest of the coil acts as a secondary circuit and path for the induced secondary currents which run up and down the antenna. This arrangement is called a single coil jigger or auto-transformer. By a celebrated judgment of Lord Parker in the British High Court of Justice in 1911 it was held that for patent purposes the two arrangements are identical, and that it matters not whether one single coil divided into two parts, or two separate coils are used, they are both included in the term oscillation transformer as a descriptive name.

Before we can explain another modification of the above spark system it will be necessary to point out the manner in which the oscillations or rapidly reversed electric currents in the antenna react upon those in the Leyden jar circuit which gave birth to them.

The electric oscillations created in the antenna are generated by the influence of the oscillations set up by the discharge of the Leyden jar in the adjacent or coupled circuit. The swinging to and fro of the electrons in this last circuit causes a sympathetic swinging of the electrons in the closely connected antenna circuit. This action is reciprocal. Not only does the oscillatory current due to the discharge of the Leyden jar create another similar current in the antenna, but the current in the antenna acts back to influence the oscillations in the Leyden jar circuit. The result of this mutual action is to produce oscillations in both the circuits of two different frequencies. This matter is somewhat difficult to understand, but it can be made plain by a simple experiment with two pendulums. Let a string be stretched loosely across a room, and to it let a couple of other strings of equal length be fastened about a yard apart, these last strings being provided at their lower ends with heavy metal balls, so as to form two simple pendulums. Take hold of one bob and draw it on one side, and let it go so that it can swing as a pendulum across the direction of the loose horizontal string. In swinging it will give little jerks to the horizontal string, and these will set the other pendulum in motion. But now watch what happens when the pendulums are left to themselves. The first pendulum will gradually come to rest whilst the second pendulum will gradually take up the motion and begin to swing. After a few moments pendulum No. 1 will begin to swing again, and pendulum No. 2 will slowly come to rest, and thus the vibratory motion will be handed backwards and forwards from one to the other. The explanation is obvious. In accordance with Newton's Third Law of Motion, Action and Reaction are equal and opposite. One moving body cannot set another in motion without giving up energy and reducing its own motion. Hence, if we could take a very accurate measurement of the speed or rate of vibration of each pendulum, we should find that each pendulum was alternately swinging a little faster and a little slower than its own natural free rate of vibration. When it is acting as the driving pendulum and giving up energy its own rate is retarded, and when it is acting as the driven pendulum and taking up energy, its own rate is accelerated.

Hence, in such a pair of equal coupled pendulums we have two rates of vibration present, which are respectively greater and less than that of either pendulum if left to swing alone without the other.

An exactly similar effect takes place in the case of two electric circuits in which oscillations exist.

If we have two wires laid side by side, and if in one of these wires free electric oscillations are set up, then these oscillations excite similar oscillations in the other circuit if tuned to the first one. The reaction of the circuits, as in the case of the two pendulums, then causes the appearance of two rates of electric oscillation in each circuit, one greater and one less than the natural free rate.

Accordingly, if we have a coupled transmitter on the spark system in which free electric oscillations are excited in one circuit by charging a condenser and letting it discharge across a spark gap; and if these oscillations are made to excite others in a closely adjacent secondary or neighbouring circuit to which the antenna is attached, then the reader will see that under these conditions when the two circuits are tuned there will be oscillations of two different frequencies in each.

This implies that waves of two different wave lengths are given off from the antenna. It is just as if an organ pipe gave out notes of two different pitches or a luminous body rays of two different colours.

In general the message to be sent is received only on one of these waves. There is a certain disadvantage in dividing the energy in this manner between waves of two different wave lengths. A discovery made by Prof. M. Wien in 1906 enables us, however, to eliminate one of these waves and cause the antenna to send out waves of one period only. Wien found that if the spark in the primary circuit is allowed to take place between two metal plates very close together it is rapidly quenched or extinguished, due probably to the cooling action of the adjacent metal surfaces. Under these conditions the primary circuit becomes open almost immediately. The secondary circuit receives an impulse which sets up in it the free oscillations and nothing else. As long as the primary spark continues the primary circuit is closed or completed, since the spark itself is a conductor. Hence the secondary circuit can act back on it and set up the duplex oscillations. If, however, the primary spark is quenched at once then the secondary cannot act back on it, because the circuit is open. Accordingly, if in the circuit containing the primary circuit we place a spark gap consisting of a pair of metal plates very close together, or better still, a series of such metal plates, say ten or twelve, with small gaps of a fiftieth of an inch between each, such a spark permits only one sudden "quenched" or highly damped discharge of the condenser to take place. The secondary or antenna circuit coupled to it has, therefore, only one single frequency in the form of a prolonged or feebly damped oscillation set up in it. The difference between the nature of the oscillations set up in the two coupled circuits when the primary condenser spark is not quenched and when it is quenched is best shown by the diagrams in Fig. 21. The lines in Fig. 21*a* represent the primary and secondary oscillations in a single train with the unquenched spark, and the lines in Fig. 21*b* the same with the quenched spark. The periodic increase and decrease in the amplitude in the lines in Fig 21 (*a*)

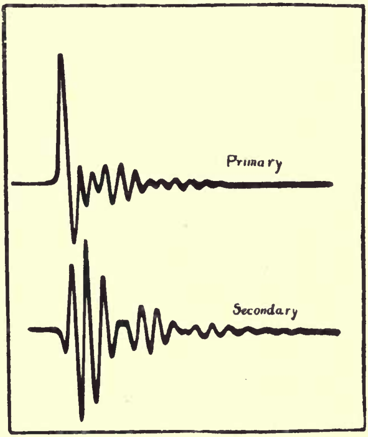


FIG. 21(*a*).

is a proof that there are oscillations of two frequencies present. The effect is quite analogous to the phenomenon known as "beats" in music. If two organ pipes slightly out of tune are sounded together the resultant sound undergoes a periodic waxing and waning called "beating," and this is the result of the co-existence of two waves in the air of slightly different frequency.

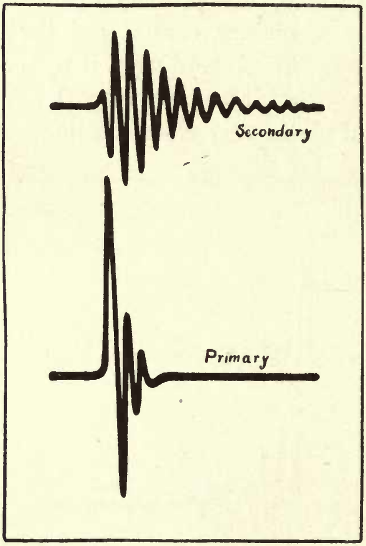


FIG. 21(*b*).

Dischargers for producing quenched sparks are now much used in wireless telegraphy. A special form exceedingly useful in the laboratory, which is a modification of one invented by Peukert, has been devised by the Author of this book. In this discharger two discs of steel are prepared with perfectly flat true surfaces. One of these is fixed to a shaft running in ball bearings, and is rotated by an electric motor. The other disc is fixed and separated from the rotating disc by a space of about 0·01 inch. The two discs are immersed in paraffin oil. The lower or fixed disc has a hole in the centre. When the upper disc is set in rotation the oil between the disc is flung out and fresh oil is sucked in at the hole. There is then a continual circulation of fresh oil. The two discs form the two surfaces of the spark gap, and when connected into the oscillation circuit the condenser discharge takes place between them. It is, however, a perfectly damped or dead beat discharge, and the condenser discharge is arrested almost immediately. Hence, when a Leyden jar circuit containing this spark gap is coupled to another tuned secondary circuit, this last circuit receives a sudden electric impulse at each discharge in the primary, which has the effect of setting up a train of oscillations in the secondary of one single periodicity.

It is of great importance, as we shall see when considering the action of the receiver, to have a single pure wave emitted from the sending antenna. When the two-coil oscillation transformer is employed with the ordinary spark gap consisting of two fixed metal balls, this is never the case. It is more perfectly achieved by the use of the single coil or auto-transformer, but it is only when a quenched spark discharger is employed that the waves emitted from the antenna are perfectly pure and of one single wave length. Another difficulty with the ordinary fixed spark gap is that the discharges do not occur at absolutely equal intervals, nor sufficiently often. As long as merely small powers were being handled for covering short or moderate distances in wireless telegraphy these difficulties were not very serious. They became prominent when long distances first began to be attempted.

Accordingly the arrangements previously used for wireless telegraphy over distances of 100 or 200 miles were no longer adequate, and transmitters had to be devised for creating much more powerful intermittent or continuous electric waves. This work was begun by the Marconi Company in 1901, at Poldhu, in Cornwall, where Mr. Marconi established the first long-distance station. The Author rendered him assistance in devising the arrangements necessary to convert the previously used short-distance laboratory apparatus into long-distance engineering plant of great power. To provide the necessary high electromotive force, in place of a small battery of storage cells, a single-phase alternator was employed, giving an alternating electric current at a frequency of about fifty. This current was raised in pressure by passing it through a transformer, which consists of two insulated wires wound round an iron ring of particular form. One of these wires is connected to the alternator, and the current passing through it creates another lesser current of far greater electromotive force in the other wire. It is thus possible to transform a large current of low electromotive force into a smaller current of very high pressure or electromotive force. This high-pressure current can be used to charge a very large condenser, consisting of glass plates coated on both sides with tinfoil, and immersed in a stoneware box full of oil. The whole of the tin plates on one set of sides are connected together, and the whole of the other. Hence the arrangement is equivalent to a very large Leyden jar.

A large number of these condensers are charged with the high-pressure current from the transformer and discharged across a spark gap, and also the discharge passed through one of two coils wound on a wooden frame, called an oscillation transformer, the other coil being connected between the antenna and the earth.

The spark gap first used as devised by the Author, consisted of two steel discs or balls, which were kept rotating slowly by means of an electric motor. The discharge of the large condenser through this rotating spark gap produced very powerful electric oscillations, which were passed through one coil of the oscillation transformer, and the other coil was connected in between a large multiple wire antenna and an earth plate. Appropriate inductance coils were introduced for tuning the circuits. The other details of the arrangements it is unnecessary to describe. The signals were made by interrupting the condenser circuit or short-circuiting part of it by means of a key.

One of the special difficulties in connection with this power plant was that the high-tension transformers used to charge the condenser had a tendency to cause an electric arc across the spark discs. In other words, part of the discharge so produced was due to electricity coming directly out of the transformers, in addition to the electricity coming out of the charged condenser. For information on the methods used to overcome these difficulties the Author's larger book on this subject must be consulted.

In the development of these appliances in 1905 and 1906, Mr. Marconi made a very important improvement in the spark gap by the invention of his high-speed disc discharger. In this appliance a steel disc with studs or pins projecting from each face is made to rotate at a high speed between two other rotating discs (see Fig. 22).

Each time that a stud passes it touches or almost grazes these two side discs and so connects them together momentarily. This contact causes the discharge of the condensers to pass. The next instant, however, the stud passes on and the condenser circuit is suddenly opened.

This has the effect of instantly blowing out any arc which may be formed, and it cuts short the condenser oscillations, and therefore tends to make the primary discharge dead beat or suddenly arrested. This, as above explained, then limits the oscillations in the coupled antenna to one single frequency. This high-speed disc discharger, among other advantages, has the effect of greatly increasing the speed of signalling.

Another improvement introduced about the same time by Mr. Marconi was the employment of large air condensers in place of glass plate condensers. The glass has the disadvantage that from time to time plates are

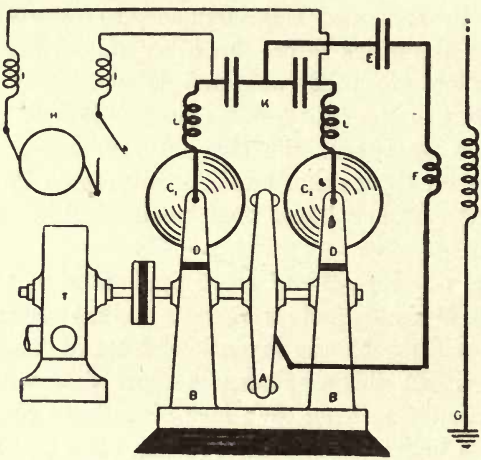


FIG. 22.—Marconi high-speed studded disc discharger.

cracked or pierced by the electric discharge, and this puts the condenser out of use until they are replaced. By using large galvanised iron sheets hung up on insulators a few inches apart in a large room it is possible to construct an air condenser which has the advantage that it is self-healing, and even if a spark does leap across between two plates the air is not permanently injured.

In his Transatlantic stations Mr. Marconi charges the condenser by means of a large storage battery, consisting of some 10,000 or more cells. This battery is kept charged by means of high-tension direct current dynamos, and the charge put into the battery is then drawn out as required to charge the condenser. Hence it is not necessary to keep boilers and engines working all day. A few hours' running suffices to put into the battery sufficient charge to last the rest of the day. This conduces to more economical working.

In smaller stations an alternating-current dynamo is employed, and this is most conveniently driven by an electric motor. For large ship plant a very usual arrangement is as follows : Ships are in all cases provided with dynamos for generating electric current for lighting and power purposes. This current is a direct or unidirectional current ; that is, flowing always in the same direction. This current can be passed through a machine called a motor-alternator which converts it into an alternating current. The motor generator can have attached to its shaft the studded disc discharger. The motor alternator is driven at a high speed by the continuous current and transforms a large part of the energy into alternating current. This alternating current is raised in pressure by a transformer up to 20,000 volts or so, and the high-pressure alternating current is employed to charge a condenser. The condenser is discharged by a studded disc rotating discharger carried on the shaft of the motor alternator, and the discharge passes through one coil of an oscillation transformer, the other coil of which is inserted between the antenna and the earth or balancing capacity.

This high-speed studded disc discharger has in addition another very valuable property. Since the disc can be kept in perfectly uniform rotation, and as the condenser discharge occurs only when a stud passes between and connects for an instant the two outer discs it follows that the series of discharges can be made to follow each other with perfect uniformity. This means that the groups or trains of waves which are emitted from the antenna are thrown off at exactly equal intervals. Moreover, by making the studs sufficiently numerous, or the speed of the disc sufficiently high, these trains of waves can be made to succeed each other with hardly any interval or no interval at all between them. Hence the head of one train is in contact with the tail of the train in front. The intermittent wave trains thus approximate to and finally merge into a continuous wave train.

Mr. Marconi accordingly carried the invention one stage further, and by the invention of his smooth disc discharger he provided a simple appliance capable of furnishing an uninterrupted wave train except in so far as that train is cut up into appropriate lengths to form the Morse signals.

This last discharger consists of a smooth disc rotating at a high speed between two lateral discs as shown in Fig. 23. In this diagram A represents a steel disc shown in section, which is rotated at a high speed by an electric motor. This disc passes between two other discs which can also be rotated, and these last are kept charged with electricity by a continuous-current high-tension dynamo N. Condensers represented by the parallel black lines are inserted as shown and represented at K and E. The oscillations in the antenna G are excited by the repeated discharge of the condenser E which is connected to the middle point between the two main condensers K. These last act as reservoirs of electricity and are kept charged by the dynamo. The smaller middle condenser is alternately discharged first to one disc C, and then to the other disc C, this discharge taking place through the rotating disc A.

This high speed of rotation of this last disc continually kills or quenches any arc discharge which starts, and causes the condenser E to be continually charged and discharged alternately. The result is to generate in the antenna persistent oscillations which can be controlled

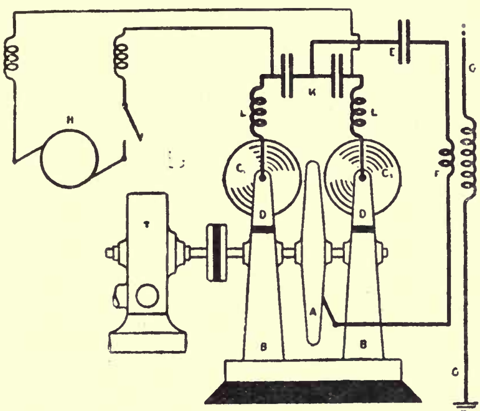


Fig. 23.—Marconi high-speed smooth disc discharger.

or cut up into Morse signals by a key in the dynamo circuit. By these two forms of dischargers Mr. Marconi has provided the means of creating very powerful intermittent or persistent electric waves, and putting into the æther as much as 150 horse-power or more, in the form of electric waves of great wave length. These waves may be either in regular intermittent groups, or they may be persistent waves, that is, non-intermittent.

At this stage it will be well to say a few words on the relative advantages and disadvantages of these two types of waves for use in wireless telegraphy. When the earliest inventions in connection with it were made, the transmitter then devised sent out waves consisting of rather irregularly spaced groups, each consisting of a very few waves rapidly decreasing in amplitude or highly damped. They may be likened to the air waves which would be emitted by a trumpet blown at irregular intervals in very short die-away blasts.

It soon became apparent that no good tuning or isolation of stations could be effected with such highly damped waves, and the minds of inventors began to be turned to the invention of various methods of producing undamped or persistent waves. When the methods which depend upon the use of an electric arc as explained later on in this chapter were put into practice in conjunction with receiving appliances employing a telephone, it was found that an absolutely unbroken or uninterrupted wave train cannot be used to form audible Morse signal unless it is cut up into sections either at the receiving end or the sending end. The reader will understand this remark better after the perusal of Chapter IV., which deals with receiving appliances. The signals heard in the telephone at the receiving end are sounds of long or short duration forming the signals. But there can be no sound at all unless there is some kind of regular and very frequent interruption in the oscillations in the receiving circuit.

It is true that highly damped trains of waves are very disadvantageous, and that what is required is a feebly damped train, but it does not follow that the extreme case of an undamped wave train gives us the best result.

As a matter of fact, the type of wave required for, and most economical in, wireless telegraphy is a type consisting of feebly damped trains of waves succeeding each other very regularly and with little or no interval between the trains. It is exactly this type of wave which is furnished by Mr. Marconi's disc dischargers.

For wireless telephony as explained in the last chapter we do require perfectly undamped waves, and these may be compared to the sound waves created by the steady blowing of an organ pipe, whereas the waves proceeding from a spark transmitter are like those emitted by a rapid series of short blasts on a cornet.

We may then consider two other methods which have been invented for the production of undamped electric waves. One of these is called the arc method, and was originally invented by Mr. Duddell, and improved by a Danish engineer, V. Poulsen. As most persons know, an electric arc lamp, such as is used for street or shop lighting, consists of a pair of hard carbon rods placed with their tips near each other. When an electric current is transmitted across the points they are rendered brilliantly incandescent, and the space between is filled with glowing vapour of carbon.

Suppose we connect the inside coating of a very large condenser or of a number of Leyden jars, having all their inside coatings connected together to one carbon rod, and the outside coatings to one end of a coil of wire which has its other terminal brought into connection with the second carbon rod, then Mr. Duddell found that high-frequency electric oscillations are produced in this last-named coil of wire, provided that the electric current actuating the arc lamp is a steady unidirectional or direct current, that is, one always flowing in the same direction.

The electric oscillations which are thus set up in the

Leyden jar or condenser circuit are high-frequency oscillations which are fairly persistent, that is, continuing steadily and not coming into groups like those produced by the spark.

To understand the manner in which these oscillations are produced, we must make use of an analogy with an organ pipe.

Consider the action of a so-called closed organ pipe. Its construction is shown by the sectional diagram in Fig. 24.

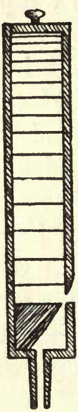


Fig. 24.—A closed organ-pipe.

A steady current of air from the bellows is blown through the mouth, and impinges on the sharp chisel-shaped lip of the pipe. That part of the jet of air which falls inside the pipe makes a slight condensation or compression of the air. This compression does not extend to all parts of the interior of the pipe at once, but moves along the pipe with the speed of a sound wave, viz. at the rate of 1100 feet per second. It is reflected at the top closed end, and travels down again, and when it reaches the mouth of the pipe the air inside the mouth is a little more dense or compressed than that outside the pipe. The jet of air is thus forced outside the lip. The result is to make a slight expansion of the air in the inside of the pipe near the mouth just as in the case of a scent spray producer when a jet of air is blown across the top of an open pipe. This rarefaction of the air travels up the organ pipe, is reflected at the top and returns again, and when it reaches the mouth the air there is slightly more rarefied than that outside. Hence the jet of air is sucked into the lip and then produces a condensation and the cycle of events repeats itself. Hence it will be seen that the jet of air blown against the lip is compelled by the action of the pipe to execute vibrations the frequency of which is determined by the length or natural pitch of the organ pipe, and the result is to produce vibrations of this frequency in the surrounding air, in other words to create a continuous sound of a pitch or note determined by the length of the organ pipe. This pitch or frequency is equal to the quotient obtained by dividing 1100 by four times the length of the closed organ pipe. Thus if the pipe were 1 foot long it would give rise to a note having the pitch or frequency 275. An entirely similar action takes place in the case of the direct-current electric arc when a condenser or Leyden jar and coil are connected to the two carbon rods.

It must, however, first be explained that the electric arc considered as a conductor of electricity possesses very peculiar qualities.

Substances which conduct electricity do not all conduct in the same manner. There is, for instance, a great difference between metallic conductors, liquid conductors, and gaseous conductors. In the case of metallic conductors, if we apply, say, to copper wire a gradually increasing electromotive force the current generated increases in the same proportion. In other words, the current is proportional to the electromotive force, and to a factor called the conductivity of the wire.

The above statement, having been first made by Dr. G. S. Ohm, is known as Ohm's law.

The highly incandescent carbon vapour which exists between the ends of the carbon rods in an arc lamp does not follow Ohm's law. On the contrary, an increase in the current through the arc is accompanied by a decrease in the electric pressure difference or potential difference of the carbons. Also a decrease in the current is accompanied by a slight increase in the electric pressure difference of the carbons.

Supposing, then, that we have a direct electric current furnished by a dynamo D (see Fig 25) flowing across the gap between the two carbons + and − of an electric arc, A, and connect to the carbons two wires which have their other ends attached respectively to the inner and outer coatings of a large Leyden jar C (see Fig. 25). Let us consider what would happen. The moment the jar is connected

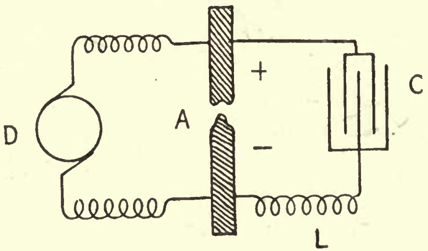


FIG. 25.—Arrangement for producing persistent oscillations by an electric arc.

as a *shunt* to the arc in the above-described manner a little of the current flowing through the arc would be diverted to charge the Leyden jar, and the result would be to rob the arc of some current or reduce the current through the arc. This, however, in virtue of the peculiar properties of incandescent carbon vapour as a conductor, would cause an increase in the electric pressure difference of the carbons, and therefore of the coatings of the Leyden jar. This increase tends to continue the charging of the jar until it is quite full, and then, since it is no longer able to divert current from the arc, the latter resumes its normal value. There is then nothing to prevent the Leyden jar from discharging back through the arc, and it accordingly does so. This, however, as is easily seen, will increase the current through the arc because it super-imposes on the normal or direct arc current the discharge current of the condenser. This increase of arc current therefore lowers the potential or pressure difference of the carbons and tends to facilitate the discharge of the condenser. Hence the condenser or Leyden jar is charged and discharged alternately, and electricity rushes to and fro along the wires connecting the coatings of the jar to the arc carbons. The frequency or time period of this ebb and flow of current in the shunt circuit is determined by the natural electrical period of oscillation of the jar and coil of wire in series with it. The energy is supplied from the source of power, whether dynamo or battery, supplying current to the arc.

This continual fluctuation of current through the arc causes it to give out a sound if the frequency of the oscillations falls within the limits of audition, that is, does not exceed about 30,000 per second. From this effect the experiment is often called that of the "musical arc." If we employ an ordinary carbon arc in air, it is found impossible to excite electric oscillations of large amplitude and yet of sufficiently high frequency for use in wireless telegraphy. V. Poulsen made the discovery in 1903, that by forming the arc between a carbon and a copper rod, the copper being the positive and the carbon the negative, and enclosing the arc in a vessel full of hydrogen, coal gas, or alcohol vapour, and also placing the arc transversely between the poles of a powerful magnet, it was possible then to obtain in a condenser circuit shunted across the arc very powerful oscillations of such high frequency as to be suitable for wireless telegraphy.

Referring to the rule already given, viz. that in all cases of wave motion the velocity of the wave is numerically equal to the product of the wave length and frequency, we can at once see that to obtain electric waves having a wave length of, say, 1000 feet as now used in oversea wireless telegraphy, we require to be able to produce oscillations having a frequency of one million or a time period of one-millionth of a second. For the velocity of electric waves in space is the same as that of light and nearly equal to 1000 million feet per second.

Hence, to produce waves 1000 feet in wave length we require oscillations in the antenna the time period of which is one-millionth of a second.

The explanation of the improved effect obtained by Poulsen is due to the fact that in the case of the electric arc formed between a carbon and a copper rod in coal gas or in hydrogen the change in electric pressure-difference of the electrodes or terminals for a given change in the current through the arc is greater than is the case with an arc formed between two carbon rods in air.

In actual practice the arrangements for producing undamped or persistent electrical oscillations of high energy and frequency by the arc method take the following form.

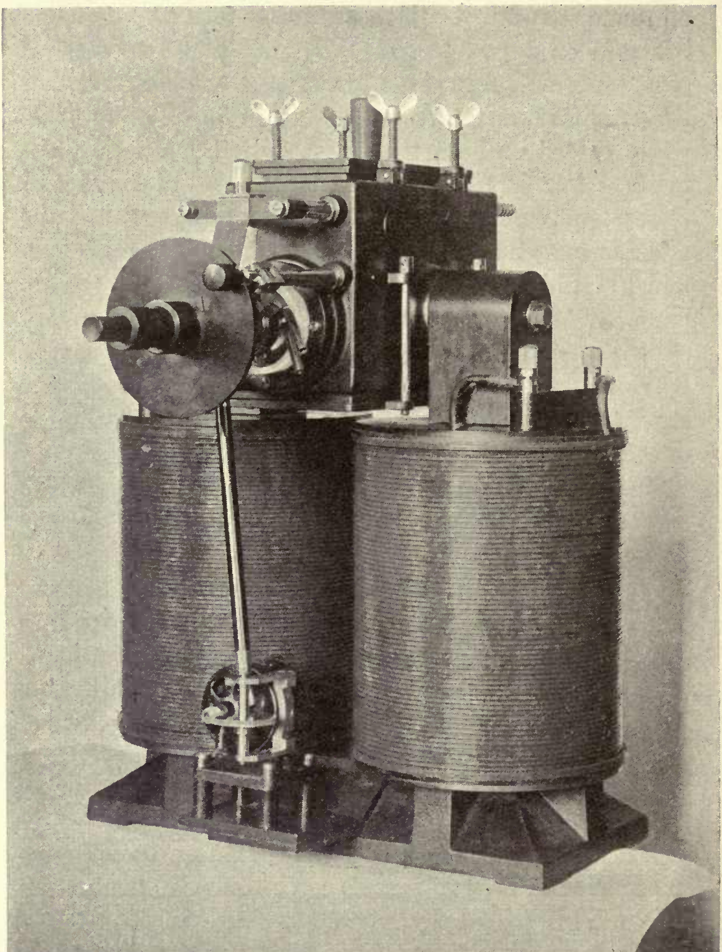
A dynamo machine must be provided capable of producing a direct current at a pressure of about 500 volts. This current is used to produce an electric arc between a carbon and a copper rod. These rods are contained in a box which is kept full of coal gas or of alcohol vapour. Special arrangements by water or air cooling must be employed to keep the box cool, and the carbon rod must be slowly rotated by clockwork to make it waste equally all round the end at which the arc is formed. The box is placed on a powerful electromagnet so as to make a strong magnetic field across the arc. A condenser consisting of either metal plates immersed in oil or of glass plates coated on both sides with tinfoil, and equivalent in effect to a large Leyden jar, has one set of coatings or plates connected to the copper rod of the arc, and the other to one end of a spiral coil of wire, the other terminal of which is connected to the carbon rod of the arc lamp. When the arc is started, powerful high-frequency electric oscillations are set up in the condenser circuit provided that the length of the electric arc and also the strength of the magnetic field applied transversely to the direction of the electric arc are properly adjusted.

The external appearance of the whole apparatus, which is called the Poulsen arc apparatus, but not including the condenser, is shown in Fig. 26.

To create persistent or undamped electric oscillations in a wireless telegraph antenna we have then to bring into proximity the coil in series with the above-mentioned condenser and the coil which is in series with the antenna. It is, however, necessary that the two circuits, viz. the antenna circuit and the oscillation circuit containing the Leyden jar, should be *tuned* together or in resonance.

This leads us to make a few remarks on the extreme importance of electric resonance or tuning in connection with wireless telegraphy.

We have already explained that if a Leyden jar or condenser has a coil of wire connected with one of its coatings, the coil and jar taken together constitute a circuit in which electricity can flow backwards and forwards



By permission of the Proprietors and Editor of "Knowledge."

FIG. 26.—A twelve kilowatt Poulsen arc generator for creating undamped electric oscillations.

rapidly, but it cannot permit the steady or uniform flow of a current because the glass or other insulator which forms the condenser is a non-conductor for such steady currents. Nevertheless since the jar or the condenser can be charged with electricity and then discharged and charged in the opposite direction, we may say that it has a conductivity for alternating electric currents, but not for direct or continuous currents.

Moreover, such a condenser in series with a coil, possesses a particular time period of electrical oscillation of its own, in the sense that if its electric charge is disturbed by a sudden electromotive force, the charge oscillates with a certain frequency depending on the electric capacity of the condenser and on the electric inertia or inductance of the coil. We have already in Chapter II. given the rule which enables us to calculate this time period of oscillation when the capacity of the condenser and inductance of the coil forming the oscillation circuit are known. It will be seen from that rule, that natural time period of oscillation depends upon the *product* of the capacity and inductance and not upon the absolute values of each separately. It is exactly the same with the natural time period of mechanical oscillation of a steel spring. This depends upon the product of the mass or inertia of the spring and its pliability.

Two oscillation circuits are said to be *in tune* with each other when in both cases the numerical product of capacity and inductance give the same number. Thus, suppose in one case we have an oscillation circuit having a capacity of $\frac{1}{400}$th of a microfarad in series with a coil having an electric inertia of inductance of 1 millihenry, and also another circuit having a capacity of $\frac{1}{800}$th of a microfarad in series with a coil of 2 millihenrys inductance.

These two circuits would be said to have the same oscillation constant or to be in tune with each other, for the product $\frac{1}{400}\times 1$ is equal to the product $\frac{1}{800}\times 2$.

When we have a wireless telegraph antenna set up at any place it constitutes an electric oscillation circuit having a certain oscillation constant or natural time period of electric oscillation. For the wire itself has electric capacity, and it has also inductance both in the wire itself and in the coil in series with it. Hence, if the electric charge in it is disturbed and left to itself it oscillates with a certain frequency which is fixed and unalterable. The antenna electrically speaking resembles a strip of steel with one end fixed in a vice which when bent on one side and released oscillates with a certain frequency which is always the same no matter what the amplitude of the displacement.

If, therefore, we wish to create oscillations in this antenna of the greatest possible amplitude by the induction or action of other oscillations in a neighbouring circuit, then the oscillations in the last circuit must be made to have the same frequency as the natural frequency of the antenna. The antenna must, therefore, be tuned to the frequency of the condenser or Leyden jar circuit coupled or connected with it if we are using the spark generator, or to the condenser circuit shunted across the arc if we are using the arc generator.

This self-tuning is accomplished in practice by altering the inductance of the coil of wire in series with the antenna until the electric current in the antenna has its maximum value.

In sending signals with the Marconi, or, in fact, any spark apparatus, it is usual to do it by inserting a key in the primary circuit of the spark coil or transformer used for charging the condenser. In the case of the arc or Poulsen apparatus it is found better not to start and stop the arc itself because this gives rise to difficulties, but to make the signals by changing the amount of the inductance in series with the antenna so as to throw it out of tune with the condenser circuit.

One advantage claimed for the Poulsen or arc transmitter is that it is possible to operate with oscillations of much smaller amplitude in the antenna than in the case of a spark or damped wave transmitter, because the persistence of the waves renders it possible to affect a suitable receiver with waves of very small amplitude. Their persistence makes up for their small intensity or amplitude.

There are, however, some difficulties in the working of an arc transmitter. The arc requires constant and careful adjustment to keep it in a suitable condition for maintaining oscillations of constant amplitude in the associated condenser circuit.

Strong claims have been made for superior efficiency on the part of the arc transmitter, that is to say, that it converts a larger proportion of the energy supplied to it into wave energy radiated from the antenna than is the case with the spark system. These claims have not yet been substantiated or confirmed by unimpeachable experiments.

In the case of the ordinary form of spark transmitter as above described and used on ships or in small stations, it is probably correct to say that about 25 per cent. of the energy supplied to the transmitter in the form of low frequency alternating on continuous electric current, is converted into and appears as wave energy of long electric waves radiated from the antenna. This value, however, might be greatly exceeded for large stations.

Much careful and unbiassed experimental work will have to be done yet before it is possible to state exactly the relative efficiency both as regards energy transformation, and telegraphic operation of the spark and the arc generators in radio telegraphic transmission.

We have then to describe in the next place a third means of generating undamped electrical oscillations which in the opinion of many experts has a future before it. This method consists in the mechanical production of forced undamped or persistent high frequency electrical oscillations by means of a high frequency alternator of special construction. In the spark method we excite the free oscillations of a condenser circuit. We so to speak strike it a blow in an electrical sense and then leave the circuit to itself. It is just as when a harp string is plucked or a piano string struck with the loud pedal down. In the case of the arc method we excite persistent oscillations by a method which has perfect analogy with the production of a continuous sound by a blown organ pipe.

In the method now to be described we create a persistent high frequency alternating current by a process which is analogous to the production of a continuous sound by means of a syren or other mechanical sound producer. In an ordinary alternating current dynamo as used for the production of the low frequency alternating currents used for electric lighting and power distribution we have a machine which generally consists of an iron ring-shaped frame carrying on it certain coils of wire which are called the armature coils. In the interior of this frame a wheel or disc is made to rotate by a steam engine or water turbine, which wheel carries on its periphery a series of electromagnets with poles alternating *North* and *South* all the way round the edge. These magnetic poles rotate past the fixed armature coils, and hence create in the latter an induced electric current which, by a proper connection of the said coils, is made to flow first in one direction, and then in the opposite through the whole armature circuit.

We can thus draw off from the armature an alternating current of electricity. The frequency of this current or number of complete cycles per second of the changes of current direction depends on the number of pairs of magnetic poles and the number of turns per second made by the wheel carrying them.

It should be stated that the number of armature coils is generally equal to the number of magnetic poles on the revolving wheel or field magnet. Thus, if the latter makes 3000 revolutions per minute or 50 per second, and if it carries 40 poles or 20 pairs of poles, then the frequency of the alternating current generated would be $20 \times 50 = 1000$, or there would be 1000 complete cycles or 2000 reversals of direction of the current per second. It will be seen, therefore, that to obtain a very high frequency we must have a magnet wheel revolving at a very high speed, or else have on it a very large number of poles.

There are practical limits to the increase of either speed or size in the magnet wheel. It is not safe to rotate such a wheel with a greater peripheral speed than about 300 or 400 feet per second. Hence, supposing we have a wheel 2 feet in diameter and put upon it 400 pairs of magnet poles and drive it at 50 revolutions per second, we should be able to produce an alternating current of 20,000 frequency. But such a frequency is not high enough for the purposes of direct excitation of an antenna for wireless telegraphy.

Suppose, however, that we could construct an alternator giving an alternating current of 50,000 or 100,000 frequency, that is to say, reversing the directing of the current, 100,000 or 200,000 times per second, and also very high voltage, then such an alternator could be applied to create directly the required oscillations in an antenna without the aid of condensers, or spark gap, or arc or any of the arrangements required in spark and arc transmitters. All that would be necessary would be to connect one terminal of the alternator to the antenna and the other terminal of the alternator to the earth or to a balancing capacity, and to tune the antenna to the frequency of the alternator by introducing between them a coil of suitable inductance. The alternator when set in rotation would then cause electric currents to run up and down the antenna which would be in tune or in step with those which would be produced by its free oscillations. The oscillations produced by the alternator would, however, be persistent or maintained oscillations and not damped oscillations. The result would be that the electric waves would flow out from the antenna in a steady stream, and not in intermittent trains as in the ordinary spark system. The signals could be made by cutting up this stream of waves into short or long periods in accordance with dot and dash signals. This could be done by interrupting the connection of the alternator with the antenna, or by interrupting the steady electric current used for magnetising the electromagnets on the revolving field wheel, which is generally called the exciting current. Many inventors have attempted to overcome the difficulties of devising a suitable form of high-frequency alternator for the direct production of electric oscillations. The solution of this problem carries with it, as we shall see in the last chapter, the possibility of conducting wireless telephony, and not merely wireless telegraphy.

Two lines of attack on this matter have been opened up. Some inventors have endeavoured to give such a form to the simple revolving field alternator as to produce the necessary speed and number of magnet poles, and thus secure the minimum frequency required which may be said to be not less than 50,000 to 100,000.

Thus, Alexanderson has constructed some very high frequency alternators in which a steel disc having 300 or 400 teeth cut on the edge is made to revolve at a very high speed between the poles of stationary magnets. This machine is of the so-called Inductor type, that is to say, the moving parts do not carry any coils on them, but the steel teeth are caused to deflect intermittently the stream of magnetic flux proceeding from these magnet poles so as to make it perforate more or less certain other fixed coils called armature coils, and thus create in these latter an alternating electromotive force which is directed first one way and then the other in the circuit. Alexanderson has constructed in this way machines giving an output of a few horse-power and a frequency of 100,000 or more (see Fig. 27). On the other hand, a different and very ingenious solution of the problem has been given by Dr. Goldschmidt in his rotating field alternator. He has devised a method by which the frequency of a low frequency current can be transformed up so as to increase its frequency as much as we please.

To make plain the means by which this is accomplished we must briefly expound a well-known property of magnetic fields. Since a magnetic force is a quantity which has direction as well as magnitude, it can be represented by a straight line, the length of which is

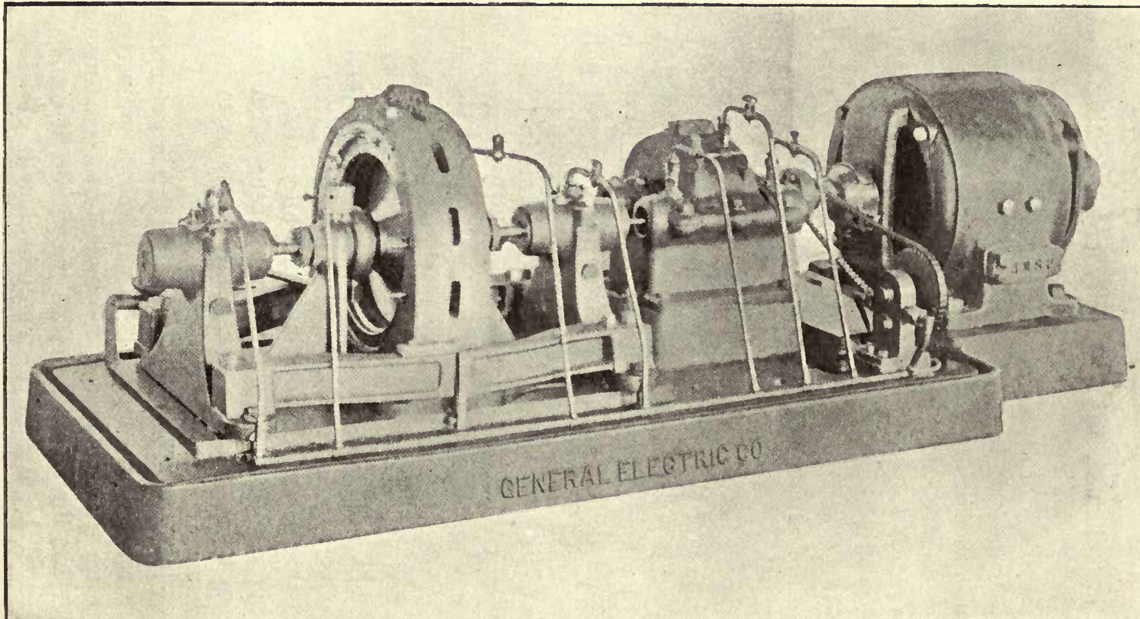


FIG. 27.—Alexanderson high-frequency alternator.

proportional to the intensity of the force and the direction of which coincides with, or is parallel to that of the force. A magnetic force may vary in one or two ways. It may remain invariable or constant in direction, but may change in magnitude, or it may remain constant in intensity and change in direction. Moreover, if there are two superimposed magnetic forces at any point these may be compounded into a single force just as two velocities or two ordinary mechanical forces acting on a body may be compounded into a single resultant velocity or force.

Suppose, then, that we have two magnetic forces at any point both of the same intensity but continually changing their directions. Let one revolve in the direction of the hands of a watch and the other in the opposite direction with the same speed. In the diagram in Fig. 28, let the thick black lines OA and OB represent these two oppositely rotating magnetic forces at any instant. It is a well-known theorem in connection with all directed or vector quantities which can be represented as to magnitude and direction by straight lines, that their resultant or joint effect is represented by the diagonal of the parallelogram of which these two lines form adjacent sides. Hence, if we complete by the dotted lines the parallelogram on the two sides OA, OB, then the diagonal OC represents at that instant the joint effect of the two magnetic forces denoted by the thick lines. It will easily be seen that if OA, OB revolve in opposite direction with equal velocities their resultant will always be along the line OC, but will have a varying magnitude and direction

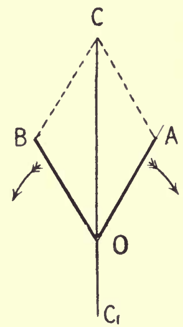


FIG. 28.

along OC. In fact the point C will move backwards and forwards along CC_1 with a motion called a simple periodic motion. Hence we have the following theorem.

The resultant of two equal and constant magnetic forces turning in opposite directions is a force constant in direction but varying in magnitude, its maximum value being twice that of each component revolving magnetic force. Again, we may reverse the theorem and say that any simple periodic force of constant direction can be resolved into two constant equal magnetic forces of half its maximum value rotating with equal speed in opposite directions. Having mastered the above theorem or idea, the reader will have no difficulty in understanding the principle of the Goldschmidt alternator. For the sake of simplicity we shall in the diagram herewith given (see Fig. 29) represent only one coil S (see Fig. 29) in the field magnet, and one coil R in the armature and also represent the field coil as fixed coil, and the armature coil as the rotating coil. Since, however, both coils act as field and armature, it is better to speak of the coil which is fixed as the *Stator,* and the coil which rotates as the *Rotor* of the machine.

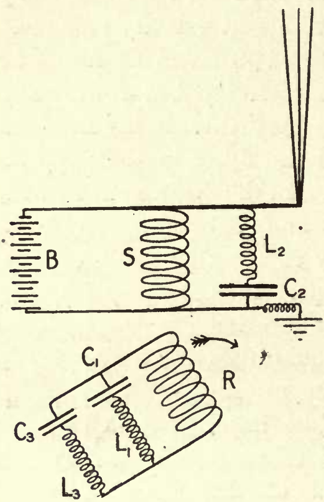


FIG. 29.—Diagram of circuits of the Goldschmidt frequency-raising alternator.

Let us then suppose that the stator coil S is excited from a battery B or direct current dynamo with a direct or steady electric current. This creates a magnetic field round the stator coil, and when the rotor coil R moves in this field it has an alternating current produced in it, and therefore an alternating magnetic field around it. This last field is pulsating, but stationary in direction as regards the rotor coil itself and moves with it. The rotor coil turns with a certain angular velocity with respect to the stator. In virtue of the theorem above given we can resolve the periodic or pulsating magnetic field around the rotor coil into two component fields of constant strength, but revolving in opposite directions with the same angular velocity with which the rotor coil itself is turning. It will easily be seen, therefore, that one of these rotating components is fixed in space as regards the stator coil because it is carried backwards by its own rotation just as fast as it is carried forwards by the rotor coil rotation. The other component sweeps through space with twice the angular velocity of the rotor coil. This component force cuts through the fixed stator coil and induces in it an electric current of twice the frequency of that in the rotor coil. To provide a complete path or circuit for these currents the coils both on the rotor and stator have their ends connected to certain circuits composed of a condenser and coil in series with each other, each such circuit being tuned to a particular frequency. Thus suppose that the number of coils on the stator and rotor and the speed of the rotor are such that the direct current in the stator coils induces an alternating current of a frequency of 10,000 in the rotor coils. Then as above explained this current would induce back a current having a frequency of 20,000 in the stator coils. To provide a complete path for these currents we have to arrange a condenser of suitable capacity and a coil of suitable inductance in series with each other, tuning them by proper adjustment so that the condenser circuit C_1L_1 attached to the ends of the rotor is tuned for 10,000, and that C_2L_2 on the ends of the stator for 20,000 frequency. The current of 20,000 frequency induced in the stator circuit in accordance with the principles above explained gives rise to a pulsating magnetic field which can be resolved into two oppositely rotating fields rotating with double the speed of the rotor. One of these fields rotates with, and one against, the direction of the rotor rotation. We have, therefore, in effect two magnetic fields cutting the rotor coils, one of them with a resultant velocity equal to the rotor velocity, and the other with a resultant velocity of three times that of the rotor velocity. The rotor circuit is then traversed by alternating currents, one having a frequency equal to 10,000, and the other having a frequency equal to 30,000. This last then gives rise to a current in the stator having a frequency of 40,000 and so on, and in virtue of the same actions we have a continual multiplication of the frequency. If then we connect a suitably tuned antenna to the stator circuit we can create in it high-frequency oscillations giving rise to electric radiation. All the lower frequency currents which are not required are taken up in the condensers short circuiting the stator and rotor circuits. The external appearance of the Goldschmidt alternator is as shown in Fig. 30.

In this manner Goldschmidt multiplies up frequency, and starting with electric energy supplied to his machine in the form of a continuous or alternating current is able to create out of part of it extra high-frequency electric oscillations in an antenna, and therefore to radiate from

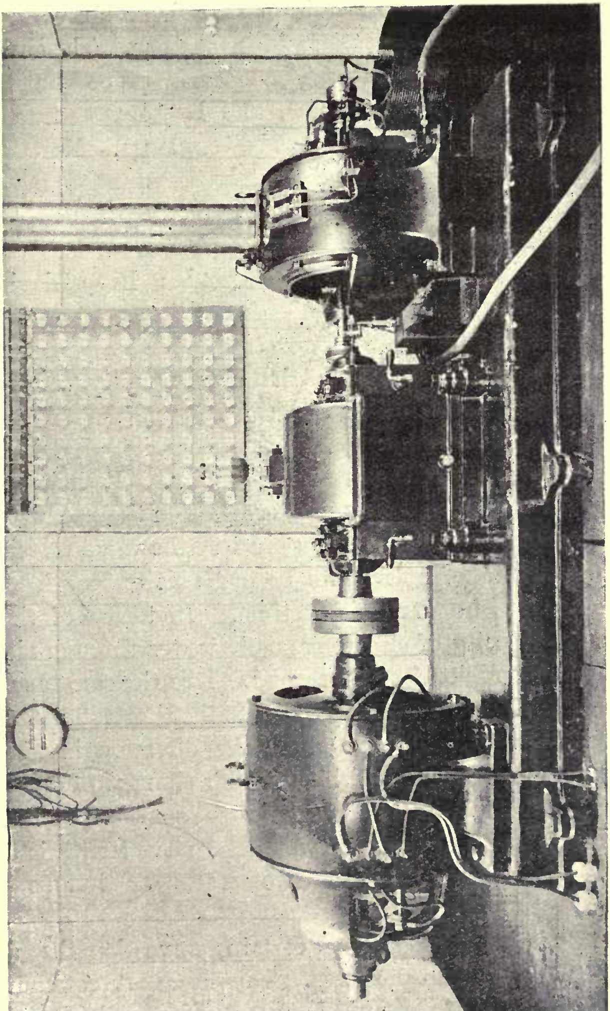


FIG. 30.—Goldschmidt's high-frequency alternator.

it electric waves suitable for telegraphic purposes. No experimental figures have been furnished, however, to show what is the efficiency of such a machine. The energy represented by the harmonics of lower frequency must be dissipated inside the machine, and hence that fraction available on the antenna cannot be very large. Moreover, the maintenance of an absolutely constant speed in the rotor is essential. This, however, Goldschmidt has provided for by ingenious devices.

Other inventors such as Fessenden have devised high-frequency alternators on different lines. Some have endeavoured by very careful construction to build ordinary simple alternators in which the necessary frequency is obtained by revolving both the armature and the field coils in opposite directions. Let us then consider what is the minimum frequency for radiotelegraphy. It has been explained that in all cases of wave motion the product of the wave length and frequency gives us the wave velocity. Suppose we take the foot to be our unit of length, and the second to be our unit of time. In terms of these units the velocity of electromagnetic waves through air is nearly 1000 million feet per second. It is the same as the velocity of light. The wave length is the shortest distance between two places taken along the direction in which the waves are moving at which similar changes of electric or magnetic force are taking place at the same instant. In the case of surface waves on water the wave length is the shortest distance between two crests or humps of water.

In wireless telegraphy certain wave lengths are allocated for certain purposes. Thus ordinary communication between ships and between ships and shore is conducted by means of electric waves having a wave length of either 1000 or 2000 feet. Hence, if we are operating with waves of 1000 feet in wave length it is clear from the above rule that the corresponding frequency must be 1 million. In other words the time interval between the passage across any point of two successive waves in a waves train will be 1 millionth of a second. Hence, this is also the time period of one complete electric oscillation on the antenna.

If we are using waves 2000 feet in length then the time period is two one-millionths of a second. In the case of long distance wireless telegraph stations the wave length used is much greater and may be anything between 6 and 20 thousand feet. Suppose we require waves 20,000 feet in wave length, then it is clear that the corresponding frequency will be 50,000, because $20{,}000 \times 50{,}000 = 1{,}000{,}000{,}000$. Hence we may say that a frequency of 50,000 or perhaps 40,000 is the very least that must be given by a high-frequency alternator if it is to be of much use in the direct production of electric waves.

If, however, alternators can be constructed capable of producing an alternating electric current having a perfectly uniform frequency, say, of 50,000 or reversing the direction of their current 100,000 times a second, and if they can in addition be built of a size to supply a considerable amount of power, say 100 to 150 horsepower, there is no doubt that they will be put into use in long-distance wireless telegraphy. Experience alone can show how far they fulfil the requirements of commercial radiotelegraphy.

Mention should also be made of one form of transmitter or mode of generating oscillations due to Galletti, which occupies an intermediate position between the continuous wave transmitters such as the arc and alternator and the intermittent spark method, but which is still in an experimental stage.

The object of Galletti's arrangements is to produce a series of oscillations by means of spark discharges following each other so quickly that the head of one train of oscillations just touches the tail of the previous one. Hence, although the amplitude of the oscillations is not always constant, yet it is claimed that there are no vacant spaces or time unoccupied with oscillations between these trains as in the case of some spark transmitters. Galletti achieves this result by the use of a high tension continuous current, and a number of spark gaps so arranged that the sparks

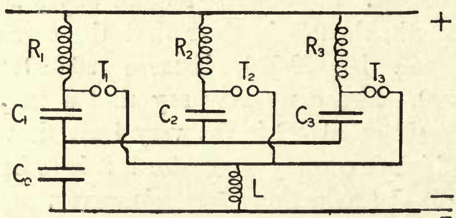


FIG. 31.—Arrangement of circuits in Galletti transmitter.

take place successively at these gaps, and one after another create oscillations due to the discharge of condensers in a certain coil of wire—which in turn induces oscillations in the antenna. The arrangement of the Galletti transmitter will be understood from the diagram of connections in Fig. 31. The lines marked + and — are the high tension continuous current supply lines. The condensers are represented by C_0, C_1, C_2, etc., and the spark gaps by T_1, T_2, T_3. The oscillations all take place in the coil L, to which the antenna can be coupled. Galletti states that by this method he can produce as many as 10,000 sparks per second. The condenser C_0 appears to be an essential part of the arrangement in making the sparks at the various spark gaps successive and not simultaneous.

The reader, however, must not take it for granted that these different methods of producing undamped or feebly damped trains of oscillations are all of equal practical value, or that they deserve the title too often given to them of being different "systems of wireless telegraphy." In the early days of electric lighting any one who invented some useful modification in an arc lamp or in a dynamo called it a "new system of electric lighting," and there has been the same tendency in connection with apparatus for electric wave telegraphy.

Moreover, on the appearance of some novelty claims are often made for it in moments of enthusiasm which subsequent experience does not endorse.

In the case of wireless telegraphy so many requirements have to be fulfilled in practical work that it is hardly possible to appraise the value of an invention by any verbal description, or in fact by anything except by the results of long experience. There is a vast difference between isolated experiments conducted under favourable conditions or at convenient times, and the regular conduct of telegraphic communication for commercial purposes at all times and under all conditions.

It may be said that no form of telegraphy is of much, if any, practical value in which the message cannot be sent at any time with perfect accuracy. It has been fully demonstrated for reasons given in Chapter V. that to cover long distances by electric wave or space telegraphy the expenditure of large power on the æther is necessary. Hence, one question of importance in connection with transmitters of any type is whether they can be constructed so as to operate with large power.

Another essential matter is that the oscillations and electric waves produced by them shall be of absolutely constant frequency and wave length, and if of the intermittent type that the sparks and therefore groups of waves shall come at absolutely equal intervals of time.

We shall see later on how necessary these qualities are in connection with ease and certainty of reception of the messages.

The energy-transforming efficiency, using this term to denote the fraction of the power applied to the transmitter which appears as electric oscillation energy, is a subsidiary question, although nevertheless important.

When we apply these tests to existing forms of transmitter we see at once how erroneous it is to conclude, as persons of limited experience and knowledge in this subject have often concluded, that we can speak of the different forms of transmitter or rather oscillation producer, such as the spark, arc, Marconi disc, or alternator methods, as if they were different appliances for doing the same thing equally well.

They are all, it is true, instruments for creating electrical oscillations of different types and power which vary all the way from widely spaced out groups of a few oscillations, through closely adjacent or conterminous groups of many oscillations, to practically unintermittent or steady persistent oscillations.

But whilst abundant experience has demonstrated the practical value of the spark transmitter, with the exception of the application to wireless telephony, it has not yet been proved that the continuous wave has any advantage over the closely adjacent groups of waves for telegraphic work.

It is therefore undesirable to speak of these as different "systems" due to rival inventors. The proper terminology is to describe them as various forms of oscillation producer by different inventors. Moreover, it is a mistake to assume as is sometimes done that Mr. Marconi's inventions are limited merely to spark producers of the intermittent type. Apart from the fact that he initiated practical electric wave wireless telegraphy generally, amongst his most important inventions are those connected with the production of closely sequent trains of oscillations and with undamped or persistent oscillations as exhibited in his two forms of studded and smooth disc discharger or oscillation producer. It is difficult to draw a hard and sharp line between various types of oscillation producer, because they shade more or less into each other. Beginning, for instance, with the most elementary form of discharger and oscillation producer, viz. the Leyden jar discharging across a simple stationary spark gap, and producing intermittent groups of oscillations which are used to induce other similar oscillations in the antenna circuit, we have here somewhat irregular trains of oscillations which may be complicated by having oscillations of two frequencies produced as above explained. This type includes the original Marconi transmitter and all others like it, whether using single or two-coil oscillation transformers. In the next place, we have the quenched spark dischargers creating rapid groups of free oscillations in the antenna of one single periodicity and feebly damped. The oscillation group frequency is here greatly increased. This type includes the Wien, Telefunken, and Von Lepel, dischargers producing the so-called musical spark.

Then we have a still greater improvement in Marconi's studded disc discharger, giving groups of closely sequent oscillations of great power and regularity, and in the limit approximating to continuous oscillations. Finally, we have the smooth disc Marconi discharger giving persistent or uninterrupted oscillations, and the arc and alternator methods for the same purpose. Neither the arc nor alternator methods have yet given proof that they can comply with all the requirements of commercial high-power radiotelegraphy. On the other hand the smooth disc Marconi continuous oscillation generator has the merits of extraordinary simplicity and proved practical value for creating persistent oscillations of high power.

It would take too much space to discuss the technical details of all these appliances, and for further information the reader must be referred to more advanced treatises.

CHAPTER IV.

Wireless Telegraph Receivers and the Reception of Wireless Messages.

THE reader must now be assumed to have a fairly clear idea of the nature of the effect produced on the æther by a transmitting station sending out wireless messages. If we can imagine ourselves to possess some kind of abnormal vision which would enable us to see lines of magnetic and electric force, and if we suppose ourselves to be looking down from a great height on a radiotelegraphic station in operation, what we should observe would be as follows: From the antenna as a centre we should see circular lines of magnetic force parallel to the earth's surface expanding out into space just like ripples on the surface of a lake when a stone is thrown into it. These circular lines of force are, however, not all of the same intensity or in the same direction. At intervals of distance called a wave length we should find the force has a maximum value, and is in a direction, let us say, similar to rotation of the hands of a watch. At some intermediate positions it would be in the opposite direction, and at places in between would vanish altogether. These ripples of magnetic force would then be seen to move outwards with the velocity of light, and would be cut up into wide or narrow groups if we assume Morse signals are being sent.

In addition to these lines of magnetic force, we should also see lines of electric force perpendicular to the surface of the earth, and therefore at right-angles to the lines of magnetic force.

These lines of electric force would be distributed in the same manner as the lines of magnetic force so that both have their positions of maximum value or zero value at the same instant at the same place.

If, then, we imagine ourselves to remain stationary at any one point near the surface of the earth and at some distance from the sending antenna, these lines of magnetic and electric force would flit past us, and at this spot there would be a periodic variation in the direction and magnitude of the forces. The magnetic force would be alternately towards us and away from us with intermediate instants of zero value and gradually changing intensity. The electric force would be alternately upwards and downwards, with intermediate instants of zero value.

Suppose, then, that at some distance another vertical wire called a receiving antenna is erected. As the lines of magnetic and electric force sweep through space, they cut across this wire just as the expanding water ripples on a pond would cut across a stick held at any place perpendicularly in the water.

It is an elementary fact in electrical engineering that when a wire is moved in a magnetic field so as to cut across the lines of magnetic force, an electromotive force, or force setting electricity in motion, is created in the wire. This was one of Faraday's greatest discoveries. The same thing holds good if the wire is at rest and the lines of magnetic force sweep across it. They create by this action an electromotive force in the wire. Hence the receiving antenna becomes the seat of an electromotive force and has an electric current generated in it, alternately in one direction and the opposite. It follows that the current induced in the receiving antenna is first in one direction and then in the opposite. In other words, it is an alternating high-frequency current. Accordingly we see that the electric oscillations in the sending antenna give rise to electric waves emitted from it, and these waves after travelling through space, strike against the receiving antenna and recreate in it electric oscillations, which are a copy on a very reduced scale of those set up in the sending antenna. Hence, as far as regards reception of signals, the problem is reduced to finding means for detecting the presence in the receiving antenna of these very feeble electric oscillations which reproduce in every respect, except intensity, those in the sending antenna.

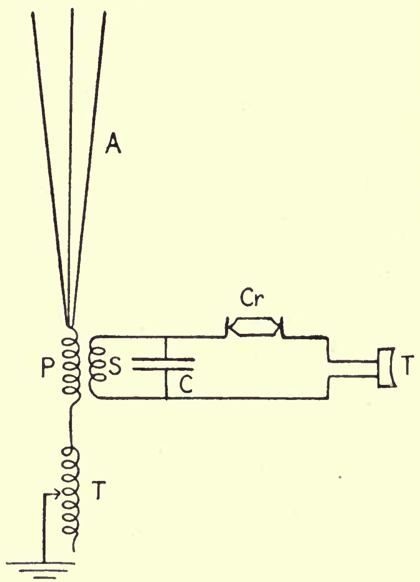


FIG. 32.—Connections of the receiving circuits.

We shall next proceed to explain how this is done. We place at the base of the receiving antenna A (see Fig. 32) a coil of wire P which is one of two wires wound on a frame and called an oscillation transformer or jigger. The primary circuit of this oscillation transformer has one end connected to a metal plate sunk in the earth, and the other end to the bottom of the receiving antenna. The secondary circuit S of this transformer has its ends connected to a condenser C and to a coil of variable inductance placed in series with it. The diagram in Fig. 32 will make the mode of this connection plain.

There are, then, two circuits, each having capacity and inductance, one of these being the antenna, the wire of which has a certain capacity with regard to the earth. We must in fact look upon such a wire set up with its upper end insulated as the inner coating of a kind of Leyden jar, of which the air is the dielectric and the earth the outer coating.

In addition, this wire and the coil in series with it possesses inductance or electric inertia. Hence the circuit has a natural time period of electrical oscillation determined by this capacity and inductance. Again, the secondary circuit containing the condenser (equivalent to a Leyden jar), which is coupled to the antenna circuit, has in it a condenser of a certain capacity and a coil of a certain inductance. It is possible to adjust both these circuits as regards capacity and inductance so that the condenser circuit is in tune with the antenna circuit. When this is the case, the feeble oscillations which the arriving waves create in the antenna give up their energy and produce other similar oscillations in this secondary or condenser circuit, and we have in this latter circuit oscillations created which are a copy on a reduced scale of those set up in the transmitting antenna. We have then to consider next how these received oscillations can be detected.

There are two methods by which this may be done. First, the aural method, or method of reception by ear, which makes use of a telephone so that the signals are heard as sounds, and secondly, a method which makes use of some means by which the signals are recorded visually or permanently, and thus appeal to the eye.

It is of advantage to have a permanent record of a message, particularly in the case of messages sent in cypher. On the other hand, the permanent record involves more complicated arrangements than the simple reception by ear. Hence for speed and simplicity of arrangements preference is now always given to the aural method of reception. We shall explain this method first and the methods for recording afterwards. It may perhaps be presumed that the reader is acquainted with the nature of an ordinary magneto-telephone receiver; but in case he should not be, a few words of explanation may be desirable. An ordinary Bell telephone receiver consists of a steel magnet M (see Fig. 33) generally of a horseshoe shape, contained in an ebonite holder. The poles of this magnet lie close to, but not quite touching, a flexible iron plate D called the diaphragm (see Fig. 33). On the poles of the magnet are wound long coils of insulated wire, having a resistance of about 1000 to 2000 ohms, comprising many hundred turns, and the ends of these coils are brought to two

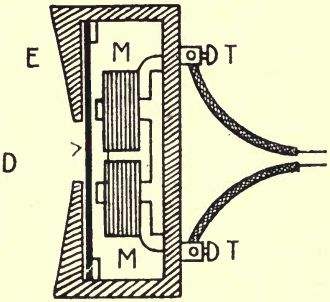


FIG. 33.—Section of a Bell telephone receiver.

terminal screws T, T. If a transitory electric current is sent through these coils, the diaphragm is suddenly attracted and then released, and this quick bending in of the plate communicates a blow to the air, which makes itself evident as a short sound. If an intermittent electric current always in the same direction is sent through the coils, the number of intermittences or interruptions being from 100 to 500 or so per second, the corresponding sounds would run together into a more or less shrill musical note, which would be heard on placing the diaphragm near the ear. If this series of interrupted currents is cut up into long and short portions, the sounds would be also cut up, and could be interpreted into Morse signals.

Assuming that the transmitter is operating on the spark system, we have to bear in mind that corresponding to each spark at the transmitter a group of electric waves, strong at the beginning, but tailing away to nothing at the end, is emitted from the sending antenna. When this group of waves strikes on the receiving antenna, it sets up a corresponding kind of electric current in it. These currents rush up and down the receiving antenna for a certain time, but die away, and then a pause or quiet time follows before the next wave train arrives and the next group of oscillations begin.

These antenna currents set up similar groups of alternating currents in the condenser circuit, which is coupled to the antenna. The result is that the condenser in this receiving circuit (which is equivalent to a small Leyden jar) is charged first in one direction and then in the other during the time that each wave train is falling on the antenna. Supposing, then, that we were to connect the ends of a telephone receiver to the two coatings of this receiving condenser C in Fig, 32, we should not find that the telephone would emit any sound when waves from the transmitter fell upon the receiver. There are two reasons for this. First, the coils of wire in the telephone possess a considerable degree or amount of inductance; that means to say, we cannot suddenly create an electric current in them by a very suddenly applied electromotive force. Hence, if a very rapid alternating electromotive force or rapidly reversed electric pressure is applied to the ends of the telephone coils, next to no current would be produced in the coils. It is as if we had a very heavy ball hung up by a long rope so as to form a pendulum. A somewhat prolonged push would set this ball in vibration, but very rapid little taps or blows alternately on either side would not move it because the inertia of the ball is very great. Secondly, even if the rapidly reversed electromotive force could produce a sensible current in the telephone coils and cause the diaphragm to move to and fro, yet since these movements would be extremely rapid the ear would not appreciate it as sound. The ear is not sensitive to any aerial vibration quicker than about 30,000 per second. On the other hand, the electric oscillations with which we are concerned have a frequency of 100,000 at least, and often of nearly 1,000,000. Accordingly it would be no use to connect the telephone alone to the receiving circuit. If, however, we can add in series with the telephone some device which will act like a valve and permit electric currents to flow only in one direction, then it will be seen that each time the group of electric oscillations takes place in the receiving condenser the telephone connected with it will be traversed only by a flow of electricity in one direction only. Every one knows that a valve in a pump or water-pipe is a sort of little trap-door which allows the water or other liquid to move in one direction, but not in the opposite. We all have valves in the veins of our body which permit the blood to flow one way, but not in the reverse direction. Now it has been found that some conducting substances act as valves to an electric current and permit it to flow more easily in one direction than in the opposite. Many such electric valves have been discovered or invented. One of the simplest of these is a crystal of carborundum. This substance is an exceedingly hard crystalline combination of carbon and silicon, made by heating in an electric furnace coke and sand to a very high temperature. It is prepared in the form of glass-like crystals of an irridescent colour, which when crushed are used as an artificial emery to make grinding and polishing wheels. These crystals of carborundum have the peculiar property of allowing electricity to pass more easily through them in one direction than in the opposite. If, then, we attach a crystal of carborundum *Cr* to one terminal of the Bell telephone T and connect the two in series, as shown in Fig. 32, to the coatings of the condenser C, we have an arrangement which enables us to *hear* the Morse signals sent out from the transmitter. Let us consider more in detail the exact operations.

When each group of electric waves corresponding to a single spark at the transmitter sweeps across the receiving antenna, it creates in this antenna a rapid oscillatory motion of the electrons in the antenna wires which endures as long as the wave train is passing. These oscillations set up other similar oscillations in the condenser circuit associated with the receiving antenna. The condenser in the circuit is therefore charged with electricity first in one direction and then in the opposite.

If the terminals of the telephone *plus* the crystals are connected to the plates of this condenser, then at each alternate oscillation a small current flows through the telephone in one direction. The crystal rectifies the alternate movements of electricity into a single gush of electricity in one direction; corresponding therefore to each spark at the transmitter there is a small rush of electricity in one direction through the telephone coil. An ear placed at the diaphragm would therefore hear a little tick or sound. If the sparks in the transmitter come at the rate of several hundred a second, these small sounds in the receiving telephone would run together into a corresponding musical note. If the repeated sparks at the transmitter are interrupted or cut up into long or short groups in accordance with the Morse code signals by means of a key inserted in the transmitter circuits, then a listener at the telephone will hear long and short sounds arranged in the same way and with sufficient skill and practice will be able to interpret these into alphabetic signs or words.

Hence by this peculiar combination of a telephone in series with an electrical valve of some kind, a person listening to the telephone can hear the sparks at the transmitter hundreds of miles away.

Since this wonderful property of carborundum was discovered by General Dunwoody in the United States, it has been found that the light contact between certain metals and non-metallic substances will act in the same manner. For instance, Professor G. W. Pierce found that the contact between a copper wire point and a substance called Molybdenite (which is Sulphide of Molybdenum) will act as an electrical valve. Also it has been found that a gold wire just touching a piece of Iron Pyrites or Sulphide of Iron does the same. A contact between a piece of Galena or Sulphide of Lead and Plumbago (black lead of a pencil) has a similar power. A very sensitive rectifier is a contact between a piece of Zincite (Oxide of Zinc) and a piece of Chalcopyrite or Copper Pyrites.

Several other minerals have also been found such as Hessite, Anatase, and others, which have the power of conducting electricity better in one direction than in the reverse, and all these substances can be used as rectifiers and electric valves.

The author discovered in 1904 that an incandescent lamp, such as is used to illuminate our houses, could be made to act as a rectifier and detector of electrical oscillations with a little modification. If a metal plate C is sealed into the glass bulb V of an incandescent lamp in the form of a cylinder surrounding the filaments, and if this cylinder is connected to a platinum wire T sealed through the glass, we have the appliance which can be used to detect electrical oscillations (see Fig. 34). The bulb contains highly rarefied air. When the carbon or metal filament is rendered incandescent by passing a current through it from a small storage battery B, the rarefied air between the hot filament and the cold plate is filled with electrons, and becomes a conductor of electricity, but will only conduct negative electricity from the hot filament to the cold metal plate, and not in the reverse direction.

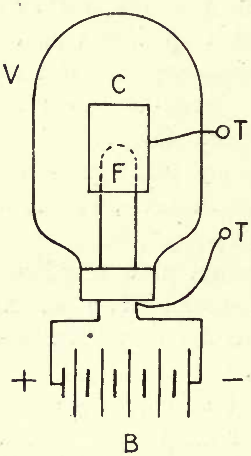


FIG. 34.—Fleming oscillation valve or glow lamp detector.

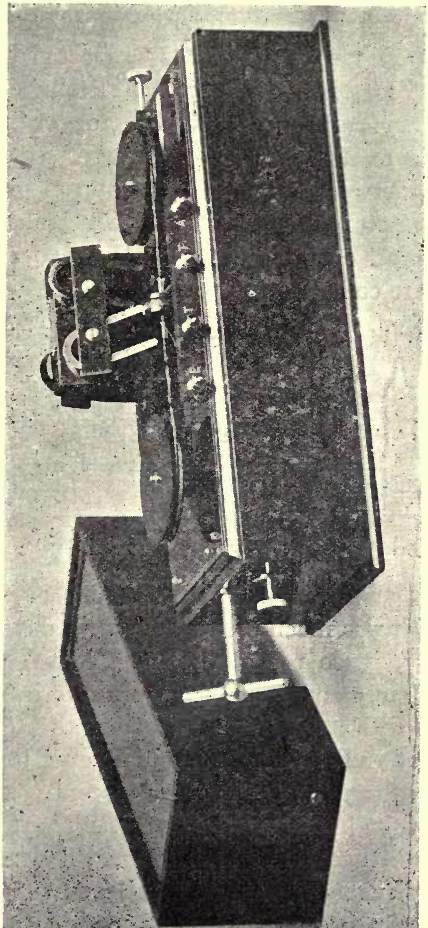
This device, called by the Author an *oscillation valve*, is used instead of a crystal rectifier as follows: The filament of the lamp is rendered incandescent by passing through it the current of a storage battery and a wire connected to the negative pole of this battery is joined to one terminal of a telephone receiver. Another wire is connected to the insulated plate contained in the lamp bulb, and the telephone receiver is thus joined in series with the vacuous space in the lamp contained between the hot filament and the cold plate. If this combination of telephone and lamp is then connected across the terminals of the condenser in the receiving circuit, as shown in Fig. 32, the listener at the telephone will hear the sound made by the spark at the distant transmitter. The lamp acts like a valve and rectifies the oscillations, just as in the case of the crystal.

This "Fleming Valve" is much used as a receiver for long-distance wireless telegraphy on account of its great sensitiveness. It has also another advantage—that it cannot be permanently injured or set out of adjustment by any exceptionally strong stray signal, such as those due to atmospheric electricity. For this reason it is the detector *par excellence* for large antenna or high-power stations.

Another detector much used in wireless telegraphy is the magnetic detector invented by Marconi. It depends on the fact that when electrical oscillations are sent through a coil surrounding an iron wire they have the power of removing any magnetism in that iron wire, and particularly of removing that quality of the iron in virtue of which it is enabled to retain magnetism.

The Marconi magnetic detector consists of an endless band of iron wire which is carried round two wooden pulleys. These pulleys are turned round by clockwork so that the endless band of iron wire moves slowly along. In part of its journey the iron wire passes through a small glass tube. On this glass tube are wound two copper wires covered with silk. One of these wires is connected to the coils of a receiving telephone and the other wire is inserted in the condenser circuit of the wireless telegraph receiver. Outside the glass tube two permanent steel horse-shoe-shaped magnets are placed to magnetise the iron wire (see Fig. 35). When the electric oscillations are set up as above described in the circuits of the receiver, these oscillations demagnetise the iron. It is well known that if a steel magnet is inserted into a coil of wire or withdrawn from it the result is to produce in that wire an electromotive force. Hence the sudden variation in the magnetic state of the magnetised iron wire which is produced by the passage of the electric oscillations around it creates an electromotive force in the wire connected to the telephone, and causes, therefore, current to flow through the telephone and a sound to be produced by it. Corresponding, therefore, to every spark at the transmitter there would be a little sound in the telephone connected to the magnetic detector, and if these sparks come at the rate of several hundred per second the sounds in the telephone will run together into a continuous musical note. If the sparks of the transmitter are interrupted in accordance with the signals of the Morse alphabet, then the listener at the telephone will hear these signals in the form of long or short sounds.

The magnetic detector has the great advantage that it is compact and self-contained, and it is very useful, therefore, as a receiving instrument for portable wireless telegraph plant, such as is used for military purposes. It is also much used for the reception of wireless messages on board ship. There are a large number of other forms



By permission of Marconi's Wireless Telegraph Company.

Fig. 35.—Marconi's magnetic detector.

of detector used in wireless telegraphy, such as the electrolytic detector and also various forms of coherer, but many of these have been now superseded, the tendency being to adopt the simplest possible arrangements. As far as regards spark telegraphy, we may say that the great bulk of the receiving work is conducted by means of the Marconi magnetic detector, the Fleming oscillation valve, or some form of crystal detector or rectifying contact, such as the molybdenite-copper contact discovered by Pierce, or the zincite-copper pyrites or "perikon" detector invented by G. W. Pickard. For fuller information on these detectors the reader must be referred to more complete treatises.*

Turning, then, to the question of recording messages,

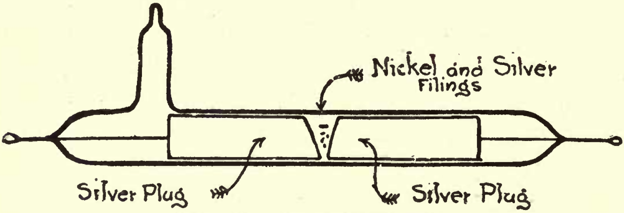


FIG. 36.—Marconi coherer.

a method which was much used in the early days of wireless telegraphy, made use of the metallic filing coherer invented by Branly and Lodge and improved by Marconi, in association with an instrument for printing down the messages in dot and dash characters on paper tape. The coherer in the form given to it by Marconi consisted of a small glass tube having in it two silver plugs with the ends very close together, and between these plugs was placed a very small quantity of nickel and silver filings, the tube was exhausted of its air and sealed (see Fig. 36).

* See "The Principles of Electric Wave Telegraphy and Telephony," by J. A. Fleming. Longmans, Green & Co., 39, Paternoster Row, E.C.

A loose mass of metallic filings possesses the property that in this condition it is very nearly a non-conductor of electricity, but if electric oscillations are passed through it the various little particles of metal cohere together, so that the mass becomes a conductor. If, however, a slight tap is administered to the tube, the filings would be separated again from one another, and their insulating quality restored. In association with this coherer an appliance called a Morse Inker was used. In this instrument a strip of paper tape about half an inch wide is caused to move slowly by clockwork over a little wheel, the edge of which is kept supplied with ink. The wheel can be moved up to touch the paper by means of an electromagnet, the current to which is supplied from separate battery. If the little wheel is pressed up against the paper for a short instant, it makes a *dot* upon the paper, and if pressed up a little longer time it makes a *dash.* In order, therefore, to make a dot or dash, all that is necessary is to send a current from a local battery for a longer or shorter time through the coils of the electromagnet of the inker. The coherer is therefore used as a means of actuating the Morse inker and the oscillations which fall upon the receiving antenna are able by the assistance of the coherer to work the Morse inker and print down in dots and dashes the message on the paper tape.

A large number of adjustments are, however, necessary to enable this to be successfully done, and on account of the skill and time required to make these adjustments properly the Coherer and Morse Inker proved to be a somewhat troublesome receiving appliance in practice. It has therefore to a considerable extent fallen out of use, having been replaced by the far quicker and simpler method of reception by ear by the aid of the telephone, as above described.

For the sake of being able to record the messages received in long-distance stations another method is sometimes now used in which the signals are photographed upon a long strip of photographic paper by means of a ray of light. The instrument employed for this purpose is called a Einthoven Galvanometer. It consists of an extremely fine thread of silvered glass, which is stretched between the poles of a powerful magnet. In series with this thread is placed a crystal of carborundum or some other form of electric valve as above described. When the electric oscillations pass through the thread of glass and the crystal, they are converted into a movement of electricity in one direction, which is practically equivalent to an uniform electric current. The glass thread is therefore deflected or bent down in the magnetic field, and this movement can be observed by a microscope and can be photographed upon a moving strip of photographic paper, and in this manner signals can be recorded upon the paper which are capable of interpretation. The appliance is somewhat complicated and not very suitable for use in any except large land stations.

Turning to another part of the subject, we have now to explain how it is that the messages starting from any particular sending station are prevented from affecting other receiving stations except those for which they are intended. To elucidate this matter we must refer again to the question of tuning electric circuits. It has already been explained that an electric circuit containing a condenser or Leyden jar in series with a coil of wire having electric inertia or inductance possesses a certain natural time period in which electric oscillations can take place in it. It resembles, therefore, a pendulum or a spring fastened at one end, which vibrates when disturbed at a certain fixed rate. We have also explained that when electric oscillations are started in such a circuit and left to themselves they die away more or less quickly. If they die away quickly they are said to be *highly damped*, and if they die away slowly they are said to be *feebly damped*. In order to set up electric oscillations in a circuit we must therefore apply to that circuit an electromotive force which is repeated at regular intervals exactly equal to that of the natural time of oscillation of the circuit. It is well known that we can set in violent vibration a suspension bridge by a single person jumping upon it, provided these jumps come at intervals, exactly corresponding to the natural time of vibration of the structure. So also in the case of an electric circuit having capacity, we can accumulate electric oscillations of extensive amplitude provided that we apply an electromotive force of exactly the right frequency. We must, so to speak, strike the circuit repeated electric blows, but our blows must be repeated exactly at the right interval of time, or else they will produce very little effect. We can do more by a number of feeble blows administered at exactly the right intervals than by one or two more powerful blows coming at the wrong intervals of time. If, therefore, we wish to set up electric vibrations in the receiving circuit of a particular wireless receiver, it is necessary to administer to the receiving antenna electrical impulses which come exactly at the right intervals of time. Accordingly the intervals between the waves sent out from the transmitter must agree exactly with the natural frequency of the receiving antenna and associated condenser or receiving circuits. The receiving antenna has therefore to be tuned to the sending antenna, and the receiving circuits to the sending circuit. Again, the waves sent out from the sending antenna must comprise a large number of waves in each train ; that is to say, the oscillations in the sending antenna must be as far as possible feebly damped. When this is the case, these feeble oscillations will set into sympathetic vibration all those receivers which are exactly tuned to the transmitter, but will hardly affect at all receiving circuits which are not so tuned. Hence, in order that we may obtain isolation of wireless telegraph stations, and as far as possible confine the reception to those stations for which the message is intended, it is necessary that the transmitting station shall send out only trains of feebly damped waves. The employment of wave trains of large amplitude and strongly damped—that is to say, consisting of very few waves in a wave train quickly dying away—is, as already remarked, very prejudicial, because it is more difficult to prevent powerful strongly damped waves from affecting any receiver on which they fall.

It is a comparatively easy matter for a receiving station to tune out, that is to say, to keep itself unaffected by, trains of feebly damped waves which are not of great amplitude because the reception of such waves implies very exact tuning in the receiving instrument to the frequency of the incoming wave. By making use of this principle of resonance it is possible to receive two or more messages at the same time on the same antenna to which are attached different sets of receivers. Thus, for instance, we can attach to one and the same antenna a receiving instrument which is tuned for waves 1000 feet long, and also we can couple another different and independent receiver which is tuned for waves 2000 feet long, and it is possible then to receive two independent messages at the same time from two different transmitting stations, because one of the receivers is only affected by one set of waves and the other only by the other set.

Applying this fact, Mr. Marconi has been able to arrange a sending and receiving station, so that it can send and receive simultaneously. In the ordinary method of working, each station is provided with one antenna, which is used alternately for sending and receiving, being attached to the transmitting apparatus during the sending of the message, and then switched over into connection with the receiving instrument for receiving the message. This method naturally requires a good deal of care, because the operator at each station must be careful not to switch over his antenna on to the transmitter and begin to send until he is quite certain that his correspondent at the distant station has finished transmitting to him. It is, however, clear that any method which enables the transmission and reception to be conducted quite independently must effect an improvement. Mr. Marconi has devised various methods for doing this, but one of the simplest arrangements is as follows :—

The receiving station at any one station is situated at a small distance from the transmitting station and the receiving station is provided with two antennæ, one a tall or long antenna for receiving from the distant station and another short antenna. The adjacent transmitting station has a single large antenna. In order to prevent this transmitting station from interfering with and spoiling the reception of messages at the adjacent receiving station it is necessary to devise some method by which this receiving station remains sensitive to the messages coming from the distant transmitting station, but is not affected by the messages which are sent from the closely adjacent transmitting station. This is achieved in the following manner. The short and long antennæ connected with the receiving station are joined to the receiving instrument and receiving circuits in such a manner that electric waves acting on both these antennæ neutralise each other's effects on the signal detecting instrument. On the other hand, owing to the great difference between the lengths of the two antennæ, the messages arriving from the distant transmitting station produce little or no effect upon the shorter of the two antennæ, and hence the reception of the distant message is affected only by the long antenna. In this manner it is possible to make the adjacent transmitting station, which may be called the home transmitter, unable to act upon the receiver in the receiving station near by, but the messages coming from the distant transmitting station do affect the instrument in this receiving station. By this method transmission and reception go on quite independently, the transmitting station sending all the time as fast as it pleases and the receiving station receiving all the time. Such a method is called a *duplex transmission.* It may be remarked in passing that the antenna required for transmission, especially long-distance transmission, is a large and expensive appliance; on the other hand, there is no difficulty in picking up messages even from very distant stations by means of a simple antenna made of one or two hundred feet of copper wire. Any one who has the necessary skill and radiotelegraphic knowledge can put up an antenna (provided he has a license for it from the Government) by means of which he can pick up messages from far-distant stations. Such an antenna may consist of one or two lengths of copper wire, the top ends of which are attached to an insulator fastened either to a factory chimney or a church steeple or any tall building and with the receiving appliances already described properly tuned to the distant transmitter, the receiver can pick up messages from far-distant stations. It is, however, quite a different matter to transmit messages to a distance. This involves an antenna having a large capacity, and therefore a great number of wires, and requires one or more tall masts or towers to support it and which is a comparatively expensive matter. Hence, the arrangements for transmitting messages, especially over long distances, are much more costly than the arrangements for receiving them.

We may now pass on to consider various kinds of measurements that are necessary in connection with wireless telegraphy. The application of all scientific knowledge in practice involves the use of exact measurements of some kind, because we become concerned then with questions of cost and with the prediction of performance. In the early days of wireless telegraphy attention therefore began to be directed to the invention of instruments for measuring the various quantities with which we are concerned. One of the most important of these is the wave-length of the waves used. In order to prevent confusion and to facilitate communication between ships and stations by electric waves, it has been found essential to fix certain wave-lengths which are to be used for certain purposes. Thus, for instance, it has been decreed by the International Radio-telegraphic Convention that inter-communication between ships and shore shall be conducted by means of electric waves, the length of which is either 300 or 600 metres, and that long-distance wireless telegraphy, such as transatlantic telegraphy, shall be conducted with much longer waves from 2000 to 10,000 metres in length. Also that experimental stations shall have a certain wave-length assigned to them which they are to use. The waves sent out by any transmitting station can have their wave-length determined provided we can tell the frequency of the oscillations in the antenna. It has already been explained that in all cases of wave motion, whether in air or water or æther, the velocity of the wave in the medium is numerically equal to the product of the wave-length and the frequency. The velocity of electric waves through space is approximately equal to that of light, namely, 300,000 kilometres per second; this is nearly equal to 1000 million feet per second, or 300 million metres per second. Accordingly, to produce waves 300 metres in length the oscillations in the antenna must have a frequency of one million. This statement does not mean that there are actually one million oscillations in one second, but merely that they take place at that rate, and that the interval of time between one oscillation and the next in the same direction is one millionth of a second. Hence, in order to determine the wave-length of the waves sent out from an antenna, we must have some appliance which enables us to determine the frequency of the oscillations in the antenna. We have already seen that if we form an electric circuit containing a condenser of a certain capacity and a coil of wire of a certain inductance and set up free oscillations in this circuit, then the frequency of these oscillations would be obtained by dividing the number 159,000 by the square root of the product of the capacity reckoned in microfarads and the inductance reckoned in microhenrys. The practical measurement can be carried out by the following means by the aid of an instrument called the Cymometer, invented by the Author.

The Cymometer consists of two brass tubes sliding over one another, but separated by an ebonite tube. This arrangement forms a condenser or Leyden jar, the capacity of which can be varied by sliding one tube on or off the other. Also the instrument contains a long coil of wire, a greater or less length of which can be joined

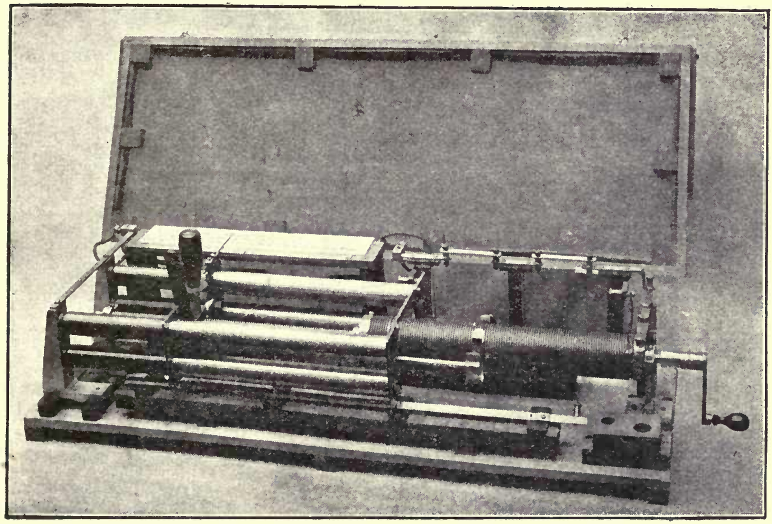


FIG. 37.—The Fleming Cymometer.

in series with the sliding condenser, and a copper bar completes the circuit. Hence, we have a complete circuit containing capacity in the form of sliding condenser and inductance in the coil of wire. The instrument is completed by connecting to the terminals of the sliding condenser a glass tube full of rarified Neon gas, one of the rare gases contained in the atmosphere (see Fig. 37).

When a tube containing rarified Neon is subjected to high frequency electric force, it glows very brilliantly with an orange colour light. To use this Cymometer we place the instrument near to a wireless telegraph transmitter and alter the capacity of the sliding condenser by moving a handle until the Neon tube glows very brightly. When this is the case we know that we have tuned the Cymometer circuit exactly to the frequency of the oscillations in the wireless telegraph transmitter. The Cymometer has upon it a printed scale which shows at once by the position of a pointer the exact frequency and the exact wave-length corresponding to that particular setting of the Cymometer. We are therefore able by simply placing the Cymometer near to the transmitter and making the above-described adjustment to tell at once the wave-length of the waves being emitted from the transmitter.

Another measurement which is of great importance in connection with wireless telegraphy is that of the damping or diminution of waves in a wave train. It has already been explained that in the spark transmitter when the condenser is discharged across a spark gap the result is to produce a series of oscillations which gradually die away. There may be, for instance, 10, 20, or 30 vibrations, beginning with a certain magnitude and tailing away to nothing. Then after a time the effect is repeated again. The rate at which these oscillations in each train die away is called the damping of the oscillations, and it can be determined numerically by stating how many oscillations take place before the amplitude or extent of them has diminished to 1 per cent. of the initial amplitude. It is easy to see that if we call the initial or first oscillation 100, then if in 10 oscillations the amplitude has diminished to 1 per cent. of 100, namely to 1, that these oscillations would be decreasing much faster than if it required 100 oscillations before the amplitude was reduced 1 per cent. of the initial amplitude. This decrement of the oscillations can be determined by drawing what is called a resonance curve, which can be done with the Cymometer. We insert in the circuit of the Cymometer a very fine wire of iron or of some material which is heated by an electric current, and we place in contact with this wire another pair of wires, one of copper and the other of nickel. When the iron wire is heated by the current, the other pair of wires, called a thermojunction, produces an electromotive force and electric current, and this electric current can be indicated on an instrument called a galvanometer, in which a needle moves over a scale and indicates the exact value of the electric current. In this manner we can measure the feeble oscillatory current which is set up in the circuit of the Cymometer.

Supposing, then, that we place the Cymometer near to a wireless telegraph transmitter and arrange the condenser of the Cymometer so that it is not in tune with the transmitter. We shall then have a very feeble current indicated by the galvanometer, showing that the current induced in the Cymometer circuit, when its capacity is not so adjusted as to put it into tune with the transmitter, is very feeble. Supposing, then, that we alter the capacity in the Cymometer so as to bring it gradually into tune with the transmitter circuit, we then find the current indicated by the galvanometer becoming greater and reaching a maximum value when the Cymometer is exactly in tune with the transmitter. If then, we proceed to alter the capacity still more in the same direction, the current in the Cymometer will again become very feeble.

From the graduations on the Cymometer and from the readings of the galvanometer we can construct a curve called a resonance curve, which can be drawn on squared paper by setting off in a horizontal direction the value of the natural frequency corresponding to any particular setting of the Cymometer and by a vertical line drawn at the end proportional to the current in the Cymometer circuit. Such a curve would run up rapidly to a maximum point and then falls down again, as shown in Fig. 38. The point at which the curve has its maximum value or greatest height corresponds to the exact tuning of the Cymometer circuit with the circuit of the transmitter. Now it can be shown by mathematical reasoning, not, however, suited to an elementary or popular book, that the degree of sharpness of this resonance curve depends upon the sum of the dampings in the Cymometer circuit and that in the transmitter circuit.

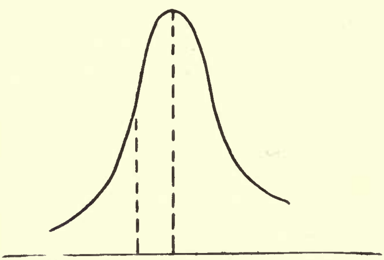


FIG. 38.—A resonance curve.

The damping of the oscillations in the Cymometer circuit can be made very small by making the resistance of the wire of which it is made very small. Hence we may say that approximately the degree of peakiness or sharpness of the resonance curve will depend upon the damping in the transmitter circuit. If these oscillations are very quickly damped, that is to say, die out very quickly, then the resonance curve will be a more or less rounded curve, as shown in Fig. 38; but if the oscillations in the transmitter circuit are very feebly damped, that is, die out very slowly, then the resonance curve will be more sharply peaked. From the form of this curve and by measurements made on it, it is possible to determine numerically the degree of damping of the oscillations, that is to say, to determine how many of them there are in a train and how quickly they die away.

We have already explained that there are two kinds of oscillations used in wireless telegraphy, first those produced on the spark system which consist of groups of oscillations, each group comprising a number of oscillations, say, 10 to 30 or more, which die away more or less quickly and are separated more or less by intervals of silence, and secondly the persistent or undamped oscillations produced by a Poulsen arc apparatus or a Goldschmidt alternator, which are undamped in the sense that they always preserve the same magnitude.

One claim which is made for the transmitters creating undamped oscillations is that with them it is possible to obtain a sharper tuning between the transmitter and the receiving station. Thus, for instance, if we have a transmitting station sending out undamped waves as produced by a Marconi smooth disc discharger, a Poulsen arc or a Goldschmidt alternator, then if the receiving station were exactly tuned to the frequency of the transmitter we should obtain powerful signals, but if the receiving station were put out of tune by as much as a half or even a quarter of one per cent., little or no indication of signals would be received. On the other hand, if a station were sending out strongly damped waves it would probably be possible to vary the tuning of the receiving station by 5 or 10 per cent., or even more, without causing it to cease to receive signals. It is obviously of great importance that a receiving station should be sharply tuned, so that whilst it can receive accurately and strongly the waves intended for it, it will not pick up stray waves or waves of a slightly different wave-length from those which it is intended it shall receive. Hence, the effort of inventors in connection with wireless telegraphy has always been to produce generators or transmitters of that type which shall yield either undamped waves or wave trains as feebly damped as possible.

In those stations employing the spark transmitter it is very often of importance to be able to count the sparks. As these sparks come at the rate of several hundred a second, they cannot, of course, be counted by the eye, but the counting can easily be done by means of a photographic spark counter invented by the Author. This spark counter consists of a photographic camera, but the image formed by the lens does not fall directly upon the photographic plate, but falls first upon a cubical mirror and is then reflected on to the photographic plate. The mirror is caused to turn round by clockwork and the sensitive plate is caused at the same time to move slowly downwards. The result is that if this camera is directed to the transmitter spark the photographic plate records a series of separate images in the form of dots of each constituent spark and by some simple measurements we can easily determine from the plate when developed how many sparks have taken place in a certain time and therefore how many in a second.

Another desirable measurement in connection with wireless telegraph transmitters is that of the efficiency, which means the fraction as a per cent. of the energy or power given to the transmitter that is converted into the energy of electric waves. In the case of an electric lamp we give to the lamp a certain amount of power in the form of electric current, but not more than 5 or 10 per cent. of this power is actually converted into light which can affect our eyes. Hence we say that the efficiency of an electric lamp is from 5 to 10 per cent., as the case may be. In the same manner we give to a wireless telegraph transmitter a certain amount of power in the form of electric current or else in the form of mechanical power from a steam-engine or oil-engine or other prime motor. All the power so given is, however, not converted into long electric waves, but a large portion is dissipated in the transmitter in producing heat. In an ordinary spark transmitter such as is used on board ship, perhaps about 25 per cent. or 30 per cent. of the power supplied may be converted into energy of long electric waves and the rest is wasted. It has been claimed that the generators such as the arc and alternator for producing undamped electric waves have a higher efficiency than spark transmitters, but this point has not been established as yet beyond dispute. The efficiency of a transmitter will, however, vary with its output or size, and it is not possible to give any figure which holds good generally. No thoroughly satisfactory method of measuring the energy radiated from an antenna has yet been devised.

Persons unacquainted with the business side of wireless telegraphy are, however, apt to attach more weight than is justifiable to strictly scientific questions such as the proportion of the applied energy which is utilised at the receiving station.

In all commercial undertakings, and especially in telegraphy, the matter of greatest moment is the efficiency of performance. For instance, in telegraphy the message must be delivered to the receiving station with absolute accuracy or else it is no use. Hence this particular kind of efficiency must attain 100 per cent. or perfection or else it fails altogether in utility. Then the question of total cost of performance stands second in importance. The total over-all costs of delivering a message to the recipient is that which matters to the sender and not the manner in which these costs are distributed over various operations. In most commercial enterprises the total costs can be divided between (i.) interest on capital outlay, including provision for depreciation and antiquation of plant, (ii.) Establishment and control charges, and (iii.) working costs and materials.

In the case of telegraphy the working costs comprise the generation of the electric energy necessary to achieve it. In comparing together telegraphy by cable with wireless telegraphy it is useless therefore to confine attention to only one of the above items of cost. For equal achievements of traffic at equal distances the cost of generating merely the necessary current for wireless telegraphy is far greater than for cable telegraphy. But then, on the other hand, the capital outlay for plant is far less, and therefore the interest and, we may add, the costs of repairs and upkeep are greater in the case of cable telegraphy. Accordingly it is quite erroneous to compare them together merely on the basis of generation of current, or on the proportion of the applied energy which is utilised at the receiving end. The particular powers of wireless telegraphy give it a field of operations peculiar to itself. Hence it is not to be evaluated merely by a comparison of one item of cost with the same item in a totally different method of intercommunication.

Returning, then, to the consideration of receiving appliances themselves, we may note some points connected with the reception of messages conveyed by undamped or continuous waves. In the Poulsen apparatus one appliance used for reception is called a "ticker." It consists of two gold wires which are brought into contact by an electromagnet 100 times or so per second. The ticker is used as follows: We have seen that the currents set up in the antenna are utilised to create other currents in a circuit containing a condenser. In shunt or parallel with this condenser is another condenser which has its terminals connected by a telephone receiver. The ticker periodically connects the second condenser with the first condenser. The continuous waves sent out by the transmitter produce steady oscillations of electricity through the main condenser in the receiver circuit, and as long as the ticker keeps the connection between the two condensers closed the same kind of oscillations take place in the condenser which connects the terminals of the telephone. As soon, however, as the ticker opens the connection, the charge, whatever it may be, contained in this latter condenser flows through the telephone. This gives rise to a short tick or sound in the telephone. The repetition of these ticks as the ticker vibrates causes a uniform sound in the telephone. When the continuous flow of waves from the transmitter is interrupted to make the Morse signals and send a message, the uniform sound in the telephone is interrupted in the same manner, and causes the signals to be conveyed to the ear of the operator listening at the telephone. The combination of ticker and telephone forms a very sensitive receiver for continuous waves. Another type of receiver for continuous waves has been devised by Dr. Goldschmidt for use with his high-frequency alternator. This receiver consists of a rotating-field electric motor constructed on very much the same principles as the high-frequency alternator. The function of the motor is to reduce the frequency just as the function of the alternator is to increase it. It has been explained in the previous chapter that the Goldschmidt alternator is a machine by which we can convert the energy of a steady or direct electric current or that of a low-frequency alternating current or current reversing its direction a few hundred or thousand times per second into a high current reversing its direction some 40,000 or 50,000 times a second. These rapidly reversed currents being transferred to the sending antenna result in the radiation of continuous waves. These waves, when picked up by the receiving antenna, can re-create in a coupled circuit the same kind of continuous current.

It has also been explained that a receiving telephone is not *per se* sensitive to these very high-frequency currents. The ordinary telephone receiver is most sensitive to alternating currents of about 500 frequency ; that means to currents reversing their direction 1000 times per second.

If an alternating current having a frequency 100 were sent through the coils of the telephone receiver it would emit a note of low pitch, for a current of 2000 or 3000 a note of very high pitch, but taken alone it is not sensitive at all, for reasons already explained, to a current of a frequency of 50,000 or so. Hence, to enable the telephone to detect very high-frequency continuous oscillations in an antenna some means must be adopted to reduce their extra high frequency to about 500 or 1000. This can be done by a form of frequency-reducing motor which reduces the very high-frequency currents in the receiving circuits to a low frequency suitable for affecting a telephone. In the attached telephone a shrill note is then heard, which is cut up in accordance with the Morse signals when a message is being sent.

It will be seen, therefore, that different types of receivers have to be used corresponding to the various types of transmitter on the spark, arc, and alternator system. The receiver suitable for picking up one sort of wave is not well adapted for another, but it is quite easy to provide a receiving station with receivers of various kinds adapted for the reception of damped or of undamped waves. The difficulty which might arise is that the operator cannot foretell the species of wave which he might be called upon to receive, and signals would be lost before the necessary selection of apparatus to pick them up could be made.

An ingenious form of telephone has been invented by R. A. Fessenden which he calls a "heterodyne receiver" for detecting continuous or undamped waves. In this telephone there are two sets of coils, one set which is traversed by the oscillations created in the receiving antenna which it is desired to detect and the other set by oscillations of a slightly different frequency created by some means locally, that is at the receiving station. These two trains of oscillations produce "beats" as already explained, the beats having a frequency equal to the difference of the frequencies of the two sets of oscillations and much lower than them are low enough to cause a sound in the telephone.

A curious physiological receiver has lately been made out of the nerve and muscle of a frog's leg. That "old martyr of science," the common frog, has the credit of being the means by which Galvani was enabled to enter into possession of the facts which later on led Volta to the discovery of contact electricity and the Voltaic battery. The nerve and muscle of the frog's leg is extremely sensitive to electric discharges.

Dr. Lefeuvre, Professor in the University of Rennes, France, has accordingly by the aid of it been able to pick up and record radio-telegraphic signals coming from the Eiffel Tower station in Paris. The oscillatory currents creating these signals were passed through the nerve of a

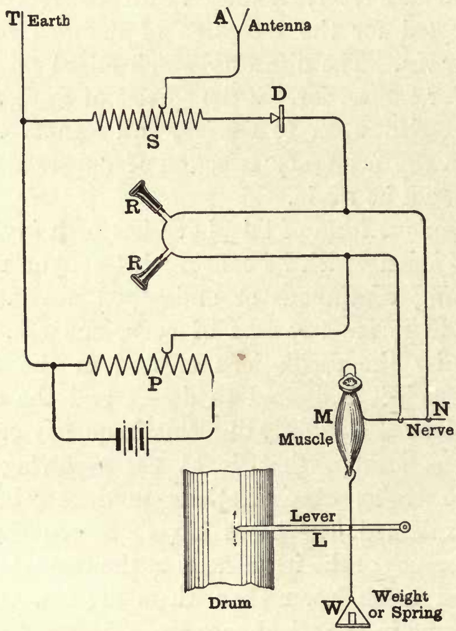


FIG. 39.—A Frog's leg used to receive wireless messages.

frog's leg, and the resulting contraction of the muscle made to move a lever which received the signal on a revolving drum covered with smoked paper (see Fig. 39).

Some of these signals received and recorded by this frog's leg receiver are shown in Fig. 40, and the appliances worked by its assistance.

Having, then, considered the various elements of the

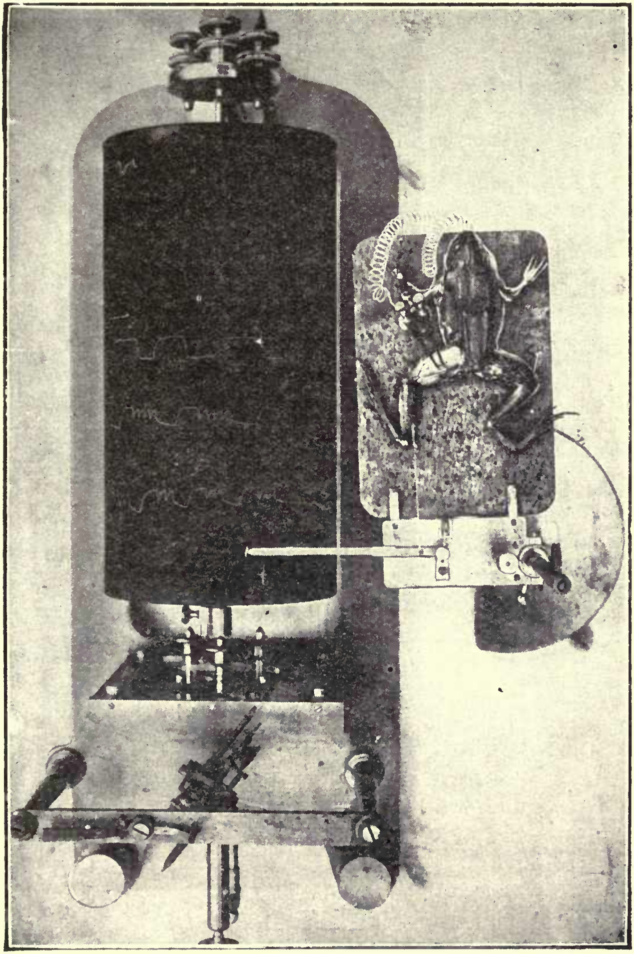


FIG. 40.—Eiffel Tower signals recorded by a frog's leg receiver.

receiver, it will be of advantage to the reader if we describe in brief the general arrangements of a receiving station such as that in the "Wireless Cabin" on board ship, say any large Atlantic liner. Assuming it to be, as in nearly all cases, a ship in correspondence with other ships and coast stations equipped on the spark or Marconi system, the following would be the equipment.

The antenna wires supported by the ship's mast are led down through an ebonite tube into the wireless cabin, and there connected to a switch which enables them to be changed over from the transmitter to the receiver or *vice versâ*. Generally speaking, a box, which is called a tuner, contains the receiving transformers, one coil of which is connected to the lower end of the antenna, and the other to a coil, the inductance of which can be varied by turning a handle, and the remaining end of this last coil is connected to the copper sheathing of the hull of the vessel. In proximity to the above-named primary coil of the oscillation transformer is another coil called the secondary circuit, which can be moved to or from the primary so as to vary what is called the coupling of the coil. This last coil has its ends attached to a condenser of variable capacity. It is then possible by varying the inductance in series with the antenna and the capacity in the secondary circuit to bring these two circuits into tune with each other so that the feeble current generated in the antenna by the impact of the arriving waves shall create by induction stronger currents in the closed receiving circuit.

In some forms of tuner, such as the Marconi tuner, the arrangement is a little more complicated, there being a third or intermediate circuit, which assists in cutting out or preventing stray or atmospheric discharges creating false signals. Then, in addition to the tuner there is some kind of detector, as already explained, either a Marconi magnetic detector, Fleming valve, or crystal or contact detector, and a head telephone consisting

By permission of Marconi's Wireless Telegraph Company.

Fig. 41.—Arrangement of receiving apparatus in the ship's wireless cabin.

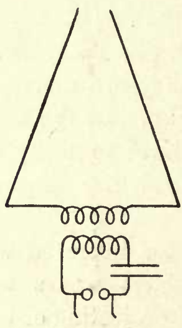
of a pair of Bell telephones attached to a steel clip to fasten on the operator's head to hear the groups of rectified trains of oscillations (see Fig. 41). One of the difficulties which has until lately been inseparable from the telephonic method of reception has been the absence of any "call" signal. Hence, the ship's operators have had to sit hour after hour with the telephones clipped over the ears, and attention on the alert, to pick up and write down any signals received. There are now means of calling the operator's attention by means of an electric bell. The transmitting operator desiring to send a message first transmits a series of long dash signals. These are made to influence either a coherer or a sensitive form of circuit-closer called a relay, which completes or closes the circuit of a local battery and rings an electric bell, and so warns the receiving operator to be ready with his telephone to his ears to listen to a message about to be sent. In default of this it is necessary to have operators who succeed each other in turn in listening for calls. As soon as a message begins to be ticked out on the telephone in long and short sounds the operator writes it down letter by letter, and when he has received the appropriate signals indicating that the message is finished he switches over the antenna on to his own transmitter, and he can then, by manipulating the sending key, transmit to his correspondent or ask a question, or require some part of the message to be repeated.

This intercommunication between ships and between ship and shore is rendered possible or immensely facilitated by the use of one common wave-length, viz. 300 or 600 metres. It is usual to provide ordinary passenger ships with transmitting apparatus capable of sending 300 or 400 miles, but certain battleships and large liners are equipped with more powerful transmitters, having a range of 1000 miles. From the explanation already given, the reader will see that it is a much easier matter to receive messages coming from a long distance than to send them a long distance.

We shall defer until a later chapter the consideration of the arrangements in high-power stations for long-distance sending, and also the organisation of the ship and shore communication over busy passenger ocean routes. Meanwhile, a few words may be said on directive telegraphy. It is of great advantage and importance for a receiving station to be able to locate the direction from which a message is arriving. With the ordinary symmetrical antenna the receiving operator cannot do this. He can determine when electric waves are striking his antenna, and he can measure their wave length and damping, but he cannot say from what direction they are arriving or how far off the transmitting station lies. In the case of ships in distress calling for help they have to notify their latitude and longitude, so that the assisting ships may know the direction in which to steer.

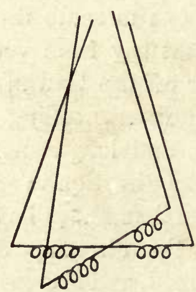
Several methods have, however, been invented which enable the direction of arriving electric waves to be determined, and also give the means of projecting or transmitting radiotelegraphic waves more or less in any required direction.

In addition to the directive antenna having a short part vertical and much greater length horizontal invented by Marconi, a very practical system of directive radiotelegraphy has been devised by two Italian electricians, Bellini and Tosi, a brief description of which may be interesting, as far as it can be explained without advanced reasoning. If we set up at any place an antenna consisting of a pair of wires elevated in the air which are joined together at the bottom and not quite in contact at the top (see Fig. 42*a*), we have an antenna called a nearly closed antenna. If electric oscillations are set swinging in this wire from one side to the other, electric waves will be sent out, but much more powerfully in the plane of the antenna than in other planes. Suppose, then, that another similar triangular antenna is set up at the same place with its plane at right-angles to that of the first one (see Fig. 42*b*). Also let there be a coil of wire inserted in the horizontal or lower part of each antenna. These two last-named coils are wound round a marble cylinder in planes at right-angles to each other (see Fig. 43). Another



a

FIG. 42.



b

FIG. 42.

third coil is then arranged so that it can be swivelled round an axis and placed parallel to either of the two fixed coils or in any intermediate position. This last movable coil has in series with it a condenser or Leyden jar and a spark gap, so that electric oscillations may be set up in the movable coil by repeatedly discharging the condenser across the spark gap in the manner described in Chapter III. Let us, then, suppose that the movable coil is placed with its plane parallel to that of one of the fixed coils which are wound on the marble cylinder. The oscillations produced in the coil in series with the condenser, which we shall call the primary coil, will induce other oscillations in that coil in series with the antenna which has its plane parallel to the primary, but it will not induce any in the other fixed coil.

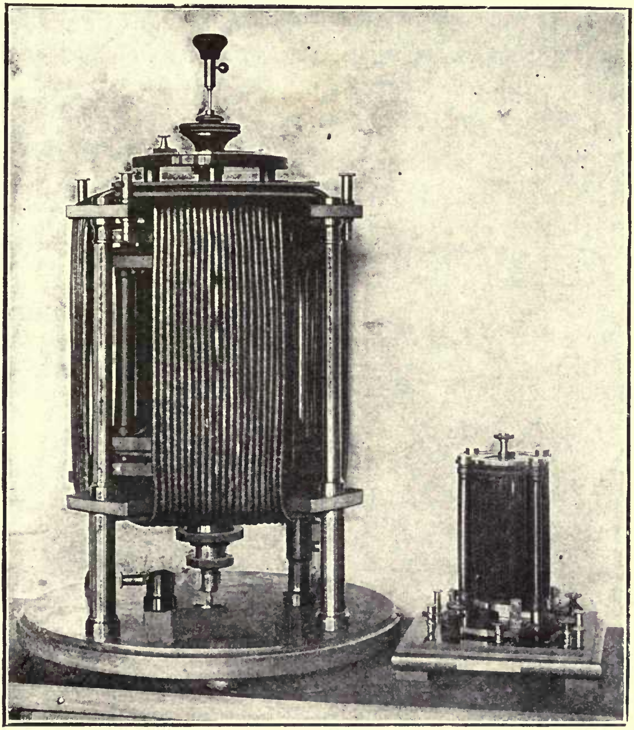


Fig. 43.—Bellini and Tosi radiogoniometer.

Accordingly oscillations will be created in one triangular antenna and waves sent out most strongly in its own plane. Next suppose that the movable primary coil is turned so as to have its plane parallel to that of the other fixed coil wound on the marble cylinder. We shall have waves sent out most vigorously in the plane of the second antenna, which is at right-angles to the plane of the first antenna. Now it can be proved mathematically and experimentally that if the movable coil in which the primary oscillations are generated occupies any intermediate position, then the waves sent out from the two antennæ will combine to make the strongest radiation lie in the plane parallel to that of the movable coil. Hence by turning round this movable coil in different directions the operator has it in his power to direct the most vigorous radiation from this duplex antenna in any direction he pleases. The arrangement of two fixed coils on the marble cylinder embraced by a third movable or rotatable coil is called by Bellini and Tosi a *radiogoniometer*.

It is a principle of wide application in all branches of the science of radiation that a substance absorbs those rays which it emits when heated. This fact lies at the very basis of all our knowledge of the chemical constitution of the stars. To give a simple illustration. If we place some metallic sodium, or even any combination such as common table-salt, which is chloride of sodium, in the flame of a Bunsen burner it gives to the flame a brilliant yellow tint. This flame coloration is characteristic of the metal sodium. If we examine the light with a prism or so-called spectroscope, we see that the yellow light consists entirely of two rays of yellow light very slightly different in wave-length. There are in the spectrum of sodium only two closely adjacent yellow lines. If, now, we examine with the prism the white light emitted by an incandescent solid such as the crater or end of the glowing carbon rods between which is being formed an electric arc, we find the spectrum contains all the tints of the rainbow in a perfectly graduated band of colour. Such a spectrum is called a continuous spectrum. Suppose, then, that we send the light of an electric arc through a flame heavily charged with sodium vapour, on examining it with the prism we find in the spectrum two black lines occupying exactly the position which the bright yellow sodium lines themselves would occupy. These black lines are missing rays. They are due to the absorption of certain rays of the light of the arc by the sodium vapour. We have thus brought before us a very important truth, viz. that a body such as sodium vapour emits when it is incandescent just the same rays to which it is opaque, or which it absorbs, when white light is transmitted through it.

When sunlight is examined with a prism in a properly constructed spectroscope, we find the rainbow-coloured band into which the white light is expanded is crossed by hundreds of fine black lines. Two of these lines occupy in the spectrum exactly the position of the yellow sodium lines. Hence it is inferred that there is sodium vapour in that part of the solar atmosphere called the reversing layer, and that the continuous light from the lower lying brilliant photosphere is absorbed by it, and that the other black lines are in the same manner produced by the absorbing effect of other metallic vapours in the sun.

This law that a body absorbs the same rays that it emits when heated is called the Law of Exchanges. It applies not only to light, but to radiant heat, and also to electromagnetic radiation of all kinds.

Hence we infer that if a complex antenna like the Bellini and Tosi antenna can radiate unequally in different directions, it can also absorb or pick up radiation unequally in the same directions.

This is found to be the case. If the movable coil, which in the transmitter radiogoniometer is in series with a spark gap, and a condenser has the spark gap closed and a detector and telephone connected to the terminals of the condenser, then the transmitter becomes a receiver, all other connections to the antennæ remaining the same.

Let us now suppose that electric waves are arriving from a certain unknown and distant transmitting station, and that the receiving operator desires to find out the direction of that station. All he has to do is to swivel round the movable coil on the radiogoniometer until the sounds of the signals become as loud as possible. The direction in which the plane of the movable coils points is then the direction in which the electric waves are travelling, and must therefore give the direction of the transmitting station. A scale of degrees like a compass card is affixed to the instrument to enable the bearings of the sending station to be thus taken. It is found that the direction of the sending station can be located generally within a few degrees. The Marconi Company have now improved this arrangement into a complete "wireless compass" for locating the direction of arriving wireless signals. It will easily be seen that the equipment of ships with such a "wireless compass" to enable the bearing of the sending station or sending ship to be fixed is highly important.

The point of practical interest about this instrument is that the only part which need be movable is a coil in an apparatus contained in the operator's room, and there is no necessity to move in any way the antenna itself.

No doubt in time improvements will be introduced which will enable the exact distance as well as bearing of the sending station, whether on ship or shore, to be determined from a ship in motion, and thus greatly contribute to render speedy assistance possible in case of disaster to a ship calling for help.

To conclude this Chapter we may say that certain recent improvements in high-speed automatic reception of signals are mentioned in Chapter VI.

CHAPTER V.

WIRELESS TELEGRAPHY OVER LAND AND SEA AND THE TRANSMISSION OF WIRELESS MESSAGES.

BEFORE wireless telegraphy could be developed into a well-organised system of intercommunication over sea and land many difficulties had to be overcome. To some of these, in the first place, we shall allude.

One fact noticed at the time of Mr. Marconi's early work was the greater facility of transmission over sea than over land. The electric waves used in those days had a length of from 300 to 1000 feet or so, and it was found that with the arrangements then employed better and stronger signals were obtained over 50 to 100 miles of sea surface than when the same transmitter and receiver were separated by an equal distance over land. This was not due merely to any difficulty in obtaining what telegraphists call a good "earth connection," that is to say, a good conducting connection to the soil round the transmitting station, but was due to the nature of the surface intervening between the two stations. Further investigations proved that it chiefly depended upon the average conductivity for electricity of the rocks soil or sea between the two stations. The materials of which the earth's surface crust is composed when perfectly dry are nearly all very good non-conductors of electricity. In their natural condition they owe their conductivity chiefly to the water contained in them. Such substances as granite, marble, slate, chalk, and sand, if made quite dry, are very bad conductors of electricity. When moist they become far better conductors. Moreover, the presence of salt in the water adds greatly to the conductivity, hence sea water is a much better conductor of electricity than fresh water.

Arranging them in the order of their conductivity we can say that sea water, fresh water, moist soils or rocks, and dry soils or rocks differ very greatly in their conducting power. Thus, suppose that on some arbitrary scale we call the conductivity of sea water 1,000,000, then the conductivity of fresh or river water would be something between 1000 and 10,000, the conductivity of moist soils might be anything between 1000 and 100,000, and the conductivity of dry rocks would be represented by numbers as small as 1 to 100 or something of that order.

It can be shown that good conductors of electricity, such as metals, are almost perfectly opaque to electric waves. A sheet of copper, for instance, offers a perfect barrier to the passage of electric waves and the radiation of a Hertzian oscillator or wireless telegraph transmitter is stopped by it as completely as a wooden board stops a ray of light.

On the other hand, electric waves pass quite freely through non-conductors. Hence, as a general rule, materials which are good conductors are opaque to electric waves, and materials which are good non-conductors are transparent. There are some anomalies in the case of light waves which, as already explained, are electric waves of very short wave length, but space will not permit us to enter into the discussion of them.

Suffice it to say that sea water is a sufficiently good conductor to offer a considerable barrier to the passage of long electric waves through it, whilst very dry sand, soil or rocks, are not. If, then, electric waves such as are used in radiotelegraphy are propagated over the surface of the sea the penetration of the wave into the water is not large. The electric waves glide over the surface and there is not much absorption of the energy of the electric waves by the sea. Hence, an electric wave 1000 feet in wave length can travel for long distances over sea surface without much diminution of amplitude as far as mere absorption of energy by the surface is concerned. If, however, the same waves are being transmitted over fairly dry soil, and especially soils of certain kinds, the electric waves would be very rapidly weakened owing to the absorption of their energy by the surface over which they are passing. It has been found that there are certain districts of the earth which have a remarkably weakening power on radio-telegraphic waves, so much so that the waves are more reduced in passing over 20 miles of these districts than they would be by travelling over 100 or more miles of sea surface.

In certain experiments made at Brant Rock, U.S.A., Dr. Austin noticed that the district round and north of Newport, which is to the north of and not far from New York, absorbs electric waves very powerfully. Experiments were conducted there by Dr. Austin for the United States Navy to obtain numerical data to facilitate the design of radiotelegraphic stations, with the aid of two cruisers, *Birmingham* and *Salem.* These ships were equipped with similar transmitters and dispatched to various distances from a receiving station at Brant Rock, at which place quantitative measurements of the signals received were made.

These researches were the means of bringing to light many interesting facts concerning the transmission of radiotelegraphic waves over sea and land.

For instance, while the *Birmingham* lay off Newport, signals were sent to Brant Rock with wave lengths of 1000 and 3750 metres respectively. The signals sent with 1000 metre wave lengths lost 90 per cent. of their energy before reaching Brant Rock, whilst the signals sent with waves of 3750 metres length arrived without measurable loss. This, as Dr. Austin remarks, shows the great importance of choosing suitable wave lengths when sending over land, as the absorption which is large for one wave length may be small for another.

The small absorption which long electric waves suffer when transmitted over the surface of sea water owing to its relatively good conductivity has facilitated the development of wireless telegraphy in a direction in which it is without a competitor in the services it can render.

When, however, we attempt to transmit over land we are always liable to find areas of special absorption, in travelling over which the waves suffer an abnormal reduction in strength. It can be shown by theoretical reasoning that these effects depend upon the wave length of the waves as well as upon the conductivity of the surface over which they are travelling, and also upon a quality of the soil and sub-soil called its dielectric coefficient, which means the quality in virtue of which electric force moves or displaces electricity through the material, such movement being only an elastic displacement and disappearing when the force is removed. For any given wave length there are certain values of the dielectric coefficient and conductivity of the surface soil for which the weakening of these waves is a maximum.

Practical experience has confirmed the conclusions of theory that by increasing the length of the wave we are able greatly to reduce the effect of this soil absorption upon the amplitude of the waves travelling over it. Hence, partly for this reason, the use of electric waves of very great wave length, 10,000 to 20,000 feet has been necessary in very long-distance wireless telegraphy.

In close connection with this matter stands the question of the law of variation of the energy and amplitude of electric waves with distance from the transmitting station. We know that when a sound is made at any place the intensity of the sound diminishes with increase of distance. The farther we are away from a speaker, or a band of music, the feebler become the sounds, and at a certain distance the speech or the music become inaudible. The same thing holds good for light. The law according to which the energy of the light waves or sound waves diminishes is stated as follows:—The loudness of the sound or brightness of the illumination on a surface, varies inversely as the square of the distance. That means to say that at twice the distance the illumination or loudness falls off to one-quarter, and at three times the distance to one-ninth and so on. Now the brightness of the illumination on any surface or the loudness of a sound depends upon the square of the amplitude or height of the waves or light or sound respectively. Hence it follows that in both these cases the amplitude or height of the waves varies inversely as the distance from the source of light or sound.

A similar law has been found to exist with regard to wireless waves. If we set up at any point a wireless telegraph transmitter and then make measurements of the magnitude of the electric or magnetic force at numerous large distances from the transmitter it is found that the force decreases almost inversely as the distance, as we go farther and farther from the transmitter. If we set up a receiving antenna at different distances and measure the current produced in this receiving antenna by the incident waves, it is found that this current gets smaller just in the same proportion that the distance gets greater. Hence, if at a distance of 10 miles from the transmitter the current in the receiving antenna is 1 milliampere, then at a distance of 20 miles it will be 0.5 milliampere, and at 30 miles 0.33 milliampere, and at 40 miles 0.25 milliampere, and so on. The law that the current in the receiving antenna varies inversely as the distance from the transmitter when using the same transmitting and receiving appliances in the same way has been tested up to a distance of several hundred miles by experiments made by Duddell and Taylor in England, and Austin in the United States. On the other hand, the accuracy is disturbed when we deal with distances more than 200 or 300 miles by another important factor, viz., the absorption of the atmosphere. As long as we are transmitting long electric waves only over a distance of a few dozen miles, or perhaps even a hundred miles, we do not find that the earth's atmosphere much affects the transmission. Everything goes on just as if the air were absent. In merely laboratory or short-distance experiments the air offers no sensible obstruction, and the electric waves travel just as if they were moving merely through the æther or in a so-called perfect vacuum.

It is quite otherwise, however, when we attempt transmission over several hundred miles. We then find that there is a want of perfect transparency in the air for these waves, apart altogether from any weakening of the waves due to soil absorption. The same thing takes place with regard to light. We do not find that the ordinary dusty air of a room hinders us from seeing across a room or even the length of a street, but when we are concerned with distances of many miles we know that the dust and moisture in the air create a haze which deprives distant objects of their sharpness and obliterates the details of mountains and hills.

We are able to conclude from this, that the atmosphere contains some ingredients in the form of free electrons or separated atoms or groups of atoms carrying electric charges which are called ions, which enables it to absorb the energy of electric waves when large distances are traversed. This absorption increases more rapidly than the distance itself. If we have a series of numbers with a constant difference between them, such as the numbers 1, 2, 3, 4, etc., such a series is called an arithmetic progression. If, on the other hand, we have a series of numbers with a constant ratio, such as 1, 2, 4, 8, 16, etc., these numbers are said to be in geometric progression. The absorption of energy of electric waves increases in geometric progression as the distance increases in arithmetic progression. Moreover, it depends upon the wave length employed, so that under given circumstances it is less the greater the wave length.

In addition to the true or regular atmospheric absorption there is another very important cause of variation in the strength of signals received due to the curious action of daylight upon electric waves. The first discovery in this matter was made by Mr. Marconi in the course of one of his voyages across the Atlantic in 1902 in the s.s. "Philadelphia." He caused certain signals to be sent out regularly from a station at Poldhu, in Cornwall, and he received these signals on board the "Philadelphia."

He noticed that at distances of 700 miles the signals sent by day ceased to be received by his receiver, whereas those that were sent out by night remained quite strong up to 1500 miles and were even readable at a distance of nearly 2100 miles. This led him to conclude that the cause of this weakening of the signals was due to the action of daylight, and this conclusion has been abundantly confirmed by other observers. At first it was supposed that the effect was due to the sunlight acting upon the transmitting antenna and reducing the current in it by causing an escape of electricity. Subsequent investigations have indicated, however, that the effect must be due to the action of the light on the atmosphere all along the line of transmission and not simply on the sending antenna.

Broadly speaking, we may say that for distances of over 500 or 600 miles or so, when sending and receiving with the same apparatus, the distance at which good signals can be obtained is about three times greater by night than by day. There are, however, many irregularities and disturbances which prevent any precisely accurate statement being made concerning the phenomenon in one single short sentence.

In addition to the absorption of the wave energy by the soil or surface of the earth over which the waves pass, and also the absorption due to the atmosphere and the effect of sunlight in hindering the wave transmission, we have also to make reference to what may be called the accidental disturbances which in certain localities and times cause difficulties in receiving, and vary very greatly the distance at which good signals can be received.

The atmosphere of the earth is continually subject to electric discharges which may vary from violent thunderstorms to merely silent electric discharges between clouds or from clouds to the earth. These atmospheric discharges give rise to natural electric waves which are created by the oscillatory nature of these lightning flashes or atmospheric discharges. Electric waves so created travel to long distances from the place where they are generated, and they give rise to disturbances in radiotelegraphic receivers which are called atmospheric X's, or strays.

At the time when the greater part of the reception of wireless messages was conducted by means of the coherer and Morse inker, as described in a previous chapter, these strays were a source of great difficulty to the operators in receiving correctly. The atmospheric disturbances create as just mentioned, vagrant electric waves, and these waves being picked up by the receiving antenna, cause various dots and dashes to be marked down on the paper tape in addition to the signals arriving from the corresponding transmitting station.

A glance at the Morse alphabet will show that even a single dot interposed in among other Morse signals may totally alter the meaning of a message. A single dot, for instance, added to the letter S converts it into an H, and a single dot added to the letter T converts it into an A, or an N. Hence, a very few dots interspersed with the regular message-bearing signals may convert the sentence into nonsense. These difficulties have been largely overcome by the introduction of the aural reception by telephone combined with the use of the high-speed spark, which, as already explained, gives rise to a shrill note in the telephone. Hence, the regular message-bearing signals are heard in the telephone as very shrill sounds of long and short duration. On the other hand, the atmospheric disturbances give rise to sounds in the telephone which are of a lower or different note and hence the observer taking down the signals by ear, can, with practice, distinguish between the proper signals and the accidental disturbances. These disturbances or stray waves are more frequent in our latitude by night than by day, and they undergo a very curious suspension or stoppage just about sunrise and sunset. For instance, Dr. Eccles has described the nature of this effect just about twilight during a London winter in the following words :—

"Starting to listen (at the telephone) at about a quarter of an hour before sunset (in London) on a favourable afternoon in autumn or winter, the strays heard in the telephone are few and feeble as they have been all day ; then at five minutes after sunset a change sets in, the strays slowly get fewer and fewer until at ten minutes after sunset a sudden and distinct lull occurs and lasts perhaps a minute. Often at this period there is a complete impressive silence, then the strays begin to come again, and quickly gain in number and force and in the course of a few minutes they settle down into the steady stream of strong strays proper to the night."

In tropical countries very great irregularities are noticeable, and some of these were particularly studied by Admiral Sir Henry Jackson, R.N., in a series of experiments some years ago in the Mediterranean Sea, where he found these atmospheric effects to be particularly prevalent. He found them stronger and more frequent in summer and autumn than in winter and spring, and also to be more prevalent with certain conditions of the wind. The Mediterranean Sea is frequently exposed to the Scirocco wind, which is a damp south-easterly wind, and often charged with salt and with particles of dust from the African coast. During the continuance of these winds he found the maximum signalling distance generally less than when the wind was in other quarters.

We have, therefore, to recognise five causes which operate to produce either reduction of the signalling distance with given apparatus or else to introduce stray signals which perplex the operators and tend to confuse the message. These are: First, the absorption of the soil, which, for some reason or another, is very marked in certain districts; secondly, the normal atmospheric absorption which, however, only makes itself felt over long distances; thirdly, the effect of daylight in reducing the signalling distance over distances greater than a few hundred miles; fourthly, the normal electric atmospheric disturbances taking place by day and night, chiefly by night; and, fifthly, irregular or storm disturbances, which may hinder more or less transmission at any time.

As regards the day and night effect some interesting observations were made by Messrs. Round and Tremellen at the Marconi Company's works at Chelmsford in 1912, which were recorded in "The Marconigraph." These observers measured at Chelmsford the strength of the signals sent out from the Marconi Station at Clifden, in Ireland, throughout a whole day and night, beginning, say, at mid-day. The strength of the signals received at Chelmsford remained tolerably constant until about an hour before sunset. The signals then increased in strength very quickly to about four times the normal day strength, and this happened a little after sunset at Clifden. This rise was followed by a sudden fall in strength and the signals reached a minimum value about an hour after sunset at Clifden. About an hour later a very sudden increase in strength set in which carried up the signal strength to nine or ten times its minimum day value.

This continued with some irregular variations during the night. About an hour before sunrise at Chelmsford there was another sudden decrease in signalling strength, followed again by a rise and then by a fall to normal day strength soon after sunrise at Clifden. There is therefore one maximum at sunset at Clifden and another about sunrise at Chelmsford.

Other observers, such as G. W. Pickard, have also noticed a similar variation in signalling strength at or about sunrise and sunset.

Mr. Marconi mentioned in a Royal Institution Lecture in June, 1912, that in transatlantic radiotelegraphy the signals are at their weakest when the boundary between day and night has moved into a position about half-way between the two stations at opposite sides of the Atlantic. Moreover, he has noticed a very curious difference between the facility with which signals are transmitted in an east and west direction and in a north and south direction. The facility of transmission being greater in the N.S. direction than in the E.W.

In evidence given before a Parliamentary Committee in 1913, Mr. Marconi sums up the facts as follows :

" Although as a rule messages can be sent at all times of the day and night between Clifden (Ireland) and Glace Bay (Nova Scotia), there still exist periods of fairly regular daily occurrence during which the received signals are at a minimum. Thus in the morning and evening, when in consequence of the difference of longitude daylight or darkness extends only part of the way across the ocean the received signals are at their weakest.

" These variations seem to be less in a north-southerly direction than in an east-westerly one.

" The strength of the received waves remains as a rule steady during the daytime. Shortly after sunset at

Clifden they become gradually weaker. About two hours later they are at their weakest. They then begin to strengthen again and reach a high maximum about the time of sunset at Glace Bay. Then they gradually return to about normal strength, but are variable through the night. Shortly before sunrise at Clifden the signals begin to strengthen steadily and reach another high maximum shortly after sunrise at Clifden. The received energy then steadily decreases again until it reaches a very marked minimum a short time before sunrise at Glace Bay. After that the signals come back to normal day strength."

Mr. Marconi has also shown that there is a variation in the mode in which the signal strength changes during the day and night during the different months of the year.

In the case of transmission of electric waves across the Atlantic conducted with waves 12,000 to 20,000 feet in length, there is thus, as Mr. Marconi states above, a regular cycle of daily variation in signal strength and such waves yield strong and steady signals during the day, but they gradually decrease in strength after sunset, reaching a minimum about 2 hours afterwards. They then increase again until the time of sunset in Nova Scotia, and when both the receiving stations are in darkness the signalling strength is then still further increased, although varying a good deal in strength during the night. Shortly before sunrise at Clifden the signals grow stronger and then decrease again to a lower value about two hours later.

At still greater distances he has noticed that signals could only be received at night. These great irregularities and variations in signalling strength have opened up very many interesting questions concerning the propagation of long electric waves through our atmosphere.

A satisfactory explanation of all these changes has not yet been reached, but there are many indications that these irregularities are due to the action of the sunlight in ionising the molecules of the atmosphere, that is to say, separating them into atoms in such a way that these atoms or groups of atoms become electrically charged, or it may be due to the impregnation of our atmosphere with electrons or electrified particles arriving from extra terrestrial regions or places such as the sun.

Before we consider this last matter it will be best to refer to a very fundamental question in connection with long-distance wireless telegraphy generally. This question is, why is it that these long electric waves travel round the world at all ?

When wireless telegraphy by electric waves began to be practised over short distances, such as 10 to 20 miles or so, the question of the earth's curvature did not arise. When in 1900, Mr. Marconi succeeded in sending his signals from Bournemouth to The Lizard—a distance of nearly 160 miles—the problem connected with the earth's curvature presented itself to the author's mind at once. Here we were concerned with a sufficient distance of transmission to make the straight line joining the sending and transmission station pass through the earth and not merely over it. When, at the end of 1901, Mr. Marconi accomplished more by receiving signals in Newfoundland sent from Poldhu in Cornwall—a distance not far from 2500 miles, the question of the earth's curvature came still more prominently to the front. Since that time he has detected in S. America waves sent out from his station at Clifden, in Ireland, a distance of 6000 miles, or one-quarter of the circumference of the earth. Those who were not physicists and familiar with the phenomena of wave motion looked at the achievement as simply a question of long-distance transmission or expenditure of power. On the other hand, physicists were greatly surprised that it should have been achieved at all, and regarded it as requiring more explanation.

It is well known that waves of all kinds in any medium bend to some extent round obstacles. This bending, however, depends upon the relative magnitude of the wave length and size of the obstacle. Sir Isaac Newton was led to reject the wave theory of light, and adopt his own corpuscular theory, because he thought that on any wave theory it would not be possible to explain the transmission of light in straight lines and the formation of shadows.

There is, in fact, a very slight bending of rays of light round opaque obstacles which is called *diffraction.* Since the average length of the waves of light is only about one fifty-thousandth part of an inch, and most bodies we can see and handle are of very much greater dimensions, the amount of bending which occurs is hardly perceptible, except to refined experiments.

On the other hand, waves in the air or sound waves are for the most part several feet in length, and hence there is considerable diffraction round small objects, and we do not notice the formation of sound shadows with such small objects. If a speaker holds a book before his face the sound of his voice is not much affected to persons at a distance. On the other hand, the interposition of a large object such as a great rock or building does weaken the sound proceeding from some appliance placed on the far side.

It has already been explained that the length of the æther waves employed in radiotelegraphy is from 1000 to 20,000 feet or so in length, and that these waves are essentially of the same nature as those which give rise to the sensation we call light, except that light waves are only a small fraction of an inch in length. Let us suppose that we take a small black ball of about the size of a pea, or say one-quarter of an inch in diameter, and place it in a perfectly dark place, and put close upon the surface of the ball a very small spark or luminous point of exceedingly small dimensions, the light emitted being yellow light of one fifty-thousandth part of an inch in wave length. Then the ratio of the diameter of the ball 0·25 inch to the wave length of the light 0·00002 inch would be 12500.

Under these conditions it is perfectly certain that the rays of light from the luminous point would not bend round the sphere to the extent of 45° or $\frac{1}{8}$th of the way round.

On the other hand, in the case of radiotelegraphy on the earth, we have here a sphere 8,000 miles in diameter. Suppose we have on it a radiotelegraphic transmitter sending out electric waves 1000 metres or 3200 feet in wave length. The ratio of diameter of earth to wave length would be therefore 12,500 nearly. Such radiotelegraphic waves have, however, been detected at a distance of 3000 miles from their source, and must therefore have travelled round the earth to the extent of 45° on a great circle. The puzzle therefore to be explained is why these long electric waves should bend round the earth in this manner to an extent which would not be possible in the case of light waves on a sphere bearing to them the same proportion in size. This problem has been carefully considered by several of our ablest mathematicians; for instance, by Lord Rayleigh, by the late Professor Henri Poincaré, by Professor Macdonald, and by Dr. Nicholson. Working by various methods they have all come to the conclusion that if the earth were a good conductor of electricity, and if we leave out of account any effect of the atmosphere, it is clear that the effect called diffraction will not exist to an extent sufficient to account for long-distance wireless telegraphy. It is tolerably certain that if the earth were for instance a ball of copper 8000 miles in diameter, and suspended in empty space, long electric waves generated at one place would soon glide off the earth altogether, and be lost in space, and would not follow round the curvature of the earth for 3000 or 4000 miles as is actually the case. It can be taken therefore as proved that diffraction in the usual sense of the term is not a sufficient explanation of long-distance wireless telegraphy, and of the bending of the long electric waves round the earth, but that some process is at work which is quite different to that by which a sound wave caused, say, by blowing a trumpet is heard on the other side of a hill or on the other side of a large building.*

Another scientific explanation of the propagation of wireless waves round the earth has been suggested by Professor Sommerfeld, of Münich. He starts with the valid assumption that the earth's crust is not a perfect conductor, but that it is a conducting dielectric, which means to say that it acts partly as a conductor and partly like an insulator in electrical actions. He has developed mathematically the theory of the propagation of electromagnetic waves from a transmitter placed at the boundary of such a conducting dielectric and the air above it, which is practically a perfect insulator. He discovered and proved

* The above definite statement that diffraction is not the exclusive cause of long-distance wireless telegraphy may seem rather inconsistent with a statement on p. 283 of "Waves and Ripples in Water, Air, and Æther," in which it is implied that the effect is to be regarded as wholly due to diffraction. The latest and most thorough mathematical investigations have, however, shown that diffraction cannot be regarded as the chief or sole cause of long-distance wireless telegraphy.

that in this case there would not only be a space electric wave, as it is called, passing through the air over the surface of the earth, but also a surface electric wave travelling along the surface of the earth. This distinction which is rather difficult to follow, may, perhaps, be made plainer by considering the phenomena connected with an earthquake. It has been known since the time of the mathematician Poisson that if a blow or shock is given to an elastic solid, waves of two kinds are propagated through it. One of these waves arises from the fact that the solid possesses elasticity of volume; that is, it resists being squeezed or expanded. The other wave arises from the elastic resistance a solid offers to change of form or distortion. In the case of the earth itself these two waves travel through it with velocities one of 10 and the other of 5 kilometres per second respectively. On the other hand, the surface of the solid is in a different condition to the interior, and hence waves are not propagated so fast just at the surface. Hence, in the case of the earth, when a disturbance is made at some subterranean point, there is not only a wave propagated through the earth, but, as Lord Rayleigh proved years ago, also a wave propagated along the surface which moves rather more slowly than the waves passing through it. When an earthquake occurs, due perhaps to some slipping down or sudden displacement of rocks in the interior of the earth, following on the slow contraction which is always going on, the result is to produce two sets of earthquake waves, one travelling through the solid earth in all directions from the centre of disturbance, and the other which creeps along the surface with a less velocity. These two effects are recorded on instruments for detecting earthquakes. In a similar manner Sommerfeld has shown that in the case of a wireless telegraph transmitter there should be two types of electric wave sent out, one which is propagated through the air or space above, and the other which is confined to the surface of the earth and travels along it.

Sommerfeld proved that this surface wave is much less rapidly attenuated or weakened by distance than the space wave. The decrease in energy of the space wave with increasing distance follows the same law as in the case of light or sound, viz., the energy decreases inversely as the square of the distance. This means that if the energy in the wave is taken to be represented by 1 at a distance of 1 mile from the transmitter, then at a distance of 3 miles it is only $\frac{1}{9}$th, and at 4 miles only $\frac{1}{16}$th of that which it is at 1 mile, and in the same ratio for larger distances. On the other hand, the energy of the surface wave decreases only inversely as the distance, so that at 2, 3, 4 miles, etc., it would have an energy represented by $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, etc., of that which it has at 1 mile. It will therefore be easily seen that the energy of the space wave decreases much faster than that of the surface wave. Moreover, the surface wave follows round the surface no matter how much it may be curved. Sommerfeld's theory, therefore, is that long-distance wireless telegraphy is achieved chiefly by means of this surface electric wave which follows round the curvature of the earth and degrades much less fast than the pure space wave.

There are many observations connected with radio-telegraphy which seem to indicate that the effect at a distance is not wholly due to a space wave but to some effect which travels through the earth. As far back as 1900 or 1901 Mr. Marconi received signals at Poole from a station in the Isle of Wight, fifteen miles away, without any receiving antenna except a zinc cylinder standing on a chair in a room, the receiver being connected to it on one side and to the earth on the other. Also Mr. Campbell Swinton has more recently received signals by merely connecting his receiver to an iron bedstead in an upper room. These facts seem to indicate that some part of the effect produced at the receiver travels through the earth and not over it.

Although this theory has much in it which is attractive and probable, yet there are well-known facts which are difficult to reconcile with it. The first and most familiar of these is the great influence of daylight and the ever-changing conditions of the earth's atmosphere upon long-distance wireless telegraphy. It has been found that the intensity of the signals received from stations at a distance of 2000 or 3000 miles is perpetually changing, not only with the regular variation of day and night, but even with such local and occasional variations as are caused by solar eclipses. Moreover, it is found that ships provided with transmitters of moderate power intended for communication over 200 to 400 miles can occasionally transmit and receive 1000 or 2000 miles, and these "freak transmissions" as they are called, are due to some exceptionally transparent condition of the earth's atmosphere. Hence, there are clearly many well-recognised phenomena which compel us to look for the explanation of these variations in radiotelegraphic transmission, and even of long-distance wireless telegraphy itself, to some state or condition of the atmosphere surrounding the earth.

It has, in fact, of late years become clear that whereas when we are only concerned with small distances, we may look upon the atmosphere as practically not different from free æther in regard to electric wave transmission through it, yet when we are concerned with distances of several hundred miles this is no longer the case, and the air itself or something in it exercises a most potent influence on long electric waves.

Long-distance radiotelegraphy therefore compels us to study the condition of our own terrestrial atmosphere, and its accomplishment has a close connection with the sciences of geophysics and meteorology. We shall therefore devote a moment's attention to the subject.

There are reasons derived from measurement of the heights of auroræ and of the trails of meteors for thinking that the gaseous atmosphere which surrounds our earth extends to a height of not much more than 200 miles. Our means of directly exploring this ocean of air are, however, limited. Sounding balloons have been sent up as high as 19 miles, but a balloon with human beings in the car has not risen above about 7 miles. Clouds can float as high as 10 miles, but mostly at far lower levels. Next, as to composition, the bulk of the air consists of nitrogen and oxygen gases mechanically mixed in about the proportion of 4 to 1 by volume. It contains also small quantities of carbonic dioxide, argon, helium, neon, krypton and xenon gases, and also water vapour. This last constituent exists chiefly or entirely at the lower levels. The temperature of the air gradually decreases as we ascend, and at about the height of 7 miles falls to about 55° below zero Centigrade. Above this level of about 7 miles the temperature remains nearly constant throughout a layer or stratum, called the *stratosphere* or *isothermal*, that is the equal temperature, layer. This 7-mile high level seems in more ways than one to be a critical level. Up to that height the air is in a state of commotion and the movements we call winds churn it up and keep it well mixed. Above that level it appears to be more or less in a stationary condition as a whole, though each molecule of it is still driven hither and thither by its molecular motion. Up to the 7-mile level the different gases in the air are kept so thoroughly mixed that the composition is uniform, although the pressure becomes less and less as we ascend. Above that level it appears that the constituents of the air begin to sort themselves out in order of density and exist more or less in isolated layers. Thus Wegener has given reasons for thinking that the outermost layers of the atmosphere contain hydrogen, helium, and other perhaps rarer gases more or less separated.

The cloudiness and moisture in the air which are such familiar effects to us who dwell upon the surface of the earth, are entirely absent at a height which is only a small fraction of the depth of the aerial ocean at the bottom of which we live. A little way up the atmosphere exists in a state of perpetual clearness and transparency. It is, therefore, penetrated all day and every day by the sun's rays, but owing to its perfect diathermacy, or property of not absorbing heat, it is not made hot.

Another important effect is, however, produced. The sunlight as it reaches the upper levels of our air is very rich in rays called the actinic or ultra-violet light. The photosphere of the sun is far hotter than any furnace on earth, nay even than the electric arc itself. Its temperature is not less than 6000° C. High temperature in a radiant body involves the emission of radiation of very short wave lengths. The wave lengths of light are generally measured in terms of a very small unit of length, viz., a ten-millionth of a millimetre. On this scale the wave-length of yellow light is nearly 5890, whilst the ultra violet rays may have about half this wave length. Now, it is found that our atmosphere absorbs all rays of wave length shorter than 2950, or about half that of yellow light. No rays can be detected in sunlight or starlight as it arrives at the earth's surface of much shorter wave length than this. But shorter waves can be made, and are emitted by many sources of radiation. Their absence in the arriving sunlight is due to their absorption by the oxygen in the air. But the solar radiation represents energy. Hence, if this short wave radiation is absorbed in passing through the air it must produce some physical effect.

These ultra violet rays are of too short a wave length to affect our eyes as light, but they have the power of shaking asunder the atoms of gases and liberating from them one or more of the electrons which compose them. This process is called *ionisation.* The electrons and the electrically charged residuum of the atoms from which they have emerged collect round them other molecules, and these small masses, which have as a nucleus positive or negative charges of electricity are called *gaseous ions.* The atmosphere, therefore, in its upper levels is no doubt extensively ionised by the ultra violet light of the sun. The greater part of this actinic light is thus absorbed, so that the sunlight as it reaches the earth's surface has been robbed of most of the rays of very short wave length.

As soon as the sunlight is withdrawn from the upper air the greater part of these positive and negative ions probably recombine, and the atmospheric gases are brought back more or less to an unionised condition.

But this is not the whole of the story. The upper and outer layers of the atmosphere are not improbably kept in a state of permanent ionisation by the discharge of radiant electrified matter from the sun. Every intensely hot body emits electrons, perhaps enclosed in or surrounded by groups of atoms which are probably projected by radiation pressure from the sun in the form of an excessively fine cosmic dust.

Maxwell proved theoretically that all electric waves such as those of light must exert a pressure upon material bodies, and the existence of this light pressure has been experimentally confirmed by Lebedew in Russia, and Nichols and Hull in the United States, by careful and most ingenious experiments. Hence, no theory of solar action can be now considered which does not take into account this radiation pressure. The sun is built up of many concentric and enveloping layers. Above the brilliant photosphere which probably consists largely of carbon clouds in a state of condensation we have the reversing layer composed of metallic vapours, and above that the chromosphere consisting of incandescent gaseous hydrogen, helium, and calcium, which reveals itself in the red flames seen round the sun during a total solar eclipse. Above this we have a more tenuous atmosphere called the Corona, which is also manifested only during the rare occasions when the moon shuts out the blazing light from the photosphere by coming between the earth and the sun. But beyond the Corona it is probable that a still more extensive gossamer garment called the Zodiacal light envelopes the visible sun and stretches far out towards the earth's orbit. The hypothesis has been advanced and supported by the Swedish physicist, S. Arrhenius, that we have a continual projection of radiant matter from the sun charged with negative electricity, and that when these projected particles reach the earth's atmosphere they are compelled to wind their way spirally round the earth's lines of magnetic force and congregate at or near the terrestrial magnetic poles. In their motion through the upper atmosphere they ionise it and render the upper regions at times luminous with electric discharges which appear visible as the Polar Aurora.

Although the principal manifestation of the Aurora is in the neighbourhood of the earth's magnetic poles, yet W. W. Campbell showed in 1895 that a green auroral spectral line ($\lambda=5770$) can be seen on moonless nights in any part of the sky.

One possible result of this bombardment with solar electrons or meteoric dust may be to keep the upper layers of the earth's atmosphere in a state of permanent ionisation, and therefore to make them a conductor of electricity.

Professor A. Schuster has concluded that at a height of 100-kilometres or 62 miles, the specific resistance of the air is as low as 10,000 ohms per centimetre cube. Hence, we have broadly a division of our atmosphere into three layers. First, an upper region beginning at about 40 or 50 miles high, probably kept permanently ionised, and in a conducting condition perhaps comparable with that of even ordinary water. Secondly, an intermediate layer, which may be considerably ionised by day or when penetrated by sunlight, but resumes a much less ionised condition by night, or when turned away from the sun. Thirdly, a lower level up to about 7 or 8 miles high, in which the ionisation is small and very variable, and in which water vapour in the form of cloud is abundantly present.

We have then to consider how the velocity of propagation of an electric wave is affected by these variously constituted layers of the air.

Bearing in mind that an electric wave consists in the periodic variation of electric and magnetic forces at various places and times along the line of propagation, it is easy to see that if an electrified particle or electron lies in the region through which electric waves are passing, then the electric force in the wave will tend to move the electron as it passes over it just as a surface wave on water lifts up and lets down an object floating on the water as the wave passes over it. The electric wave cannot move the ion or electrified particle without imparting energy to it, and this involves losing energy itself.

Hence, when electric waves pass through a region of ionised air they must lose energy and therefore become weakened. The presence of ions, electrons, or electrified particles in the air will therefore cause an absorption of energy or diminution of amplitude in electric waves passing through that space.

It is, therefore, very probable that the absorption which radiotelegraphic waves experience when passing long distances of several hundred miles through air is due to the presence of these ions or electrons or charged groups of molecules in the air. This absorption may be greatly increased by an abnormal or unusual ionisation. Such ionised air acts towards electric waves just as a slightly misty or dusty air acts towards light, viz., absorbs it, or weakens the radiation. A matter which has been much discussed is whether the atmospheric and soil absorption of the wave energy is less for undamped than for damped waves. Experiments have been conducted in the United States between a radiotelegraphic station at Arlington and a ship the U.S.S. *Salem* using both an arc and a spark transmitter. It has been stated that up to a distance of 1400 miles the arc transmitter having an antenna current of about half that of the spark transmitter, gave about an equal strength of signals, but that at 2100 miles the arc gave somewhat stronger signals.

This would indicate a somewhat less absorption for undamped waves.

In the next place we have to consider the effect of the ionisation and moisture in the air on the velocity of the wave.

We have already explained that the velocity of an electric wave through a dielectric or insulator depends upon the quality of it called its dielectric constant or coefficient. The velocity of the wave is inversely as the square root of the dielectric coefficient or dielectricity of the insulator. It is usual to reckon this quality by stating it in terms of the dielectric coefficient of dry pure air taken as unity.

Thus the approximate values of the dielectric coefficients of some common insulators are as given below.

DIELECTRIC CONSTANTS OR COEFFICIENTS.

Dry air or vacuum	1·0
Sulphur	4·2—4·7
Mica	4·0 to 6·0
Paraffin wax	2·2—2·4
Indiarubber	2·2—2·7 or more
Gutta-percha	2·5—2·9 or more
Dry paper	1·5—2·0
Ebonite	3·1 or more
Glass	6 to 10
Quartz	4·6

The values are only approximate, as specimens differ very much. It follows that the velocity of an electric wave through sulphur is only about half of that which it is through air, and in the case of paraffin wax only about two-thirds. The dielectric coefficient of pure water is very high, being nearly 80 times that of air.

It has been found by the Author that air through which moisture is distributed in the form of minute globules, has a higher dielectric constant than dry air, and therefore the velocity of electric waves through the moist air is slightly less than through dry air.

Dr. Eccles has mathematically shown that the velocity of an electric wave through ionised air should be rather greater than through air which is non-ionised. This last fact, if experimentally confirmed, gives us a basis for a third possible explanation of the propagation of electric waves round the earth, and also of the effect of sunlight in hindering it.

In order that the reader may the more easily follow this explanation, we shall consider in the first place a somewhat analogous effect in the case of sound. It is well known that sounds are better heard when the sound travels with the wind than when it moves against it. Some remarkable instances of the vagaries of sound transmission in this respect are given in the Author's little book, " Waves and Ripples in Water, Air, and Æther," Chapter III. In one case the sound of a siren was heard at a distance of 20 miles in calm weather, whereas with an opposing wind it could not be heard more than $1\frac{1}{4}$ miles away.

The most probable explanation of this difference was given by the late Sir George Stokes, as follows: When the wind is blowing horizontally its velocity near the earth is less than at higher levels, because it is retarded by friction against the ground. Hence, if we suppose a sound made at any place and to travel against the wind, the sound travels less fast at higher levels than near the earth, because the velocity of the wind at higher levels is greater. Hence, the sound wave surface, which would otherwise be a vertical surface near the earth, or more accurately, a portion of a great hemisphere with the sound origin as centre, will become distorted in such fashion that this vertical surface near the earth inclines backwards. Now, the direction in which a sound or ray of light appears to travel is perpendicular to the wave surface. If, then, the wave surface is quite vertical, the sound travels horizontally. If the wave surface inclines backwards, the sound would proceed upwards in a slanting direction. Hence, at a considerable distance the sound, which would reach an observer if the air were still, may pass over his head and not be heard if the wind is blowing from the observer towards the source of sound. The sound, as it were, is lifted above his reach. By a change in the wind it may even be brought down again to a more distant observer. Very curious effects of this kind are often noticed in the distances at which loud sounds such as gun-firing or explosions can be heard. The reader will find further instances of this mentioned in the Author's book, "Waves and Ripples in Water, Air and Æther," in Chapter III, to which he may be referred.

The same kind of action may be manifested in the case of æther or electric waves if they are passing through a medium in which, for any reason, the wave velocity is not uniform. Let us consider a plane electric wave, as it is called, advancing over the surface of the earth with the plane of the wave vertical. This means to say that at all points on a vertical plane the electric and magnetic forces which constitute the wave have the same value as regards magnitude, phase, and direction at the same instant. If the dielectric or insulator through which the wave is advancing is uniform in nature, then the velocity with which the wave advances will be the same at all levels, and the wave will be propagated horizontally. If, however, the upper levels of the air are ionised, and if the ions are of a certain kind, the wave velocity will be greater through the ionised air than through the non-ionised air at the earth's surface. Hence, the wave surface will lean forward, and the direction of propagation will bend so as to follow round the earth's curvature provided that the difference between the velocity at the earth's surface and that at higher levels is of appropriate amount.

This is what would happen to a ray of light if emitted horizontally from a source at a point near the earth's surface if the atmosphere round the earth were extremely dense near the earth's surface, and decreased very rapidly in density with increase of height above it. The ray of light would be bent so as to follow round the earth's curvature.

The suggestion has, therefore, been advanced by Dr. Eccles that an explanation of long-distance wireless telegraphy may be found in the "ionic refraction" of the electric waves emitted by the transmitter as follows:— During the night time the rate at which the ionisation of the air increases as we rise upwards is sufficient to cause the long wave radiation emitted horizontally from suitable long wave wireless transmitters to bend round in the direction of the earth's curvature, and therefore to reach places on the earth's surface 2000, 3000 or 4000 miles away, and not to glide off the earth into space after travelling a few hundred miles, as it would do if not bent. Thus the ionic refraction or bending by the ionisation of the air may be the effective cause of our ability to telegraph long distances by radiotelegraphy.

On the other hand, when the sun rises and the air is more ionised by the ultra violet light, a still greater rate of ionisation upwards takes place which may bend the rays downwards in such a fashion that they fall short of long distances. Hence, the sunlight should inhibit or reduce the range of long-distance wireless telegraphy, but not much interfere with short-distance work.

This is what we find to be the case. Again, the curious drop or reduction in strength which takes place in the signals at sunrise and sunset may perhaps be explained as follows :—

At the boundary plane of darkness and daylight in the earth's atmosphere there is a rather sudden change in the ionisation of the air and owing to air currents and winds, masses of ionised air and non-ionised air may be mixed up together, somewhat in the fashion in which air and water are mixed up in foam or when air is blown through water. Such a mixture of bodies of different refractive power is always more opaque than either of the bodies separately. Every one knows that whereas clear ice is transparent, and also clear air, yet a mixture of powdered ice and air in the form of snow or hail is opaque. The same thing holds good for powdered glass and salt. A powder made of any transparent body is opaque to light. The light is unable to pass through it because of the loss of light by continual reflections at the surface of the small particles of the transparent body, whether glass, ice or salt.

In the same manner a mixture of masses of ionised and unionised air may act towards long electric waves as if it were a turbid medium or froth which stops light waves passing through it by continual reflection and refraction at the boundary surfaces of the non-uniform medium. Hence, when the two radiotelegraphic stations, transmitting and receiving, are so situated with regard to the boundary line of daylight and darkness in the atmosphere that one or other of them is near or in this boundary band or the two are separated by the band, then there will be considerably more difficulty in getting signals through from one to the other.

Although we cannot by any means say that all difficulties are explained, yet there appears to be evidence that the above theory of ionic refraction deserves careful consideration. It points to the fact that the achievement of long-distance wireless telegraphy and also the difficulties that beset it, are largely connected with the state of the atmosphere and dependent upon it. It is not only a question of power, or wave-lengths, and of disturbances, but also a question of the nature and state of ionisation of the medium (the air) through which we have to send our waves.

It seems possible that long electric waves generated at our stations reach distant places on the earth's surface only in virtue of some bending action due to the ionisation of the earth's atmosphere, and that no such long-distance working would be possible if our earth were not provided with an atmosphere ionised in its upper layers. On the other hand there are many effects such as the reception of signals from a distance by connection of the receiver to an insulated metal body and on the other hand to the earth which are difficult to explain unless we assume that some part of the energy sent out from the distant transmitter passes through the earth or at least along its surface.

Our knowledge on these matters is still very imperfect, and it is only by the continual collection and analysis of observation that it can be increased.

Sufficient, however, will have been said to show that there are problems of great interest and immense practical importance connected with the transmission of long electric waves between points at great distances on the earth's surface, which have still to be more perfectly understood and solved.

In the case of radiotelegraphy over moderate distances, the chief difficulties with which the radiotelegraphist has to contend at present are the stray or vagrant disturbances due to atmospheric electricity, and the elimination of signals arriving from stations other than those from which it is desired to receive. These "strays" are more numerous in our latitudes by night than by day, because they are generated at distant places and therefore travel to us more easily by night.

As already mentioned the cutting out of atmospheric disturbances has been made easier by the adoption of the aural or telephone method of reception, and by the use of a high spark frequency, so as to give a shrill musical note in the telephone on which to receive the message signals. It is found in practice that a frequency of about 500 per second is best. A higher note, viz., 1000 per second, seems to be much more fatiguing to the ear, and a lower one is not sufficiently distinguishable from the sounds made in the telephone by distant thunderstorms or atmospheric discharges.

A large number of devices have been invented to render receivers immune from stray electric waves or non-desired signals, or deliberate attempts at jamming or hindering the reception of messages as would take place in war. The general principle which underlies most of these is the utilisation of resonance, so that sudden or brief electric disturbances or those of different wave length shall affect two antennæ or two circuits in such a manner as to neutralise each other's effect on the detector, whereas prolonged trains of waves of just the right wave length will, by their accumulated effect, set up electric swings in only one of these antenna circuits and hence affect the detector and produce the signal.

We have yet to discover by practical experience how far exchange of signals between ships and ship and shore could be worked when deliberate and powerful æther disturbances are made, as would probably be the case in time of naval warfare, to prevent it.

At present radiotelegraphy over sea and land is greatly facilitated by certain conventions and regulations just as general conversation in a room, or the conduct of public meetings, is rendered possible by rules and etiquette. If, however, all wish to shout or speak at once it becomes impossible. Hence, radiotelegraphy under peace conditions is one thing. It might be quite another in time of war. Meanwhile, however, invention will not be idle, and the adoption of means for disturbing the ætherial calm will have to be met by further inventions for increasing the privacy of communications through the æther.

CHAPTER VI.

WIRELESS TELEGRAPHY AND TELEPHONY IN PRACTICE, AND THE UTILISATION OF ELECTROMAGNETIC WAVES.

ALTHOUGH many different plans have been proposed or tried for communicating intelligence through space without interconnecting wires, the method depending on the use of unguided electric waves of great wave-length is the only one which, up to the present, has been found not to be subject to severe limitations as to distance or other conditions. Though all methods of signalling by means of visual signals, such as the semiphore, heliograph, flags, or other ways, are, in fact, forms of wireless telegraphy, yet they are dependent upon a clear sky and uninterrupted line of sight. Moreover, they are limited in range by the curvature of the earth as well as by fog and rain.

It will probably be of advantage to the reader to furnish in the first place in very brief outline a slight sketch of the historical development of practical wireless telegraphy by means of these long electric waves. After Hertz's great experiments had become widely known there is good evidence that many persons turned their thoughts towards the utilisation of these electric waves as a means of transmitting intelligence from place to place without the aid of wires. Even previously to this date the late Prof. D. E. Hughes, eminent for his invention of a printing telegraph, had carried out some novel researches and exhibited the results to scientific friends, which deserved more attention than they actually received. These experiments might, if encouraged, have led him to anticipate some of the inventions which form the basis of electric wave telegraphy. Sir William Crookes made in a magazine article in 1892 a remarkable forecast of the possibilities of this type of telegraphy, apparently based on the result of Professor Hughes' experiments which he had witnessed. Meanwhile, the announcement of Hertz's achievements in 1888 and 1889 caused scientific experimentalists all over the world to repeat them carefully, and to endeavour to find new methods for producing and for detecting free electric waves in space. The ring resonator used by Hertz as a wave detector was too insensitive to provide the means for anything which could properly be called telegraphy, but a number of valuable discoveries by Professors Calzecchi Onesti, and Branly, Sir Oliver Lodge, Prof. Minchin, and others, on the effect of an electric spark and of electric waves on the electric conductivity of loose aggregations of particles of metal gave us a new and far more sensitive means for detecting electric waves. These investigators showed that if a glass tube is filled loosely with metallic filings, preferably iron, and the ends of the tube closed with metallic plugs, the tube is a non-conductor for the electric current from a single Voltaic cell or other source of low electromotive force. If a Hertzian oscillator is set in operation at a little distance, or even a simple electric spark, thus creating electric waves, Branly and Lodge had found that the loose metallic filings suddenly changed to a conductor, and that then an electric current could be passed through it sufficient to ring an electric bell. In 1894 Sir Oliver Lodge delivered Lectures and Discourses in London and in Oxford, at which all Hertz's experiments were repeated, using this metallic filings tube, which he called a coherer, as a wave detector, the waves being detected at distances, varying from a few yards to half a mile or so. A large number of researches and inventions followed, employing this new method of detecting electric waves. Rutherford, at Cambridge, also invented a detector of electric waves based on the power of electric oscillations to demagnetise a steel needle. In 1895, Popoff, a Russian physicist, employed the coherer in association with a Morse printing telegraph connected to a lightning conductor to record distant lightning flashes, and he devised a method for giving to the metallic filings tube automatically a little tap with the hammer of an electric bell so as to shake up the filings and bring them back to the non-conducting condition after each coherence had taken place. Meanwhile, a young investigator, Guglielmo Marconi, had been engaged at Bologna, in Italy, on his father's estate, in a series of experiments which enabled him to make a fundamental discovery.

He was animated by the clear idea of evolving from purely scientific researches a new and practical method of wireless telegraphy. His important contribution to the subject was not merely an improvement in the means of detecting electric waves, but the invention of the means for projecting them far enough; in other words, the creation of a far more powerful radiator than had previously been made. At the same time he gave a more sensitive form to the metallic filings coherer of Branly and Lodge, and improved the tapper by which the tube is continually brought back to the receptive condition, and made the coherer operate a relay, which in turn acted on a Morse printing telegraph and recorded the signals. His earliest apparatus for wireless telegraphy as made in 1894 and 1895 was as follows :—

At the sending station he raised some insulated conductor, such as a metal can to a considerable height above the earth and connected it by a wire with one of a pair of spark balls, the other ball being connected to a metal plate laid on or buried in the ground. These spark balls were connected to the secondary terminals of an induction coil capable of giving a spark 8 or 10 inches long in the air. The spark balls were, however, only placed about half an inch apart. In the primary circuit of the coil he placed a key for interrupting the discharges, and the coil itself was furnished with the usual automatic interrupter or vibrator for rapidly making and breaking the primary circuit, and so producing a succession of sparks between the terminals of the secondary coil. Such an induction coil resembles in every respect the ordinary spark coil used for ignition with petrol engines. In place of the metal can elevated on a pole, Marconi soon began to employ a simple long wire or strip of galvanized wire netting 100 or 150 feet long, elevated in the air by having its upper end suspended from an insulator attached to a mast, and its lower end connected to one of the discharge balls. When the balls were connected to the coil as described, this wire, or the strip of netting, became equivalent to one-half of a very large Hertzian oscillator set vertically, the other part being buried in the earth. When the key in the primary circuit of the coil is closed a torrent of sparks leaps across between the spark balls, and at each spark, of which there may be 50 or 100 per second, the wire or strip is charged electrically to a high pressure, say about 30,000 volts, and then immediately discharged to the earth. This causes an electrical oscillation in the wire. The free electrons in it are set in rapid agitation, vibrating to and fro along the direction of the wire, and the result is to radiate from the wire very powerful electric waves. At each spark a train of waves is emitted, which, however, is rapidly damped or dies down in amplitude very quickly.

The height of this wire, called an aerial or air wire, or antenna, has a great influence upon the distance at which the waves can be detected. Marconi found that other things being equal the distance varied as the square of the height, that is, by making the wire twice as high the waves could be detected at four times the distance, and by making it three times as high they could be detected at nine times the distance; and so on. There are, however, many qualifications to the above rule. He found also that by attaching a similar aerial wire to one end of the coherer, the other end being connected to the earth, that this air wire served not merely to radiate waves, but also to collect them. In the earliest experiments his improved silver and nickel filings coherer, which has already been described in Chapter III., was connected in this manner between an air wire and the earth.

The coherer T (see Fig. 44) had attached to it also a single voltaic cell L, and in series with this was a sensitive relay R or circuit closer, which served to complete the circuit of a more powerful battery which operated the telegraphic printing instrument. In addition, this relay closed another circuit which set in operation a tapper constructed like an electric bell without a gong, the hammer of which administered little taps to the coherer tube, and so brought it back continually to a sensitive condition. The combined result of all this apparatus was that, when the operator, at the sending end gave a short tap on the primary key a few sparks passed between the discharge balls and a few trains of electric waves started out from the sending air wire, and these being captured

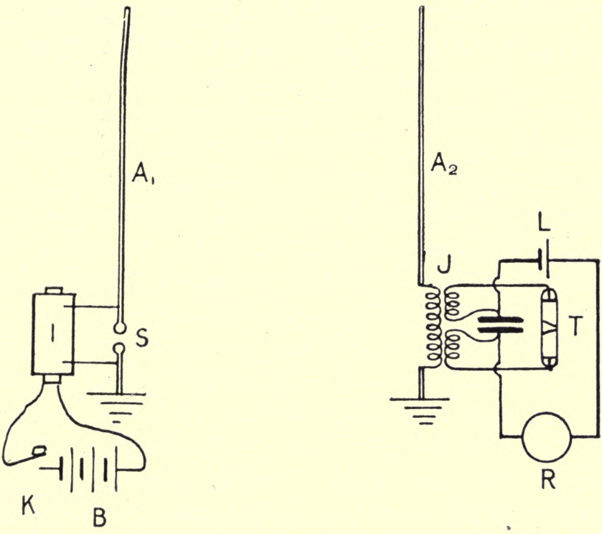


Fig. 44.—First form of Marconi's wireless telegraph apparatus. A_1, sending antenna; A_2, receiving antenna; I, induction coil; S, spark balls; B, battery; K, signalling key; T, coherer; J, jigger; R, relay; L, local battery.

by the receiving air wire created in it feeble oscillations. These acting on the coherer tube caused it to become conductive, and, hence, allowed it to pass a current through the relay and work the Morse printer, printing down on the paper tape a single *dot.* If the sending operator depressed the sending key for a longer time, then the coherer was maintained for a longer time in a conductive state, and a *dash* was printed on the tape. At a later date, Marconi removed the coherer from the circuit of the receiving air wire, and introduced a small transformer J, called in slang terms a "jigger," as Lodge had also done, in such fashion that the electric oscillations set up in the receiving antenna by the impact of the electric waves did not act upon the coherer directly, but created a secondary oscillation in another circuit which affected the coherer and caused the filings to agglomerate. Various other modifications were introduced into the receiving circuit which enabled better results to be obtained. With this apparatus, however, Marconi was enabled to establish wireless telegraphy on a practical basis, and to conduct it over such distances that it at once became available as a most valuable means of communication with moving ships.

This apparatus proved to be particularly well adapted for use on board ship. The erection of one or more long insulated wires suspended from a gaff on a mast did not in the least interfere with the ship's rigging. A small cabin on deck was quite sufficient to contain all the necessary sending and receiving apparatus, whilst most passenger ships being electrically lit had a dynamo on board and means for generating an electric current or charging storage cells. The copper bottom of the ship afforded a good conducting connection to the sea, whilst obviously the movement of the ship in no way interfered with the efficacy of the communication. It was, therefore, seen to be an ideal method of telegraphy between ship and ship or the shore, whilst the simplicity of the apparatus enabled an operator of no great technical knowledge to take charge of it.

About the beginning of 1897 Marconi conducted demonstrations on Salisbury Plain over a distance of 8 miles before representatives of the British Navy and Army. Also across the Bristol Channel between Penarth and Weston-super-Mare, a distance of 9 miles, and in Italy for the Italian Government, at Spezzia, where he telegraphed 12 miles.

Two permanent stations were then set up by him, one at Alum Bay in the Isle of Wight, and the other at Bournemouth, and wireless telegraphy conducted 12 miles over sea, where it was inspected and tested by many persons, such as Lord Tennyson, Lord Kelvin, and others, including the Author. In 1898 communication by this means was established for the Corporation of Lloyds between Ballycastle and the Rathlin Island Lighthouse, off the North of Ireland, a distance of 7·5 miles. In that year Marconi employed his invention for reporting the results of yacht races at the Kingstown Regatta for the *Dublin Express* newspaper, and established it also on board the Royal Yacht *Osborne* in Cowes Bay for intercommunication between Her Majesty Queen Victoria and H.R.H. the Prince of Wales, subsequently King Edward VII.

These successes led to its installation on board the East Goodwin Lightship on the Goodwin Sands for communication with the South Foreland Lighthouse, where it proved to be of great practical value and opened up a vista of extreme usefulness in connection with the transmission of signals between ships at sea and the shore.

He then attempted the more ambitious feat of bridging the English Channel by electric waves. He established two stations, one at the South Foreland Lighthouse near Dover, and one at Wimereux near Boulogne in France.

In March, 1899, he was able to exhibit to numerous persons and to representatives of the Press the transmission of wireless messages across the English Channel by electric waves. This achievement attracted great public attention, and after carefully examining it the Author communicated a letter to *The Times* on April 3, 1899, concerning its practical utility and value.

Part of this letter was as follows :—

" No familiarity with the subject removes the feeling of vague wonder with which one sees a telegraphic instrument merely connected with a length of 150 feet of copper wire run up the side of a flagstaff begin to draw its message out of space and print down in dot and dash on the paper tape the intelligence ferried across 30 miles of water by the mysterious æther.

" Up to the present time none of the other systems of wireless telegraphy employing electric or magnetic agencies has been able to accomplish the same results over equal distances. . . . " If scientific research has forged a fresh weapon with which to fight Nature ' red in tooth or claw ' all other questions fade into insignificance in comparison with the inquiry how we can take the utmost advantage of this addition to our resources."

In the same year the British Association met at Dover, in September, and as that year was the Centenary of Volta's invention of the Voltaic Cell, an evening lecture was given by the Author at the request of the Association, entitled, " The Centenary of the Electric Current." The Marconi wireless telegraph apparatus was set up in the Lecture Hall, and during the lecture messages were transmitted to and received from France and the East Goodwin Lightship, to illustrate its thoroughly efficient operation.

About this time Mr. Marconi went over to the United

States, and arranged to transmit Press messages concerning the yacht races for the International Cup over the course.

More important demonstrations were, however, given by him during the Autumn Naval Manœuvres of the British Navy, when three vessels of the Reserve Squadron were equipped with the Marconi apparatus, and its enormous utility in naval scouting effectively demonstrated.

By the end of that year it had established itself on a firm basis as a most valuable and necessary means of intercommunication between ship and ship and shore, even up to distances of 80 or 100 miles. Its great value in case of accident caused various shipping companies to install it on their ships, and Marconi's Wireless Telegraph Company erected at various places corresponding shore stations. The naval authorities of various countries began to experiment with the new method of signalling with great zeal. Early in 1900 Marconi made a new departure. Up to that point the energy utilised in signalling had been that which could be stored up in the antenna itself. The amount of it was comparatively small and hence the oscillations created or waves sent out at each spark discharge were very quickly quenched. Sir Oliver Lodge had already in 1897 pointed out in a fundamental Patent Specification, No. 11575 of 1897, the great importance of tuning together the transmitter and receiver for securing the privacy of intercommunication. In a subsequent British Patent, No. 7777 of 1900, Marconi disclosed extremely important and valuable inventions having for their object the increase in the energy radiated and also the practical means for securing this privacy. He employed an induction coil I to charge a condenser L of considerable capacity, consisting, say, of six or ten Leyden jars, or even more, and he allowed this condenser to discharge itself across a spark gap S and through a coil of wire P wound once or twice round a wooden frame (see Fig. 45).

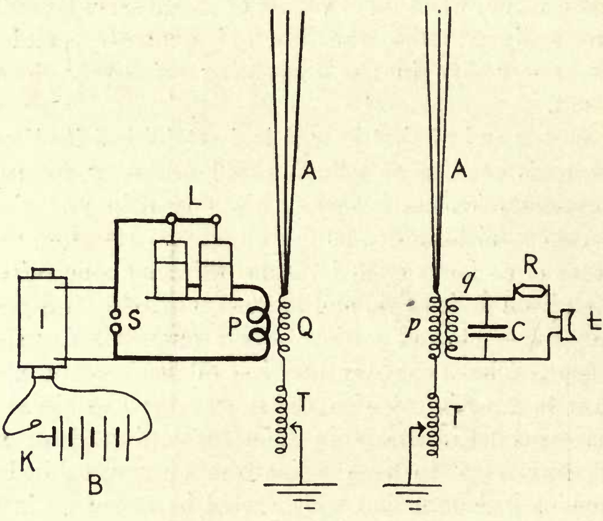


FIG. 45.—Marconi syntonic transmitter and receiver.

On the same frame he wound a second coil Q of a few turns and connected one end of this last coil to the bottom of the insulated antenna wire A, and the other end to the earth plate through a coil T of a variable number of turns called a tuning coil. The two circuits, one comprising the condenser, spark gap and primary coil of the oscillation transformer or "jigger" as it was called, and the other comprising the antenna and the secondary coil of the "jigger," were tuned together by varying the number of turns of the tuning coil included until these two circuits were exactly in tune with each other. When this was the case electrical swings or oscillations set up in the condenser circuit by charging and discharging it created other sympathetic swings or oscillations in the antenna of similar nature and maximum strength. By this arrangement the energy discharged into the æther by the antenna at each spark was greatly increased, and, what was equally important, each train of waves made to consist of a much larger number of slowly decreasing waves; in other words, a long, feebly damped train, rather than the very quickly quenched train of the simple original transmitter. As usual, a signalling key K was inserted in the battery circuit to enable the operator to send out long or short signals. At the same time other changes were made in the receiver. The receiving antenna A had a coil *p* inserted in its lower end which was wound on a little glass tube and over this was wound a second coil *q*, the ends of which were connected to a small condenser C. Another coil T of a variable number of turns called a tuning coil was inserted between the earth plate and the remaining terminal of the first coil wound on the glass tube. In this manner two coupled circuits were constructed. One consisting of the antenna, the primary coil of the receiving "jigger" as it was called, and the tuning coil. The other comprising the secondary circuit of the jigger and the condenser. These two circuits were also tuned together, so as to have the same period of electrical oscillation, and they were also tuned to the two circuits of the transmitter. Hence there were four circuits in tune with each other, viz. the condenser circuit and antenna circuit in the transmitter, and the condenser circuit and antenna circuit in the receiver. The condenser in the transmitter stored up at each charge a considerable amount of energy, and at its discharge imparted this energy to the antenna, setting up in it prolonged trains of electrical swings, causing the electricity in it to rush to and fro, these swings dying away very slowly. These oscillations gave up their energy in part to the æther, just as the vibrations of a piano or violin string are gradually communicated to the air and set up sound waves, so the electrical oscillations in the antenna set up æther waves which travel away from the antenna in all directions with the speed of light. The receiving antenna picks up a very small fraction of this radiated energy, just as the earth receives only a very small fraction, viz. about 1 part in 2000 million of all the heat and light sent out from the sun. Nevertheless, the receiving antenna picks up a sufficient amount to create in itself electrical oscillations and imparts most of this absorbed energy to the closed condenser circuit in association with it. This last circuit is a sort of trap in which accumulates a very small fraction of all the energy in the form of æther waves sent out by the transmitter. At the date when these inventions were made Marconi was still using his coherer and Morse printer, and printing down the messages on paper tape.

Although somewhat troublesome to use on account of the numerous adjustments of the coherer, tapper, relay, and printer, yet nevertheless it did very good service, and enabled the inventor to establish the first practical system of syntonic wireless telegraphy. The great advantages of employing the long trains of feebly damped waves or wave trains comprising many waves and the above described syntonic or tuned receiver is that the receiver can then be made to be unaffected by other waves of a slightly different wave-length from those sent out by the transmitter, provided these other incident waves are not too strong. In the case of the old original plain self-charged transmitting antenna (*see* Fig. 44, A_1) the small amount of energy stored up was released in the form of a single æther impulse, or at most two or three æther waves, emitted from the antenna, and with such a very brief train it was impossible to obtain any true tuning with the corresponding receiver. We have already explained that a circuit consisting of a Leyden jar or condenser having its plates joined by a coil of wire possessing inductance or electric inertia has one particular rate of oscillation of its own in which the electrons in the wire swing to and fro when an electrical impulse is given to it, and then the circuit left to itself. It is just like a strip of steel fixed at the lower end which vibrates at a certain rate when struck and then left to swing freely. These swings can in both cases be greatly increased by giving repeated feeble blows or electrical impulses which come at intervals exactly equal to that of the free natural period of swing of the circuit. The wireless telegraph receiving circuits can be set in electrical vibration better by a large number of electric waves arriving on the antenna at intervals exactly to the free period of vibration of the circuits themselves than by a single sudden impulse or solitary wave. Hence, with a syntonic receiver constructed in accordance with the above principles, although the air may be full of electric waves of different wave-lengths flying about in every direction, the receiver will only be affected by waves of the particular wave length for which it is tuned, provided the other impulses are not too powerful. This does not mean to say that a syntonic receiver cannot be affected at all by powerful waves even if not of the right wave-length made in proximity to it, but it means that if the waves are not of more than a certain amplitude or strength the receiver can be made immune to all but waves the wave-length of which lie within certain narrow limits, and for which it is tuned. It is as if we had the power of rendering our ears insensitive to all notes of a band of music playing at a certain distance, except one or two particular notes, although perhaps not if the band is loud or very near.

Marconi showed it was possible to attach two or three receivers to one and the same receiving antenna, and to receive two or more messages at the same time from different transmitting stations sending with different wave-lengths. Experiments of this kind were witnessed by the writer in the summer of 1900.

In January, 1901, the above arrangements were employed by Marconi for sending signals and messages from St. Catherine's in the Isle of Wight to The Lizard in Cornwall, a distance of 155 miles.

These successes encouraged him to attack a still more difficult task, viz. that of sending radiotelegraphic messages across the Atlantic. For this purpose it was recognised that considerably more power would have to be employed, and that the above described transmitter, constructed with Leyden jars as condensers and a 10-inch spark induction coil with batteries as the source of power, would be insufficient. Accordingly the apparatus had to be transformed into an engineering plant. Knowing the previous experience of the Author in dealing with the practice and theory of high-tension alternating electric currents, Mr. Marconi invited his assistance in the electrical engineering work connected with this novel enterprise of constructing a power plant for the production of electric waves on a scale not previously attempted. For this purpose a site was selected by Mr. Marconi at Poldhu, in

Cornwall, and a building erected there, in October, 1900. The first plant erected comprised a 25-h.p. oil engine, and an alternator for producing a low-frequency alternating current at a pressure of 2000 volts. This current was raised at pressure to 20,000 volts by transformers, and employed to charge condensers. The condenser employed in place of Leyden jars consisted of a number of glass plates coated on each side with tinfoil, the plates being immersed in a highly insulating oil contained in stoneware vessels. All the tinfoils on one side were connected together, and all those on the opposite side, so that the arrangement virtually formed a large Leyden jar. A very large number of these condensers were arranged together and charged by the high-pressure alternating current. The condensers were discharged across a spark gap and through one of two coils of wire wound on a wooden frame immersed in a vat in oil. Some trouble was experienced with the spark gap at first, but the Author designed a form of discharger consisting of two slowly revolving balls or steel discs between which the spark passed. The second coil on the wooden frame was connected in between the antenna and a large copper earth plate, a tuning coil being interposed.

Omitting some details, the arrangement was the same in principle as that described in Mr. Marconi's Patent No. 7777 of 1900. The antenna consisted at first of a fan-shaped arrangement of wires upheld between masts 200 feet high. When this plant was completed and tested, Mr. Marconi and assistants went across to Newfoundland, taking with them kites and balloons by means of which to elevate a receiving antenna wire in the absence of permanent masts. He had previously provided a programme of signals, viz. the letter S (. . .), and other signals to be sent at arranged hours. On December 11, 1901, he found he was able to receive the S signals sent from Poldhu on a wire elevated by a kite in Newfoundland. The signals were received by telephone employing some form of self-adjusting coherer which did not require to be tapped. This transmission of signals across the Atlantic by electric waves excited not only the attention of the general public but also that of physicists, in consequence of the quite unexpected propagation of the waves one-eighth part of the way round the earth. The results showed, however, that with proper permanent antennæ telegraphic signals could be sent and received across the Atlantic.

An immense amount of labour had to be expended on the problem by Mr. Marconi and his staff before this initial success expanded into a regular system of Trans-Atlantic radiotelegraphy. Whilst Mr. Marconi was grappling with these difficulties, his already described small-power apparatus was put into regular operation in the form of a system of intercommunication between ships and the shore. The Marconi Company established various shore stations, and began to equip ships, and organised a regular "wireless exchange" over the Atlantic. This small-power apparatus was suitable for transmission up to 300 to 400 miles or so under ordinary daylight conditions, but could be arranged for reception over much longer distances. The ocean routes taken by the leading passenger lines are carefully kept, and as the dates of sailing of the principal ships are settled a considerable time in advance, it is possible to prepare a communication chart showing the position of the vessels on certain days, excepting accidents, on the Atlantic or other routes (see Fig. 46). The communication chart, of which a copy is

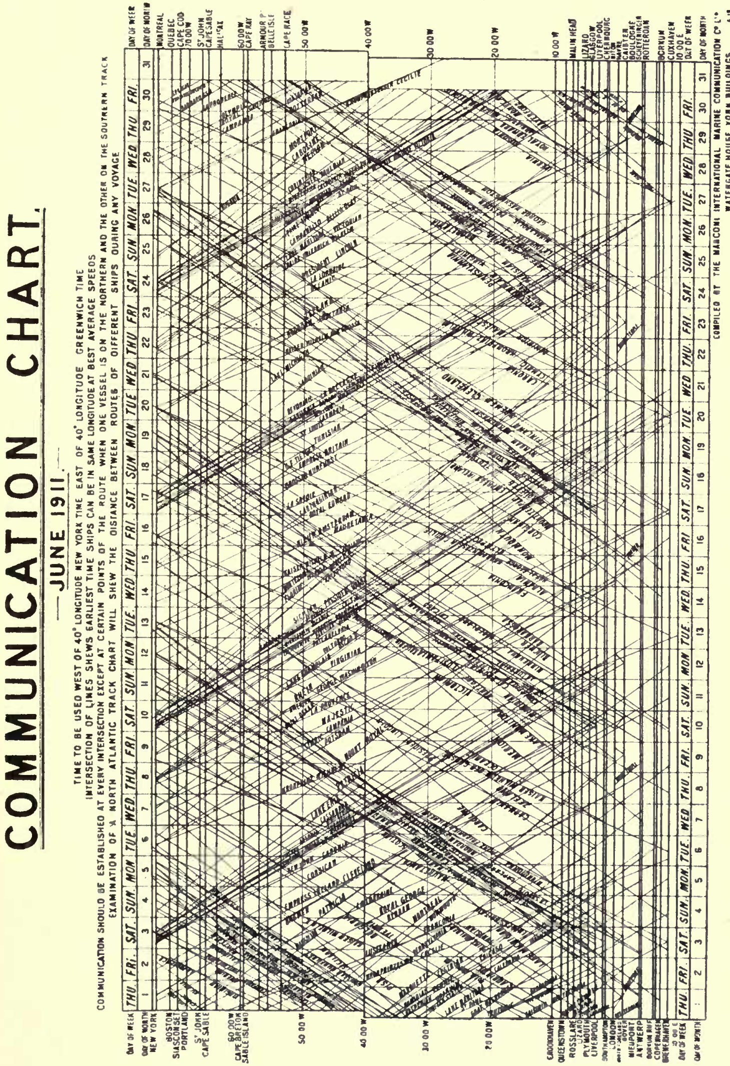

COMMUNICATION CHART.
JUNE 1911.
TIME TO BE USED WEST OF 40° LONGITUDE NEW YORK TIME EAST OF 40° LONGITUDE GREENWICH TIME
INTERSECTION OF LINES SHEWS EARLIEST TIME SHIPS CAN BE IN SAME LONGITUDE AT BEST AVERAGE SPEEDS
COMMUNICATION SHOULD BE ESTABLISHED AT EVERY INTERSECTION EXCEPT AT CERTAIN POINTS OF THE ROUTE WHEN ONE VESSEL IS ON THE NORTHERN AND THE OTHER ON THE SOUTHERN TRACK
EXAMINATION OF A NORTH ATLANTIC TRACK CHART WILL SHEW THE DISTANCE BETWEEN ROUTES OF DIFFERENT SHIPS DURING ANY VOYAGE
COMPILED BY THE MARCONI INTERNATIONAL MARINE COMMUNICATION Cº Lᵀᴰ
WATERGATE HOUSE, YORK BUILDINGS
ADELPHI LONDON W.C.

FIG. 46.

given on the previous page by kind permission of Marconi's Wireless Telegraph Company, shows for each day of the month in advance the distance of all the ships on the Atlantic fitted with Marconi apparatus from all the ports and enables the shore operator to know what ships are within reach. It was possible then to organise a system of message transmission of the following kind: A wireless telegraph station was established on the South of Ireland, say, to which messages could be sent by Postal Telegraph Service. It could then be transmitted by wireless to any vessel within radiotelegraphic range. Supposing, however, that the vessel for which it was intended was out of range, it could be transmitted to another ship within range and then repeated by this last and sent forward to the vessel just out of range of the shore station, and if necessary a similar retransmission could be made a second time to reach a still more distant vessel. In this manner a highly organised service of intercommunication was established by the Marconi International Marine Communication Company. The business of placing wireless telegraphic apparatus on ships then commenced. The Marconi Companies alone have equipped up to the present date (1913) 1600 vessels with their telegraphic apparatus.

After the second International Conference on radiotelegraphy, of which three have been held, two in Berlin in 1903 and 1906, and one in London in 1912, this ocean radiotelegraphy was subjected to International regulations, since ratified and accepted by all the principal nations of the world.

Moreover, all the chief Powers have subjected it to national legislation to control the disturbance of the æther by amateurs and unauthorised persons. In Great

Britain a Wireless Telegraphy Act was passed in August, 1904 (4 Edward VII.), and in 1906 an Amendments Act extended the duration of the first, making it a penal offence to establish a radiotelegraphic station even for experimental purposes without a licence from the Post-master-General. Similar Acts have been passed in other countries.

In 1910 the Marconi Coast Stations in Great Britain were taken over by the British Post Office, and greater facilities offered for intercommunication by vessels equipped with radiotelegraphic apparatus, no matter by whom installed.

Meanwhile other inventors had not been idle. The improvements of Sir Oliver Lodge and Dr. Muirhead were utilised in a system of spark-telegraphy, and those of Professors Braun, and Slaby, and Von Arco in Germany were acquired and worked by a German Wireless Telegraph Company under the name of the "Telefunken system." In France, the United States, Russia and Japan—an immense number of patents have been taken out for radiotelegraphic inventions between the years 1899 and the present time, and detailed contributions to the subject made by scientific investigators which have provided new forms of detector, spark producer, condenser, and tuners, but which have not altered in any essential particular the fundamental principles. In the present small book it would be impossible to mention even a tithe of these inventions.

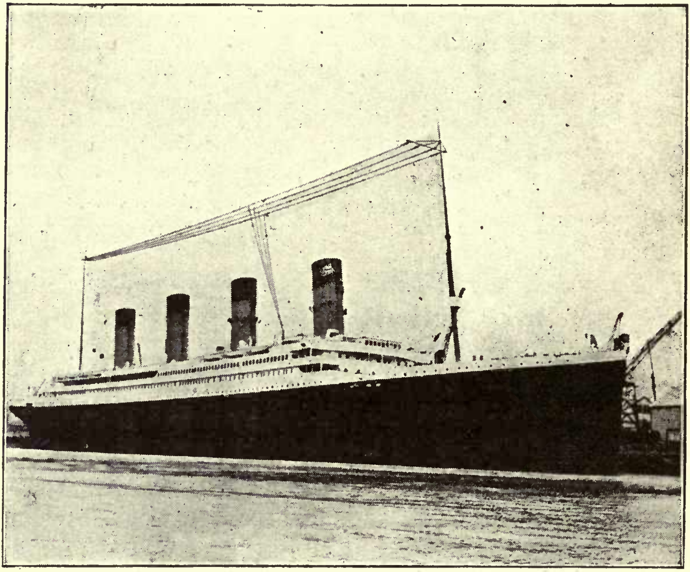
According to some official statistics collected by the authority of the International Conference, there were at the end of 1912 107 radiotelegraphic coast stations equipped by the Marconi Company, 85 by the German Wireless Telegraph (Telefunken) Company, and 76 by others, whilst 726 ships carried Marconi apparatus, 289 carried Telefunken apparatus made by the German company, and 294 were equipped by other companies or firms. These figures do not include the British or German battleship installations, or those on the navies of other countries. If, however, these are included it is possible to say that at present (1913) not less than 3000 ships, naval and mercantile, carry on them apparatus for radiotelegraphy. At the middle of 1913 the Marconi Company and allied companies alone had established 1641 wireless installations on ships of the mercantile marine. They had built 224 land stations in various parts of the world and are erecting 45 more. Foreign ships to the number of 181 carried Marconi apparatus. The whole British Navy is equipped with apparatus on the Marconi system.

After the high-power plant at Poldhu had been brought into a condition suitable for regular service, Mr. Marconi organised a system of direct long-distance transmission of news to ships on the Atlantic, and the Cunard Line took the initiative in publishing small daily newspapers on board their chief passenger ships during the voyage, containing news sent by wireless during the previous night. The *Cunard Daily Bulletin,* published on the R.M.S. *Campania* in 1904, contained a regular service of news throughout her voyages concerning events in the Russo-Japanese War, and other public happenings. These "Marconigrams" and "Bulletins" have now become a familiar feature of transatlantic travel. Vastly more important service has been rendered by this ocean radiotelegraphy in the case of accidents at sea. A few of the more striking cases may be mentioned.

In 1909 on January 23rd the White Star liner ss.

Republic collided with the ss. *Florida* in the Atlantic. The *Republic* was, however, furnished with Marconi wireless apparatus, and the operator, J. R. Binns, was able to get into communication with the shore station on Nantucket Island, and this latter signalled the ss. *Baltic* and six other vessels to go to the aid of the *Republic*. The Captain of the *Baltic* was able to reach the *Republic* in time, and passengers and crew were all rescued. Another case of the same kind occurred on June 10, 1909, when the ss. *Slavonia* was stranded on Flores Island in the Azores, but wireless messages brought the ss. *Batavia* and ss. *Prinzessin Irene* to her rescue, and all the 410 passengers and crew were saved without the loss of a single life.

No such happy exemption, however, accompanied the still more terrible event of the loss of the great White Star liner *Titanic* on her maiden voyage (see Fig. 47). On the 10th of April, 1912, this magnificent vessel, assumed to be the very last word in passenger ship construction, and to embody all that experience could suggest in security as well as luxury, left Southampton with more than 2000 persons on board bound for New York. When four days out she collided at 10 p.m. on a Sunday night with an iceberg, four hours later sinking to the bottom, and 1513 out of 2224 passengers and crew were lost. Those who were saved owed their lives unquestionably to radiotelegraphy, and to the skill and heroism of the operators who utilised to the very utmost the resources which the wonderful powers Marconi's wireless telegraphy placed in their hands for calling for assistance. The full story of this heart-rending disaster was told in the course of two inquiries, one held by a Committee of Congress in the United States under Senator W. A. Smith, and the other a Special Commission held in London under Lord Mersey. The *Titanic's* wireless call for help was picked up 70 miles away by the *Carpathia* (Capt. Rostron), who hastened to the sinking ship, and was able to save 711 persons who had taken to the boats, but the loss of



By permission of Marconi's Wireless Telegraph Co., Ltd.

FIG. 47.—The s.s. *Titanic* starting on her first and only voyage.

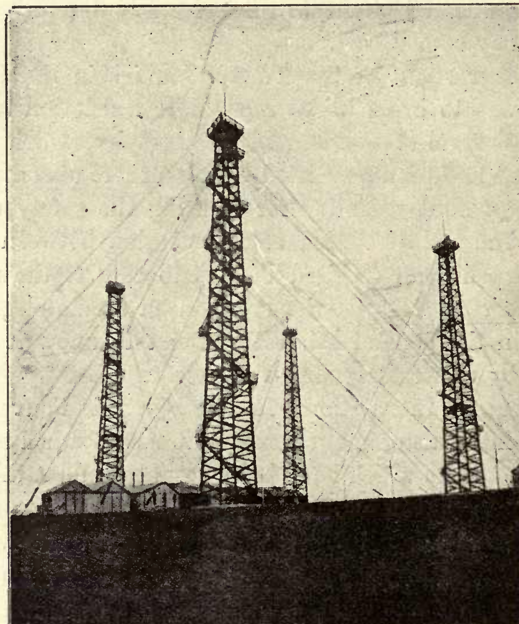
life was appalling, viz. 817 passengers out of 1316, and 696 out of a crew of 908. Both the Commander, Captain E. J. Smith, and the chief Marconi operator, J. G. Phillips, were amongst the lost. One of the lessons drawn from this disaster, and from the failure of the *Californian*, although nearer to the *Titanic* than the *Carpathia*, to pick up the wireless distress signals was that the wireless apparatus on board passenger liners should never be left unattended day or night. As the signals are heard by telephone, this implies that in the absence of a sufficiently reliable bell call one operator must sit always at the receiver with telephone to his ear ready for any signal which may come along.

Another result of the *Titanic* Inquiry in the United States was to bring about immediate legislation for the stricter control of amateur radiotelegraphy, which up to that time had been permitted to go on there uncontrolled. The paramount necessity for securing the safety of life at sea and uninterrupted communication between ships has compelled all civilised Powers to control the use of the æther as regards the creation of radiotelegraphic waves in the general interest and not to allow it to be ruffled by unnecessary disturbances.

Hence the International Radiotelegraphic Conventions held at intervals of about three years have framed regulations and codes which have been accepted and ratified by all the principal nations of the world.

Returning, then, to the history of long-distance wireless telegraphy, we may say that after Mr. Marconi had obtained sufficient evidence that electric wave signals could be transmitted across the Atlantic, he returned to England to make arrangements for the completion of permanent high-power stations. At Poldhu four wooden lattice towers 215 feet high were erected, and the engine power increased (see Fig. 48). Larger condensers and transformers were erected, so as to greatly increase the electric wave-making power. Also in the course of the year Mr. Marconi invented his magnetic detector described in Chapter IV, and so improved the receiving apparatus. The Italian Government lent to him their naval cruiser

Carlo Alberto for long-distance experiments, and this was equipped with an antenna and receiving appliances. In the course of two voyages to the Baltic and Mediterranean



(By permission of Marconi's Wireless Telegraph Co., Ltd.)

FIG. 48.—Lattice towers originally erected at Poldhu station to support the antenna.

seas messages were received from Poldhu as far as Cronstadt (1500 miles) and Spezzia in Italy.

At the end of 1902 the stations erected at Glace Bay in Nova Scotia and Cape Cod in U.S.A. were sufficiently advanced to transmit messages across the Atlantic, and in the next few months many such messages were sent, and sufficient knowledge gained of the difficulties and power required to base an estimate of the conditions under which permanent service could take place. It was then decided to build two new and much more powerful stations, one at Clifden on the West Coast of Ireland and another at Glace Bay, in Nova Scotia, and to equip these with considerably greater power.

Meanwhile in 1905 Mr. Marconi had made the important invention of the bent or directive antenna both for reception and transmission. He found experimentally that if a wire was laid horizontally above the earth and a receiving instrument connected between one end of the wire and an earth plate that he could receive electric wave signals most clearly and strongly when they were arriving from a station situated in the opposite direction to that in which the free or insulated end of the antenna wire pointed.

Also he showed that if the receiving instrument was replaced by a transmitter, then such horizontal antenna sent out waves most vigorously in a direction opposite to that in which the free end points.

Proceeding still further he found that if such a pair of horizontal antennæ with one end free and one end joined to the earth through a receiving instrument and transmitting instrument respectively were placed back to back, that is with the free ends of the antennæ pointing away from each other, these two antennæ so placed had remarkable powers of sending and receiving more vigorously, and therefore over greater distances than plain vertical antennæ. They had also the good quality that the radiation was concentrated in the direction in which it was required. Hence such a bent transmitting antenna having a short length vertical and the greater part of its length horizontal, the transmitting or oscillation-making apparatus being placed at the lower part of the vertical portion, has the peculiar power of sending out most of its radiation in the direction opposite to that in which the free or insulated end points. It is therefore something like a lighthouse having a reflecting mirror behind, or a Fresnel lens in front of its light, to project the light most in one direction.

Shortly after he made the important improvements in the spark discharger mentioned in Chapter III. Up to that time the Author's type of disc discharger had been employed at Poldhu, in which the discharge spark of the condenser took place between two slowly revolving massive discs of steel. This form of discharger, however, did not prevent the formation of an electric arc discharge superimposed upon the true condenser spark discharge, due to electricity coming directly out of the charging transformers without having been stored in the condenser at all. Neither did it prevent the reaction between the condenser circuit and the antenna circuit which, as explained in a previous chapter, results in the radiation of two sets of waves from the antenna differing in wavelength. Mr. Marconi invented in 1907 and 1908 several forms of greatly improved spark discharger giving very uniform nearly continuous wave trains and also perfectly continuous trains. One of the most useful of these has already been briefly mentioned in Chapter III (see Fig. 22), and is made as follows: A massive steel disc is provided with studs or pins projecting on both sides of it near the outside edge. This disc is caused to revolve by an independent electric motor at a high speed, or it may be keyed to the shaft of the alternator supplying current.

Two other revolving discs are placed on the two sides of the main disc, which are just touched by the pins on its edge as they pass. The revolving pins in fact connect together for a very brief instant these outside discs at frequent intervals.

This connection is caused to complete the circuit through which the discharge of the condenser of the transmitter takes place, and the electric discharge passes in its course through the primary coil of a pair of coils of wire wound on a frame, the other or secondary coil being connected in between the antenna and the earth. The rapid passage of the studs cuts short the discharge of the condenser, and hence it is a very brief discharge, that is, consists of very few oscillations, probably not more than half-a-dozen, even if so many. When this takes place through the primary coil it gives to the secondary coil, and therefore to the antenna connected to it, an electrical impulse or shock which causes prolonged free electrical oscillations of one single period, each group having very many oscillations in it, to take place in the antenna circuit. Also the rapid and regular passage of the studs being accompanied by a great blast of air keeps the studs cool and stops at once the formation of any electric arc due to the direct flow of electricity out of the charging transformer. This contributes greatly to increase the possible speed of signalling. Again, the regularity of the discharge causes the groups of oscillations set up in the antenna to follow each other with great regularity. Hence at the receiving end the operator hears in the telephone as already explained a note or sound corresponding in pitch to the frequency of the spark or condenser discharge. If this discharge comes at very regular intervals, as in the case of these high-speed dischargers, the receiving operator will hear an intermittent shrill musical note in his telephone corresponding to each dash or dot. This high musical note is easily distinguished from the lower pitched sounds due to atmospheric discharges, and hence the clearness of the message signals is much increased. Also, since the condenser circuit is only closed for a very short time, the primary spark is quenched and the primary circuit is opened as soon as the secondary or antenna circuit has had a shock given to it sufficient to set up its free oscillations.

Therefore there is no transference of energy to and fro between the condenser circuit and antenna, but the antenna emits a wave of one single frequency.

The new transatlantic high-power stations, one at Clifden in Connemara, Ireland, and the other at Glace Bay in Nova Scotia, were equipped with all these latest inventions of Mr. Marconi. He also employed air condensers, consisting of sheets of insulated metal suspended in a large room with a space of several inches between them, in place of the glass plates covered with tinfoil which had previously been used. The air condenser was not only cheaper to make, but could not be injured permanently by a discharge passing through the insulator (the air) as in the case of the glass plate. The directive antenna consisted of many copper wires elevated on masts, the wires rising up for some 200 feet vertically and then being extended horizontally for 1000 feet or more.

The wave-length employed in these large stations is now approximately 20,000 feet. This corresponds to an oscillation frequency of 50,000 per second. At each spark or discharge of the main condenser a train of 50 to 100 waves is emitted from the antenna, the interval of time between two waves being nearly one-fifty-thousandth part of a second. Each wave is nearly 4 miles long from crest to crest. Hence the whole 100 waves or so in a train cover a distance of nearly 400 miles, and 300 or 400 such trains are emitted per second. Accordingly if the train is 100 waves long, and each wave corresponds to $\frac{1}{50000}$th of a second the whole train occupies about $\frac{1}{500}$th of a second in moving past any point, and the trains succeed each other at the rate of 300 or 400 a second. It is therefore clear that with such arrangements the silent interval between the trains of waves is nearly abolished and the head of one wave train almost touches the tail of the one in front. These wave trains rush across the Atlantic with a speed of 186,300 miles per second, and take about $\frac{1}{75}$th part of a second to cross the 2300 miles of ocean which roughly separate the two stations in Ireland and Nova Scotia. At any one moment about 6 or 7 wave trains are so to speak on their way across the Atlantic. The possible explanation of why they follow round the curvature of the earth instead of gliding off it has been given in the previous chapter. As soon as these stations were completed in 1907 a limited service of Press messages was undertaken, and the evidence of the *New York Times* and London *Times*, making use of this wireless service of news, was that it was in every way satisfactory as regards speed and accuracy. It is worth while to quote these letters as showing that even as far back as 1907 Mr. Marconi had so far overcome the chief difficulties of transatlantic radiotelegraphy as to be able to give a Press service quite comparable with that by cable as regards general accuracy.

The *Times Engineering Supplement* of November 27, 1907, said as follows :—

" We hold no brief for the Marconi Company. It is fair to state our experience of the wireless service, which is, that out of ten dispatches from our correspondent in America nine have been delivered correctly; the only case of failure being due to a breakdown of the land lines."

Also the *New York Times* on March 11, 1908, said:—

"The *New York Times* congratulates you (Mr. Marconi) upon the successful operation of your transatlantic wireless service during the five months since it opened in October last. In that period the *Times* has received from its correspondent in England and on the Continent news despatches totalling 68,404 words promptly and efficiently transmitted by your system."

This excellent beginning was, however, interrupted by a fire which destroyed the station at Glace Bay, and it was then boldly determined to erect a new station embodying all the latest improvements. The station at Clifden was also partially reconstructed, and on April 23, 1910, the service again restored to the Press and public, since which time it has never been seriously interrupted.

In the course of an inquiry by a Parliamentary Committee in 1912–1913 concerning a proposed contract with the Marconi Company for the erection of a chain of radiotelegraphic stations for Imperial intercommunication a Technical Committee was appointed by the Postmaster-General to "consider and report on the merits of the existing systems of long-distance wireless telegraphy, and in particular as to their capacity for continuous communication over the distance required by the Imperial chain."

This Committee was composed of Lord Parker of Waddington (Chairman), Mr. W. Duddell, F.R.S., Dr. R. T. Glazebrook, F.R.S., Sir Alexander B. W. Kennedy, F.R.S., and Mr. James Swinburne, F.R.S.

In their Report dated April 30, 1913, this Committee say with regard to the Marconi high-power transatlantic stations at Clifden and Glace Bay, as follows :—

" The Marconi Company is, we are satisfied, working on a commercial scale between Clifden and Glace Bay, a distance of 2300 miles, though at present the number of messages transmitted either way is not so great as to require duplex working or high-speed transmission. We were, however, present when messages were transmitted automatically at the rate of 60 words (of five letters) a minute, and we see no reason why the rate should not be considerably increased if it becomes necessary. The communication is practically continuous, though there are no doubt periods when the signals become very weak, and even occasional periods when no signals can be got through. Periods of this nature are due to natural conditions and will be incident to the working of any system. During such periods communication can in our opinion be insured only by the use of great power in the aerial.

" We understand that having regard to the increased power required for high-speed transmission the Marconi Company proposed to employ for the Imperial stations practically double the power now used at Clifden. Even so, we think there may be periods when the communication is impracticable, especially in tropical regions where atmospheric disturbances may be expected to cause more difficulty than over the Atlantic."

In August, 1913, after prolonged discussion and an investigation by a Parliamentary Committee, a contract was confirmed by Parliament with the Marconi Company and with Commendatore Marconi for the erection of a number of high-power long-distance radiotelegraphic stations forming a chain of stations for Imperial intercommunication.

In redemption of our promise a word may here be said on the subject of automatic high-speed reception of wireless signals. We have already explained how the

Einthoven galvanometer is used as a detecting instrument. The deflections of the fine silvered glass thread in the magnetic field can be photographed on a strip of sensitive film, and then present the appearance shown in Fig. 49. It is easy to apply in radiotelegraphy means for sending the signals automatically; as is done in ordinary telegraphy with wires. The message is first punched out on paper tape like the paper scrolls used with the mechanical

FIG. 49.—Photographic record of wireless signals recording at a rate of 60 to 110 words per minute.

piano. This can be done in sections by several operators working at once. This tape is then passed through an instrument by which the key controlling the wireless transmitter is moved in accordance with the positions of the holes in the paper. This can be done very rapidly at the rate of 75 to 100 words (five letter) per minute or more. The signals so sent are received and recorded on photographic tape, or they may even be made to record themselves on a disc or cylinder like a gramophone and from this latter can be read off by ear when rotated again slowly. Great advances have been recently made in this respect and enabled radiotelegraphy to place itself in regard to speed of transmission on a level with ordinary telegraphy with wires.

With respect to the actual power required to transmit signals regularly by day and by night across the Atlantic Mr. Marconi gave some very interesting information in the evidence he laid before the above-mentioned Parliamentary Committee. Referring to early experiments he said that messages had been sent across the Atlantic by night between Cape Cod (Mass. U.S.A.) and Poldhu (Cornwall, England) with as little as 7 horse-power (5 kilowatts). To secure regular service he increased the available power to 80 h.p. (60 k.w.), but this proved inadequate. He, therefore, laid down plant for 500 h.p. (370 k.w.) in the new stations. He stated that his difficulty was to utilize this large power in the antenna. The average power used at Clifden and Glace Bay was about 80 k.w., or 107 h.p., taking into account the signalling load factor.

Mr. Marconi stated that his experience at Clifden had enabled him to design a radiotelegraphic station at Coltano, near Pisa in Italy (see *Frontispiece*), which is probably the largest in the world, and in which an effective power of 300 k.w., or 400 h.p., is used. It is in regular communication day and night with Massana on the East Coast of Africa, at 2238 nautical miles distance, of which 1599 are overland and mostly desert, since Massana is situated well within the tropics.

This is proof that long distances overland in tropical countries do not form any insuperable barrier to radiotelegraphic communication when conducted with the right wave-lengths and in the light of previous experience as to methods.

One fact which emerges, however, from all the experience is that in the case of long-distance working a considerable reserve of power is necessary to be able to force signals through in all states of the atmosphere. At certain times the air is exceptionally pellucid or transparent to radiotelegraphic signals, and at other times it is, as it were, murky or misty and greater power is required to get them through against the absorptive ions present in the air.

These difficulties are inherent in radiotelegraphy conducted with any type of electric wave, and would not be removed or sensibly ameliorated by the adoption of persistent waves generated with any kind of arc or alternator, but are without doubt due in some way to the ever varying condition of the terrestrial atmosphere as regards the presence in it of ions or electrons of different kinds.

These facts are sufficient to indicate the great gulf which separates isolated experiments in radiotelegraphy or occasional signalling from that regular day and night, summer and winter, uninterrupted transmission which is essential before any system of telegraphy can be called commercial.

With respect to long-distance stations other than those constructed by Mr. Marconi, mention may be made of the one at Paris, which makes use of the Eiffel Tower as a support for its antenna, and the one at Nauen, near Berlin, which was established by the German Wireless Telegraph Company called the " Gesellschaft für Drahtlose Telegraphie," in connection with the development of radiotelegraphy by the appliances called the " Telefunken System " resulting from a combination of the inventions of Prof. A. Slaby, Count Von Arco, Prof. F. Braun, and Prof. M. Wien.

The Eiffel Tower Station which is under the control of the well-known radiotelegraphic expert, Commandant G. A. Ferrié, contains a transmitter on the spark system, the general principles of which do not differ in any essential element from the Marconi system, but it is also provided with special devices for sending out time signals controlled from the Paris Observatory. A group of high-tension transformers are employed to charge a battery of glass tube condensers, which are in fact Leyden jars. These are discharged through one portion of a coil of wire, and across a spark gap in series with it, and give rise to a series of electrical oscillations. The antenna is connected to the above-said coil, which thus forms what is called an auto-transformer. The antenna itself consists of 6 wires nearly 1000 feet in length extending from the station (which is underground) to the top of the Eiffel Tower, being sustained at the upper end by insulators. This station is now maintained by the French Government chiefly for sending out time and weather signals at appointed hours each day, to enable ships on the Atlantic and within range elsewhere to have given to them Greenwich mean time (G.M.T.), and also information as to weather and barometric height at selected places.

As far back as 1908 the Bureau of Longitudes in Paris suggested that the French military radiotelegraphic station at the Eiffel Tower might be utilised to send out a series of hourly signals to aid in the determination of longitude by giving Paris time or Greenwich time to distant places. This attempt met with so much appreciation that the French Government invited a certain number of other Governments to send delegates to a Conference on the subject, which took place in October, 1912, in Paris, and a programme was formulated for the distribution of time and weather signals from numerous selected stations situated in various parts of the earth. Meanwhile, before this date such a system of signals had been organised and put into practice at the Eiffel Tower Station and at the Norddeich-Wilhelmshaven station in Germany.

The exact determination of a ship's place at sea is a matter of the utmost importance. This can be achieved if the ship determines its latitude and longitude. The former can be found by sextant observations on the altitude of known stars above the horizon. To find the latter the ship has to determine its local time by observations made on the sun or certain stars and it has also to know Greenwich mean time, which is furnished at least approximately by a chronometer. If, however, the chronometer is wrong or has stopped, there is no means in the absence of intercommunication with some other ship or the shore of recovering Greenwich time. At this point wireless telegraphy has stepped in and furnished another invaluable service to the mariner by enabling any ship provided with simple receiving apparatus to pick up time signals sent out from the Eiffel Tower and other stations which give correct Greenwich time, and therefore, enable the navigator to be independent of or check his chronometer.

This International Conference has arranged that the following group of radiotelegraphic stations shall co-operate in these time signals, all working with a wave length of 2,500 metres, and all sending out the same group of signals at the following hours by Greenwich mean time.

Station.	*Time.*
Paris (Eiffel Tower)	0 midnight
San Fernando (Brazil)	2 A.M.
Arlington, U.S.A.	3 A.M.
Manilla	4 A.M. provisionally
Mogadiscio (Italian Somaliland) ..	4 A.M.
Timbuctu	6 A.M.
Paris	10 A.M.
Norddeich-Wilhelmshaven	12 noon

Station.	*Time.*
San Fernando (Brazil)	16=4 P.M.
Arlington, U.S.A.	17
Massowah (Erythrea)	18
San Francisco	20
Norddeich-Wilhelmshaven	22=11 P.M.

A station on the East Coast of Japan, at Choshi, has, since September, 1912, sent out time signals at 9 p.m., Japanese standard time, equal to Greenwich noon, and this station will no doubt be joined with the others. The idea is that every portion of the ocean and habitable globe should be within reach of some station which furnishes Greenwich time and weather data.

The following description of the code of signals which is to be used is taken from the Report of the Conference in the *Comptes Rendus* for November 4th, 1912, Vol. 155, p. 872.

The accompanying diagram (see Fig. 50), taken from the chart given in the *Comptes Rendus*, will make the matter plain.

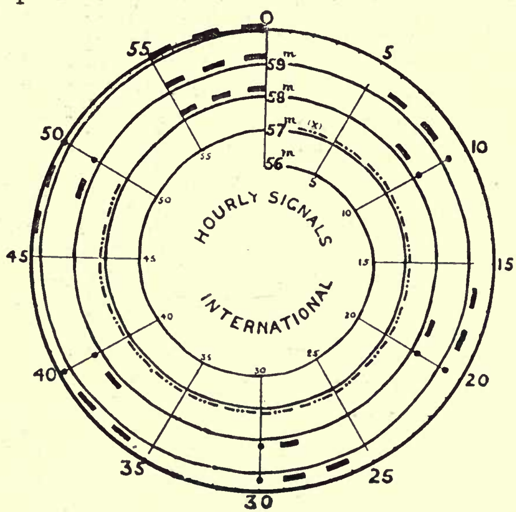


FIG. 50.

Three minutes before the hour by Greenwich time, each station at its appointed time sends out X signals on the Morse code (*dash-dot-dot-dash*). These are repeated regularly until 10 seconds before the beginning of the second minute. At 5 seconds before the conclusion of the third minute before the hour, three dashes are sent, the first beginning at the 5th second before the minute and the last ending exactly at the minute. Each *dash* lasts precisely 1 second and has 1 second interval between it and the next. During the second minute before the hour, five signals are sent consisting of the letter N (*dash-dot*); dispatched every tenth second, each *dot* coming exactly at the 10th, 20th, 30th, 40th and 50th second, and then three *dashes* are sent as above described during the last 5 seconds of the second minute; the end of the third *dash* coming exactly at the end of the 59th minute or 1 minute before the hour.

During the final minute of the hour, six signals, each consisting of the letter G (*dash-dash-dot*) are sent in the same manner, the *dots* falling at the 10th, 20th, 30th, 40th and 50th second, and finally three *dashes* during the last five seconds, the end of the last dash coming exactly at the hour. Hence abundant opportunity is given to check a chronometer at any place within reach, say about 2000 miles radius, and enable a recipient to fix Greenwich time. If the observer can ascertain by observation his local time, he can determine his longitude. The above-mentioned signals are sent slowly and clearly so that no special skill is required to pick them up.

In addition to these time signals which are sent out at the above-named hours by each station, certain of the stations—notably the Eiffel Tower in Paris and Norddeich —distribute information concerning the weather and meteorological conditions at assigned stations around the North Atlantic ocean. Those from the Eiffel Tower are collected by the French *Bureau Central Météorologique* (B.C.M.) and notified in cypher, according to the following code :

The height of the barometer at certain places, the force of the wind and the state of the sea are given, and also information as to the weather in Paris at the time.

The places from which information is collected are Reykjavik (R) (in Iceland), Valencia (V) (in Ireland), Ouessant (Ushant) (O) (in France), Corunna (C) (in Spain), Horta (H) (in the Azores), and St. Pierre (S) (in Newfoundland). The capital letter after each place is used to denote it telegraphically. The height of the barometer is signalled in millimetres, leaving out the first digit 7 which is always the same. Thus V 51 means that the height of the barometer at Valencia is 751 mm. The direction of the wind is denoted by two digits, according to the following code.

N=32,	NNE=02,	NE=04	ENE=06
E=08,	ESE=10,	SE=12	SSE=14
S=16,	SSW=18,	SW=20	WSW=22
W=24,	WNW=26,	NW=28	NNW=30

The force of the wind is denoted by a single digit from 0 to 9, where 0 means dead calm and 9 means a hurricane. In the same way the state of the sea is indicated by a digit between 0 and 9, 0 being dead smooth and 9 extremely rough. If then the signal V 491424 is sent, this means that at Valencia the barometer stands at 749 mm., the wind is SSE and a gentle breeze, whilst the sea is fairly rough.

The state of the weather, sea and wind being known at these six places, ships in the North Atlantic receiving these signals can determine approximately the weather they are likely to meet in approaching the European coasts. These messages give the weather conditions at Reykjavik (in Iceland), Valencia, Ushant, Corunna, and Horta at 7 a.m. and for St. Pierre (in Newfoundland) for the day before at 8 a.m.

As an instance we may give an example of an Eiffel Tower message picked up at the Author's radiotelegraphic laboratory in University College, London, by his assistant, Mr. P. R. Coursey, on June 7th, 1913. At the time of writing this paragraph the new code had not yet come into operation. The time and weather signals were therefore still distributed from the Eiffel Tower station between 10.40 a.m. and 11 a.m. on the Code which was in use prior to July 1st, 1913. The message is as follows:

Saturday, June 7th, 1913.

8.0 a.m. The Eiffel Tower station called up with the signal — · — · — repeated several times. Then followed a message giving the weather in Paris as subjoined: *Vent* 6 *métres décroit ouest sud ouest décroit pression* 764 *cc. ciel nuageux.* This means that the wind at Paris at that moment had a velocity of 6 metres per second (a light breeze) and was decreasing in strength. Its direction was W.S.W. The barometric height was 764 millimetres falling and the sky cloudy.

At 10.42 a.m., the Eiffel Tower station called up again to give the Weather Bureau report. The call signal — · — · — was followed by the words *Paris Observatoire Signaux horaires,* followed by · — · · · — · · · — · · · which means "be on the look out." Then followed the following signals at the minutes named, to give the exact Greenwich mean time, 10.44 a.m. *dash ; dash ; dash ;* etc., for 55 seconds.

10.45 a.m. one *dot* exactly at the 10.45 a.m. G.M.T.

10.46 a.m. *dash, dot, dot ; dash, dot, dot ;* repeated for 55 seconds.

10.47 a.m. one *dot* exactly at 10.47.

10.48 a.m. *dash, dot, dot, dot ;* etc., repeated for 55 seconds.

10.49 a.m. one *dot* exactly at 10.49.

The recipient had thus *three* chances of getting a *dot* exactly at a known Greenwich mean time, and three warning signals to tell him at which minute before the hours it is sent out.

After the receipt of this time signal, the weather report from the six stations above mentioned was picked as follows :—

Saturday, June 7th, 1913.

B.C.M. R. 46327, V 592066, O 642256, C 702815, H 731433, S xx263, *dépressions nord ouest et nord Europe forte pression sud ouest et Azores. Paris vent* 10 *métres croit nord croit pression* 763 *décroit ciel couvert.*

The above message de-coded tells us that the *Bureau Central Météorologique* (B.C.M.) notify that the weather at 8 a.m. was as follows :

At *Reykjavik* (Iceland), barometer 746 mm. Wind N. Fresh gale.

At *Valencia* (Ireland), barometer 759 mm. Wind S.W., strong breeze, sea very rough.

At *Ushant* (France), barometer 764 mm. Wind W.S.W., good breeze, sea very rough.

At *Corunna* (Spain), barometer 770 mm. Wind N.W., calm, sea rough.

At *Horta* (Azores), barometer 773 mm. Wind S.S.E. light breeze, sea choppy.

At *St. Pierre* (Newfoundland), wind W.N.W., light breeze.

In addition to these day signals, the Eiffel Tower station sends out at present (June, 1913) a series of *dot* signals, beginning at 11.30 p.m. 180 dots are sent, the interval between them being exactly 0·98 of a second, and the 60th and 120th dots are omitted. About 10 minutes afterwards, the exact time of the first and last *dot* to within one-hundredth of a second is signalled on a code. This enables an observer to check a chronometer so as to determine, knowing the local time, his longitude with great exactness. By this means it has already been possible to determine the difference of longitude between Paris and Brest, Bizerta, Brussels, Algiers, Toulouse, and Nice, and determinations are in progress for thus determining the difference of longitude of Paris and Washington.

It is clear that wireless telegraphy will thus render services of great value to astronomy, geodesy, and meteorology. For a long time past, the publication of weather prognostications and charts has been greatly facilitated by the information furnished by wireless telegraphy by ships at sea and by coast stations. As the establishment of wireless stations extends and organisation welds them together, it is clear that we shall be able to gather to one focus a statement of the atmospheric conditions existing simultaneously over wide areas of the inhabited earth or traversed oceans, and be thereby enabled to extend the power of weather pretelling. The state of our enveloping atmosphere at any one time at numerous points will be transmitted through the æther, and the analysis of these conditions will enable inferences to be drawn as to the states immediately to come.

With regard to the Telefunken appliances for radio-telegraphy which are used for ship equipment and coast stations in Germany and other countries within its sphere of influence, these are identical in principle with those employed in the Marconi system, except in the details of the spark discharger, and in the nature of the particular wave detector used.

The spark discharger used is based on Wien's discoveries of the rapid extinction of a condenser spark when taken between two smooth, good conducting metal

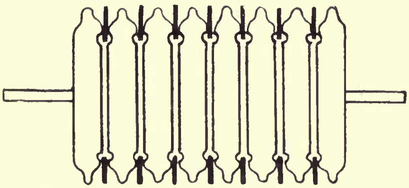


FIG. 51.—Telefunken quenched spark discharger.

surfaces placed very near each other. The discharger, as employed by the Telefunken Company, consists of a series of copper plates having their surfaces plane and very smooth (see Fig. 51). Between each plate is a thin mica ring and the interval between each adjacent plate is not more than $\frac{1}{100}$th of an inch. A large number of these plates are built up one on the other, forming a number of air gaps in series which constitute the spark gap of a condenser. The condenser consists of a number of Leyden jars, which are charged by an induction coil or alternating current transformer. The condenser discharge passes through the above multiple air gap and through a portion of a long coil which acts as an auto-transformer. One end of this long coil is connected to the antenna and the other end to an earth plate or a balancing capacity. When the condenser discharges through this peculiar form of discharger and the spark leaps from plate to plate across the successive narrow gaps, the spark is almost instantly killed and the condenser circuit opened. The result, however, is to give the antenna a sudden electrical impulse which is repeated 500 or 600 times a second, and at each impulse the antenna is set in free electrical oscillation, and radiates a train of waves. One receiver much used by the Telefunken Company is the plumbago-graphite rectifier, or else a receiver called an electrolytic receiver, which consists of a platinum plate and very fine platinum wire just dipping into a little cup of nitric acid. Both these receivers are used with the telephone to give audible signals.

For testing various appliances and for experiments on long-distance radiotelegraphy, the German Wireless Telegraph Company established a station at Nauen, about 25 miles from Berlin, where they erected a tall steel lattice mast, which originally was 300 feet high but has since been increased to 600 feet. This mast supports an umbrella antenna and a system of wires buried in the earth forms the corresponding earth plate. With this large antenna, experiments are being made on long-distance transmission with the spark and alternator methods, and signals have already been transmitted by night between Nauen and Togo in the German Congo, a distance of 3,200 miles.

Regular commercial long-distance working has not been attempted.

As regards other long-distance working, the Poulsen arc generator system is in operation between San Francisco and Honolulu, a distance of 2,396 miles. A contract has been lately made between the Canadian Government and the Company controlling the Poulsen inventions for Transatlantic stations working between Canada and Ireland, in which a speed of 400 letters (80 words) per minute has been guaranteed. It is reported that the United States Government will employ the Poulsen transmitter in a station at Colon on the Panama Canal to communicate with Washington.

The Post Office Technical Committee, to which reference was made above, reported that although both the Poulsen and the Goldschmidt transmitters were admirably adapted for high-speed transmission, yet at the date of their Report (April, 1913), the possibility of regular long-distance transmission with them had not yet been demonstrated. A station has just been completed at Hanover, in Germany, which is equipped with Goldschmidt alternators, and a corresponding station is being erected at Tuckerton, N.J., in the United States. Since the above paragraph was written it has been stated in the daily Press that signals have been transmitted by the aid of the Goldschmidt alternator from Hanover in Germany to Atlantic City in the United States, a distance of 4000 miles.

It is impossible within the limits of space of a small book to do justice to the inventions of all those who have aided in the development of radiotelegraphy. The names of Sir Oliver Lodge, Dr. A. Muirhead, Prof. R. A. Fessenden, Profs. A. Slaby, F. Braun, Count von Arco, and Prof. M. Wien are closely identified with fundamental inventions or improvements. A consideration of the history of the subject as given in larger books will show, however, that in spite of continual references to different "systems" of wireless telegraphy, on which too much emphasis has been laid, there is really only one system of electric wave telegraphy, but there is a distinction between the type of wave used, and mode of creating it. In certain stations they are created by the discharge of a charged condenser, which is made to set up the free electrical oscillations in an antenna of some kind. These oscillations come in groups more or less prolonged, and more or less regularly and frequently. They may, in fact, succeed each other so often that there is no sensible interval of time between them, but they are, nevertheless, the free unconstrained oscillations of the antenna. They resemble the free oscillations of an elastic spring, which is bent and released, and left to vibrate freely. On the above method are worked the present ordinary ship Marconi stations, and also those of the Telefunken Company, and other stations erected by Lodge, and Muirhead, Fessenden, and others.

On the other hand, we have the method which consists in setting up sustained oscillations in the antenna which resemble in nature not the free vibrations of a spring which is displaced and then suddenly released, but the sustained vibrations of a clock pendulum, organ pipe, or harmonium reed; whilst those in the former case are analogous to the vibrations set up in a piano or harp string when struck repeatedly. The two cases merge into each other, and are not separated by a very sharp line.

Electrical engineers are watching with interest the development of these various methods of generating radiotelegraphic waves. Neither the arc nor the alternator generators of sustained waves have at the date of writing (July, 1913) been put into operation continuously over long distances, on such a commercial scale so as to bring them into adequate comparison with the methods invented and successfully put into commercial operation by Mr. Marconi employing his disc dischargers. Meanwhile it may be said that it is quite erroneous to conclude that Mr. Marconi's inventions are limited to methods for the production of damped or intermittent waves. He has devised efficient means for the production of undamped or persistent oscillations, and for the conduct of radiotelegraphy on a commercial scale by them.

It may be that in the future the mechanical method of generating electric waves by suitable high-frequency alternators will prove itself to be a serious competitor with the spark and arc methods. A high-power radiotelegraphic station of the future may come to resemble very much an electric lighting or power station, occupied only by suitable large high-frequency alternators driven by electric motors or engines, and delivering their current directly, or through transformers, into a large antenna.

Such a method was even suggested at one time by Nikola Tesla, though his theory of its operation was not in accord with modern views. We have not yet arrived, however, at this stage, and the difficulties which may arise in its development are probably something quite different from those that are anticipated. Meanwhile, in France, Germany, and the United States high-power long-distance radiotelegraphic stations are being projected and equipped, and before long it will be possible to collate the results of much practical experience with various methods and appliances for radiotelegraphic communication between stations separated by 2000 to 4000 miles.

Turning then to the question of radiotelephony, it must be remarked that an efficient and simple generator of sustained oscillations is necessary for the accomplishment of wireless telephony as contrasted with telegraphy, to which a few paragraphs may in conclusion be given.

When a sound of any kind is made the air particles are set in complicated vibratory motion, moving to and from the source of sound alternately. If we speak against the mouthpiece of an ordinary telephone transmitter, a thin plate called the diaphragm is caused to bend in and out nearly in the same manner. This action is caused to compress more or less some little blocks or particles of hard carbon C contained in a flat box of which the diaphragm D forms the lid (see Fig. 52). This greater or less compression of the carbon particles alters their electrical conductivity, and hence if a Voltaic battery is applied to the carbon the changes in conductivity created by the movements of the diaphragm which are themselves made by the corresponding motion of the air, can be made to modulate in the same manner the electric current flowing through the carbon. This appliance is called a microphone transmitter.

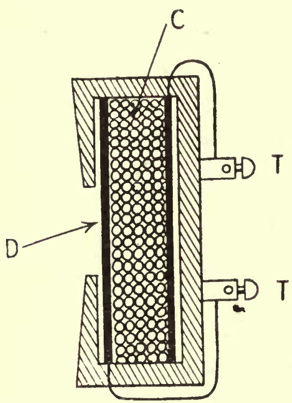


Fig. 52.—Section of a carbon microphone transmitter.

In the case of an ordinary telephone line the microphone transmitter is caused to modulate the current flowing along the line wire, to the other end of which a Bell receiving telephone, as already described in Chapter IV, is attached. The diaphragm of the receiver is therefore caused to move in and out with a motion which is approximately an imitation of that of the transmitting microphone. This, therefore, communicates a similar motion to the air, and therefore recreates a sound for a listener's ear, which is nearly the same as that of the sound made by the speaker to the transmitter, or at least near enough to be recognised.

In wireless telephony we have no line wire connecting the two places, and yet can make the receiving telephone reproduce the sound made to the transmitter. This can be done as follows :—

We set up at one station an antenna, and connect it as already described in Chapter III with some form of continuous oscillation generator so as to create in this antenna electric oscillations which are sustained and non-intermittent as far as may be. These oscillations will, therefore, cause the antenna to emit continuous or undamped waves, which must have a frequency greater than about 40,000 ; that is, must have a wave-length not less than 25,000 feet, or about 5 miles.

Suppose that a receiving antenna is set up at a distant place, and that we provide it with a detector consisting of a crystal of carborundum, or a Fleming valve, in conjunction with a telephone, but put no ticker or interrupter in the telephone circuit. Then if the waves have at least the above frequency no sound would be heard in the receiving telephone, provided the waves were perfectly uninterrupted and always of the same strength or amplitude. The reason for this is because the ear cannot detect sounds caused by aerial vibrations greater than about 30,000 per second, or less than 30 or 40 per second. Hence, if the electric waves falling on the receiver have a frequency higher than 30,000 they will not produce any audible sound in the telephone.

If, however, we insert in the lower end of the sending antenna a microphone transmitter T_1 (*see* Fig. 53), so that the oscillations in the sending antenna have to flow through the carbon granules in the box of the microphone, then when we speak to the microphone the variable compression of the carbon will alter the resistance, and therefore the strength of the oscillations. The electric waves emitted

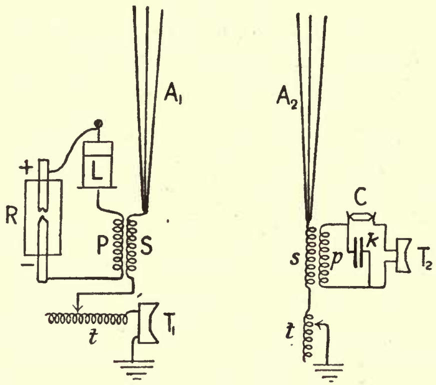


FIG. 53.—Diagrammatic sketch of apparatus for radiotelephony.

from the antenna will, therefore, vary in amplitude just in the same manner. We can, in fact, modulate the electric wave amplitude to follow the variations of air pressure due to the speaking voice without altering the number of electric waves sent out per second, or interrupting their continuity. When this is done the ear at the distant receiving telephone hears the speech reproduced. For the receiving telephone, aided by the rectifying crystal C (see Fig. 53), is traversed by a current which varies with every change in the amplitude of the received waves, and therefore of the transmitted waves.

By this device we can make the receiving telephone reproduce more or less perfectly musical sounds and speech made to the transmitter.

The chief difficulty which arises is that of constructing a microphone transmitter which will pass the necessary large antenna current. An ordinary carbon microphone cannot well pass more than half an ampère of current without becoming overheated and put out of adjustment.

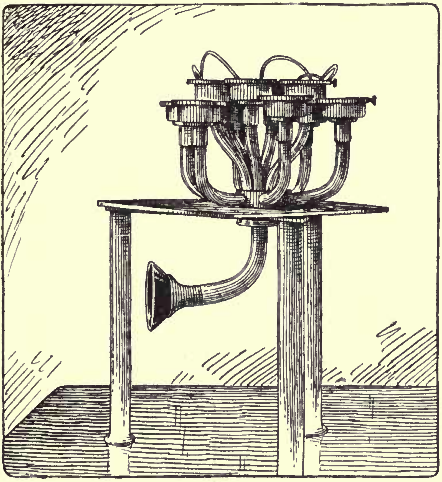


FIG. 54.—Multiple microphone used in wireless telephony.

A number of such microphones, in some cases cooled by water, have to be employed to be able to pass and modulate a current of 5 or 10 ampères, which is the usual current in the base or earth end of an antenna (see Fig. 54). Microphones have been invented by Dubilier and Majorana adapted for heavy currents. Up to the present time the usual method of creating the persistent electric oscillations required in the sending antenna has been by means of the Poulsen arc or some modification of it.

But this apparatus requires some skill to control, and does not invariably produce unbroken or perfectly continuous oscillations. Any such irregularity may be detected in the following way. If the electric arc has the condenser circuit, which is connected across the copper and carbon terminals, connected to a long spiral of wire, then if the oscillations were truly undamped the electric field near this helix should be perfectly persistent. If, however, we cause a vacuum tube (that is, a glass tube fitted with some rarified gas, preferably the gas Neon) to be rotated or waved to and fro rapidly near the helix, then the tube does not always glow or shine with a uniform light as it would do if the field were truly persistent, but exhibits an appearance which shows that the oscillations are extinguished at frequent but irregular intervals. Any irregularity in the production of the oscillations by the arc generator causes irregular sounds in the receiving telephone when the arc is used as a transmitter in wireless telephony. Nevertheless, in skilled hands it can be made to work, and various experimentalists have conducted wireless telephony, or the transmission of music and speech, over distances of two or three hundred miles.

Thus Mr. Poulsen succeeded some years ago in transmitting speech by the above method from Berlin to Copenhagen, a distance of 290 miles, and from Lyngby to Esbjerb, a distance of 170 miles. Fessenden has stated he has also radiotelephoned in the United States from Brant Rock to New York, a distance of 200 miles.

Prof. Majorana, in Italy, who has invented a liquid microphone, has telephoned from Monte Mavio to Porto Danzig, a distance of 60 kilometres. In France Lieutenants Colin and Jeance and Engineer Mercier have transmitted speech from Paris to Finisterre, 300 miles, whilst Prof. Majorana, using the Author's glow lamp detector, has telephoned without wires from Rome to the Coast of Sicily, a distance of 260 miles. More recently speech has been transmitted in this manner from Nauen near Berlin to Vienna. It is also reported to have been transmitted from Nauen to stations on the French frontier, a distance of 500 miles. Dr. J. Vanni has, by means of a liquid microphone of his own invention, achieved the feat of transmitting speech without interconnecting wires a distance of over 600 miles, viz. from Rome to Tripoli. His microphone consists of a jet of water rendered slightly conducting by acid or salts, which falls down between two inclined metal plates. One of these is fixed, and the other is moved by a diaphragm or flexible plate against which words are spoken. The vibrations of this plate are communicated to the jet of water, and this varies the electrical conductivity of that part of the jet which bounces off one plate on to the other. These two plates are connected respectively to the sending antenna and the earth. Hence, when speech is made to the diaphragm, the continuous waves emitted from the antenna are varied in amplitude. At the receiving end the oscillations picked up are rectified by a form of Fleming oscillation valve, and are heard as articulate words in the telephone. In this manner Dr. Vanni transmitted speech from Rome to the island of Ponza, to Maddalena, Palermo (Sicily), and finally to Tripoli.

Hence, as an experimental feat the transmission of speech by electric waves is quite feasible, but it cannot be said yet to have been reduced to such a practical everyday performance as wireless telegraphy. What is needed is a more effective form of microphone transmitter, capable of passing large high-frequency currents, and a more perfect and easily managed generator for undamped or persistent oscillations. Mr. Marconi, using his smooth disc generator of continuous oscillations, has recently directed his attention successfully to the solution of these problems of radiotelephony. There is nothing scientifically impossible in the radiotelephonic transmission of speech across the Atlantic, but it may be some time yet before it is possible to make radiotelephony comparable in efficiency with radiotelegraphy over large distances.

As regards wireless telegraphy the future is assured. It will not be long before every passenger ship that sails the high seas will be compelled to carry apparatus for wireless telegraphy, and to keep a look-out day and night with it. The immense services rendered in saving life in the case of the ss. *Volturno*, on October 9th, 1913, are fresh in recollection. This ship, carrying over 600 emigrants from Rotterdam to New York, took fire in Mid-Atlantic. Fortunately it was provided with Marconi wireless telegraph-plant, and it sent out the S. O. S. call for help. The call was picked up by the Cunard liner *Carmania*, and her Captain rushed to the rescue. Nine other ships also heard and responded to the call, the *Grosser Kurfurst, Seydlitz, Minneapolis, Rappahannock, Tzar, Devonian, Kroonland* and *La Touraine*. The sea was too rough to effect a transfer of the crew of the burning ship to the boats until an oil ship, the *Narragansett*, arrived and literally poured oil on the waters. This calmed the waves and enabled 521 passengers and crew to be taken off, although 136 were lost in the disaster. Had it not been for this great invention of wireless telegraphy, every one would undoubtedly have met a fearful death. With respect to long-distance wireless telegraphy we may be sure that progress will continue to be made. The chief problem in connection with it is a more thorough understanding of the ever-varying conditions of our atmosphere, particularly with respect to its periodic and exceptional changes of transparency to long electric waves. These may be governed by laws as complex as those which control the weather itself, but they are amenable to investigation. It was for this reason that the Author proposed in a paper read to the British Association at Dundee in 1912 the formation of a Radiotelegraphic Committee for organising joint research, and the suggestion was adopted by the Association. Already much valuable information has been collected by many observers, and in time this will furnish materials for a valid theory of long-distance wireless telegraphy.

In bringing to a close this brief description of the processes and wonders of wireless telegraphy, we can hardly avoid observing the astonishing manner in which the scientific guesses of one age become the accepted certainties of the next, or the difficult experimental achievements of some illustrious pioneer are transformed into factory processes in the course of a few short years. Before the date of publication of Maxwell's great Treatise on Electricity and Magnetism in 1873, the æther was mentioned merely as a physical hypothesis to account for optical phenomena, in books on the theory of optics. To-day to the radiotelegraphist it seems almost as real as the air he breathes, whilst its disturbance has to be regulated by Acts of Parliament, like the pollution of rivers, or the emission of smoke from factory chimneys.

It is a brief quarter of a century since Hertz first delighted the scientific world in 1888 by providing objective proof of the existence of Maxwell's electromagnetic waves, and giving life to the dry bones of certain mathematical equations, until then "caviare to the general." To-day, thanks chiefly to the indomitable perseverance and practical inventions of Marconi, and the labours of an army of inventors in this same field, these waves are used as means of everyday communication with ships in mid ocean, or saving from a watery grave the passengers and crew of some vessel in distress. There is evidence to show that up to the present (1913) nearly 4000 persons have been saved from shipwreck and death by the applications of wireless telegraphy on the Marconi system.

Sir Francis Bacon tells us in his "Advancement of Learning" that the "last or furthest end of knowledge" is "the glory of the Creator, and the relief of man's estate," but not solely the benefit of the individual or the welfare of the few.

The general public which judges by results rather than by details or processes is apt to value pursuits chiefly by their utilitarian fruits, and asks what is the use of increasing knowledge if it is not inspired and directed by some useful purpose? Nevertheless, the search after the truth as an end in itself concerning the intricate processes of Nature makes a direct appeal to certain faculties of the human mind and is unquestionably one of its worthiest occupations. Of wireless telegraphy it may certainly be said that it satisfies both of these requirements. In its purely scientific aspects it is based upon, and has extended investigations which constitute, a most notable advance in our knowledge of Nature's secret machinery. To carry it beyond the experimental stage into the wider field of practical application has needed vast labour and resources, but the power it has given of intercommunication between distant ships at sea, and the salvation it has brought in many cases to those who would otherwise have perished in deep waters has been a worthy object of that labour and given it a high place amongst those applications of electrical science which have bestowed benefits on all mankind.

INDEX.

A

Aberration of light, 4
Absorption of electric waves by the earth, 186, 187
Aerial wire, 79
Æther, the, 20
—— and energy, 43
——, electricity and electrons, 1
——, the elasticity of the, 22
—— and matter, 23, 43
Alexanderson, high-frequency alternator of, 125
Alpha rays, 42
Alternator, high-frequency, 122, 133
Ampère, J. M. A., 28, 47
Antenna, 79, 80, 88, 89
Antennæ, forms of, 87, 88, 89
Arago, 24
Arc transmitter, 118
Arco, Count von, 263
Arrhenius, S., 207
Atmosphere, the, 204
Austin, Dr. L. W., 186, 189

B

Bell telephone receiver, construction of, 143
Bellini, E., 179
Bent antenna, invention of, by Marconi, 242
Beta rays, 42
Bradley, J., discovery of aberration of light by, 4
Branly, E., 152
—— coherer, 152
Braun, F., 263
British Association Committee on radiotelegraphy, 272

C

Capacity, electrical, 62
Carbon microphone, 266
Carborundum, crystals of, used as a wave detector, 147
Carlo Alberto, cruises of the, 242
Charged electric sphere, motion of a, 34
Clifden radiotelegraphic station, 243
Codes of signals, 84
Coltano, radiotelegraphic station at, 251
Communication chart for Atlantic liners, 235
Conductors and non-conductors of electricity, 52
Corpuscular theory of light, 9
Crookes, Sir William, 37
Cunard Daily Bulletin, 238
Curie, M. and Mme., 1, 42
Curvature of the earth, effect of, on wireless telegraphy, 197
Cymometer, Fleming, 161

D

Damped oscillations, 81, 82
Damped and undamped waves, relative absorption of, by the earth, 209
Davy, Sir Humphry, 46
Daylight, effect of, on radiotelegraphic transmission, 190
Decrement of electric waves, 82
Desaguiliers, Dr., 52
Detector, carborundum, 146
——, crystal, 146
——, Fleming valve, 148
——, Marconi magnetic, 149, 151

Detector, Molybdenite, 147
——, Pyrites, 147
——, valve or glow lamp, 148
Dielectric, definition of a, 51
—— coefficients of insulators, 210
Diffraction of electric waves, 198
Directive antenna, 89
Dot and dash signals, 95
Duddell, W., 111
Duddell arc, action of the, 114
—— musical arc, 114
—— oscillograph, 59, 60
Dufay, C. F. C., 26, 52
Dunwoody, General, 147

E

Earth, the effect of motion of, through the æther, 24
Eccles, W. H., 193
——, theory of ionic refraction of long electric waves due to, 213
Eiffel Tower radiotelegraphic station, 252
Electric current, chemical power of an, 46
—— —— direct and alternating, 48
—— oscillations, 46
—— phenomena, 26
—— units, 62
—— waves, 46, 77, 78, 79
—— —— emitted by High Power Marconi Stations, 246
Electron, definition of an, 36
Electrons, motion of, 48
Emanation of radium, 42

F

Faraday, M., 27, 47
Faraday's discovery of electromagnetic induction, 48
—— "Thought's on Ray Vibrations," 32
Fessenden, R. A., 132, 263
—— heterodyne receiver, 171
Fizeau, A. H. L., measurement of velocity of light by, 6
Fleming, J. A., 102, 104, 148, 152, 211, 226, 258
Fleming, discharger of, 102, 104
—— cymometer, the 161
—— oscillation valve, 148, 149
Foucault, J. B. F., measurement of velocity of light by, 6
Franklin, Benjamin, 51
Frequency, definition of 61
—— rule for calculating, 66
—— alternators for raising, 128
Frog's leg receiver, 172

G

Galletti transmitter, 134
Gamma rays, 42
Gilbert, Dr. W., 27
Goldschmidt alternator, 126, 127, 131
—— ——, long-distance transmission by, 263
Gray, Stephen, 52
Guericke, Otto von, 52

H

Hertz, R. H., 67
Hertzian oscillator, 67
—— radiation, 70
—— resonator, 69
Hertz's experiments, 70
Hughes, D. E., 218
Huyghens, C., 9

I

Imperial Wireless Telegraph Stations, contract for the, with the Marconi Company, 249
Induction coil, 92
Interference of light, 10
International conferences on radiotelegraphy, 236
Ionic refraction of long electric waves, 213
Ionisation of the atmosphere, 206
Ions, 41

K

Kaufmann, investigations on mass of an electron by, 39

Kelvin, Lord, 40, 57
Kleist, von, 50

L

Larmor, Sir Joseph, 40
Leyden jar, discharge of a, 54
—— ——, invention of the, 51
Light, refraction of, 11, 15
Light-year, definition of a, 7
Lodge, Sir Oliver, 263
—— coherer, 152
——, discourse on work of Hertz, 220
——, experiments on motion of matter through æther by, 25

M

MacCullagh, James, 41
Marconi, G., 1, 88, 89, 103, 105, 106, 108, 137, 149, 195, 220, 226, 228, 232, 234, 243, 246, 248
Marconi coherer, the, 152
——, continuous wave system of, 265
—— directive antenna, 89
——, discovery of effect of daylight on radiotelegraphy by, 191
——, early demonstrations of wireless telegraphy by, 225
——, first apparatus for wireless telegraphy of, 223
——, first High Power Station for wireless telegraphy by, 241
—— high speed disc dischargers, 105, 106, 109, 244
——, improvements in radiotelegraphy by, 271
—, invention of radiotelegraphy by, 221
—— smooth disc discharger, 109
—— spark transmitter, 90
—— studded disc discharger, 106
—— syntonic transmitter and receiver, 228, 229
——, testimonials to the success of transatlantic wireless telegraphy due to, 247
Marconi's Wireless Telegraph Company and Ship Installations, 237
Marconi's Wireless Telegraph Company Limited, 96
Marconigrams, 238
Matter, constitution of, 43
Maxwell, James Clerk, 24, 29
Maxwell's theory of electricity, 29
Michelson, A. A., measurement of velocity of light by, 7
——, experiments on effect of motion of the earth on velocity of light, 24
Microphone, carbon, 266
——, multiple, 269
Minchin, G., 219
Modulus of elasticity, Young's, 18
Molybdenite detector, 147
Morley, 24
Morse alphabet, the, 84
Muirhead, Dr. A., 237, 263
Musschenbroeck, P. Van, 50

N

Nauen, radiotelegraphic station at, 262
Newcomb, Simon, measurement of velocity of light by, 7
Newton, Sir Isaac, 8
Newton's First Law of Motion, 31
Nicholson and Carlisle, 46

O

Oersted, H. C., 27
Oersted's discovery of the magnetic properties of an electric current, 27
Onesţi, Calzecchi, 219
Organ pipe, action of an, 112
Oscillations damped, 82
—— undamped, 82
Oscillator, Hertz's, 67
Oscillatory discharge of a Leyden jar, 57
—— spark, photograph of a, 58
Oscillograph, Duddell, 59, 60
——, use of an, 60, 61

P

Parker, Lord, 98
Perrotin, measurement of velocity of light by, 7

Photographic record of radiotelegraphic signals, 250
Pickard, G. W., 195
Pierce, G. W., 147
Poldhu, first High Power Radiotelegraphic Station at, 103, 232, 241
Postmaster General, technical committee appointed by the, 248
Poulsen, V., 111, 114
—— arc generator, 118
——, long-distance transmission of signals by, 262
Poynting, J. H., 36
Propagation of radiotelegraphic waves round the earth, theories of the, 198, 199, 200, 201

Q

Quenched spark, 100
—— —— discharger, 102, 261

R

Radiotelephony, achievements of, 270
——, apparatus for, 267
Radiotelegraphic Committee of the British Association, 273
—— measurements; 159
—— stations at Coltano, 251
—— —— Clifden, 243
—— —— Glace Bay, 243
—— —— Eiffel Tower, 252
—— —— Nauen, 262
Radiogoniometer of Bellini and Tosi, 179
Radium, 42
——, transformations of, 42
Reaction of oscillations in two coupled circuits, 99
Receivers for wireless telegraphy, 139
Receiving apparatus on board ship, 175
Refraction of sound waves, 211
—— of long electric waves, 213
Relations of electricity, magnetism and motion, 28
Resonance curve, 164
Resonator, Hertz's, 69
Rive, de la, 75
Roemer, O., measurement of velocity of light by, 4
Röntgen, W. K., 37
—— rays, 36, 39
Rowland, H. A., 27

S

Salvation of ships by wireless telegraphy, 238
Sarasin, 75
Schuster, A., 208
Scientific theories, 44
Signals, Morse, 84
—— recorded by photography, 250
Signal strength, variation of, during day and night, 194, 195
Snell, Willebrord, 15
Soddy, Professor, 42
Sommerfeld, A., 200
Spark transmitter, Marconi's, 89
Speed of signalling, 250
Stokes, Sir G. G., 25
Stoke's theory of sound wave refraction, 211
Stoney, Dr. Johnstone, 36
Stray electric waves, 192
Sun, constitution of the, 207
Syntonic transmitter and receiver, Marconi's, 228

T

Telefunken discharger, 261
Telegraphy with wires, 85
—— without wires, 86
Telephony, wireless, 267
Theory of discharge of a Leyden jar, 57
Thomson, Sir J. J., 38
Time of oscillation of an electrical circuit, 64
—— period of an oscillation, definition of the, 61
—— and weather signals sent out from radiotelegraphic stations, 253
Titanic, s.s., the loss of the, 239, 240
Tosi, A., 179
Transatlantic wireless telegraphy, 233

Transmission of electric waves over sea and land, 185
Transmitters, wireless telegraph, 83, 87
Transmitting apparatus on board ship, 97
Tuned circuits, 119

U

Undamped oscillations, 82
Undulatory theory of light, 9
Unit of electricity, 36
Units, electrical, 62, 63

V

Vanni, Dr. J., 271
Vanni liquid microphone, 271
Velocity of an electromagnetic disturbance, 30
—— of light, 3, 6, 13
—— of a wave motion, 17
Vibrations, longitudinal and Tranverse, 20
—— on lines of electric force, 34
Volta, A., 26
Voltaic pile, 26
Volturno, s.s., rescue of crew and passengers of the, by wireless telegraphy, 272

W

Wave length, velocity and frequency, law connecting, 15
Waves in an elastic solid, 20
Weather reports transmitted by wireless telegraphy, 258
Wheeler, Granville, 52
Wien, M., 100, 263
Wireless cabin on ships, 97
—— message, sending a, 95
—— telegraph receivers, 139, 141
—— telegraphy across the English Channel, 226
—— ——, general principles of, 86
—— —— in practice, 218
—— telephony, general principles of, 267

Y

Young, Thomas, Dr., 9

THE END.

PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, LONDON AND BECCLES.