RESEARCHES IN RADIO-TELEGRAPHY.[1]

II.

IN a previous discourse explanations were given of the property of a closed or partly closed antenna of radiating more in some directions than others, and the action of Marconi's bent antenna was described. Two other inventors, Messrs. Bellini and Tosi, have taken advantage of this fact to construct antennæ of a very interesting character. They erect an antenna consisting of two wires, each bent into a triangular form, the top ends nearly meeting, the planes of these triangles being at right angles to one another, and both of them vertical. The nearly closed antenna circuits are then inductively coupled with a condenser circuit, which is capable of being swivelled round in various directions. If the said condenser circuit is placed in such a position as to be coupled with one of the triangular antennæ it will cause the maximum radiation to take place in the plane of that antenna, but none at all at right angles to it. If it is coupled with the other antenna it will cause radiation to take place to a maximum degree in the plane of that second antenna. If, however, the oscillatory circuit is placed in an intermediate position, so as to act inductively upon both the nearly closed triangular antennæ, then it can be shown, both mathematically and experimentally, that the radiation of the combined system is a maximum in the direction of the plane of the oscillatory circuit which is coupled with the antenna. Hence, with such a combined antenna, we have it in our power to create radiation most strongly in one direction, although not entirely suppressed in all other directions. By combining together, however, a single vertical antenna with two nearly closed circuit antennæ at right angles to one another, Messrs. Bellini and Tosi have constructed a complex antenna which has the property of producing radiation almost entirely limited to one-half the circumjacent space (Fig. 13). It therefore corresponds to a certain extent in effect to the optical apparatus of a lighthouse, with catoptric or dioptric apparatus, which projects the light from the lamp largely in one direction. It is not yet possible to make with electric radiation of long wave-length that which corresponds precisely with a beam of light wholly concentrated along a certain cone or cylinder, but it is possible, by the use of a complex antenna as described, greatly to limit the diffusion of the radiation. Since radiating and absorbing power go hand in hand, it is obvious that such a directive antenna also enables the position of a sending station to be located. Messrs. Bellini and Tosi have accordingly applied their methods in the construction of a *radiogoniometer* and receiving antenna, by means of which they can locate the direction of the sending station without moving the antenna, but merely by turning round a secondary circuit into a position in which the maximum sound is heard in a telephone connected with the receiver. By the kindness of Captain Tosi I am able to exhibit to you their ingenious apparatus (Fig. 14).

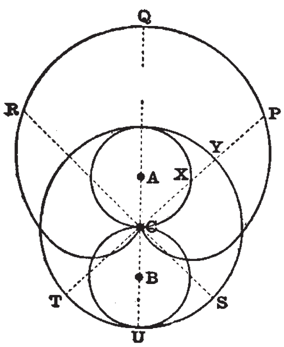

FIG. 13.

The space occupied by such closed antennæ has hitherto prevented their employment on ships. There is still, therefore, an opening for the invention of apparatus capable of being used on board ship which will enable one ship to locate, within narrow limits, the direction of another ship sending signals to it, and therefore of ascertaining immediately the direction from which some call for help is proceeding.

We must pass on to notice, in the next place, some improvements in oscillation detectors and means of testing them. As already explained, the æther waves sent out by the transmitting antenna fall on the receiving antenna and create in it, or some other circuit connected to it, very feeble oscillations. These oscillations being very feeble, alternating currents of high frequency cannot directly affect either an ordinary telegraphic instrument or a telephone, but we have to interpose a device of some kind called an oscillation detector, which is affected by oscillations in such a manner that it undergoes some change, which in turn enables it to create, increase, or diminish a local current produced by a local battery, and so affect a telephone or telegraphic relay. One kind of change the oscillations can produce in certain devices is a change in their electric resistance, which in turn is caused to increase or diminish a current through a telephone or telegraphic relay generated by a local battery. To this type belong the well-known coherers of Branly, Lodge, and Marconi, which require tapping or rotating to bring them back continually to a condition of sensitiveness.

Coherers, however, have been devised which require no tapping. Thus it has been found by Mr. L. H. Walter that if a short length of very fine tantalum wire is dipped into mercury there is a very imperfect contact between the mercury and tantalum for low electromotive forces. This may perhaps arise from the fact that tantalum, like iron, is not wetted by mercury. If, however, feeble electric oscillations act between the mercury and tantalum, the contact is improved whilst they last. If, then, the terminals of a circuit containing a telephone in series with a shunted voltaic cell are connected to the mercury and tantalum respectively, and if damped or intermittent trains of electric waves fall on an antenna and excite oscillations which are allowed to act on the mercury-tantalum junction, then at each train the resistance of the contact falls, the local cell sends current through the telephone and produces a short sound, and if the trains come frequently enough this sound is repeated and will be heard as a continuous noise in the telephone (Fig. 15). This sound can be cut up into dot and dash signals by a key in the sending instrument. If the transmitter is sending persistent oscillations, then some form of interrupter has to

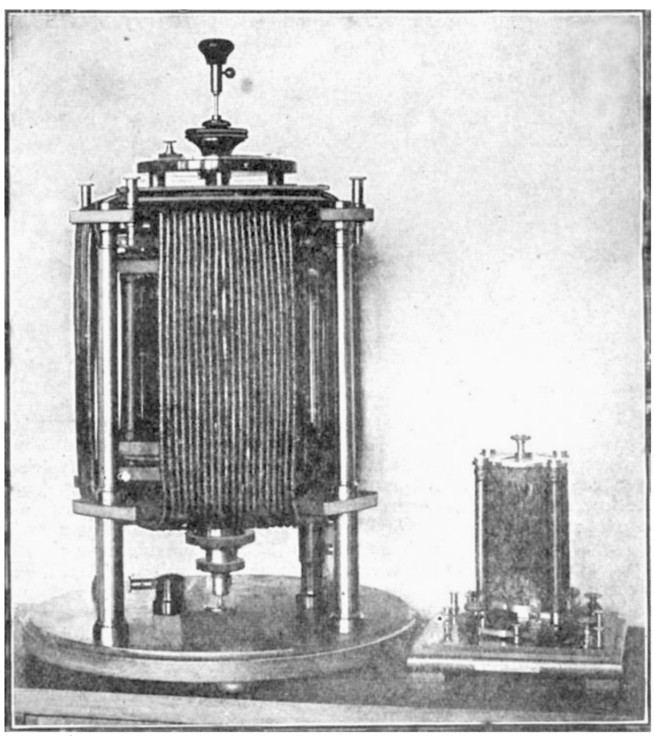
FIG. 14.—Bellini and Tosi's Radiogoniometers for Directive Radiotelegraphy.

[1] From a discourse delivered at the Royal Institution, on Friday, June 4 By Prof. J. A. Fleming, F.R.S. Continued from p. 144.

be inserted in the receiving circuit to enable us to receive a continuous sound in the telephone, which can be resolved into Morse dot and dash signals by the key in the transmitter. The operator usually wears on his head a double telephone, and listens to these long and short sounds in the telephone, and writes down each letter or word as he hears it.

The reception of signals in modern radio-telegraphy is most usually effected by ear by means of some type of oscillation detector capable of actuating a telephone. It is important, then, to notice that, to obtain the highest sensitiveness when using the telephonic method of reception, the spark frequency or number of oscillation trains or the number of interruptions of the persistent train per second must take place at such a rate that it agrees with the natural time period of the diaphragm of the telephone used. An ordinary telephone receiver is most sensitive, according to the researches of Lord Rayleigh and M. Wien, for some frequency lying between 500 and 1000. Thus Lord Rayleigh (see *Phil. Mag.*, vol. xxxviii., 1894, p. 285) measured the alternating current in microamperes required to produce the least audible sound in a telephone receiver of 70 ohms resistance at various frequencies, and found values as follows:—

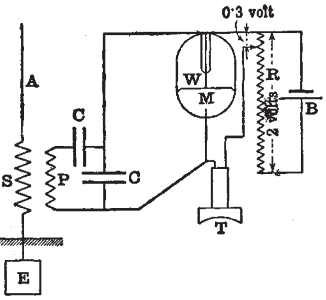

FIG. 15.—Walter's Tantalum Detector.

TABLE II.

Frequency...	128	192	256	307	320	384	512	640	768
Least audible current in microamperes ...	28	2·5	0·83	0·49	0·32	0·15	0·07	0·04	0·1

M. Wien found for a Siemens telephone somewhat different results, viz.:—

Frequency...	64	128	256	512	720	1927	1500
Least audible current in microamperes ...	12	1·5	0·13	0·027	0·008	0·013	0·024

Both, however, agree in showing a maximum sensitiveness for currents of a frequency between 600 and 700. This is due to the fact that the frequency of the actuating current then agrees with the natural frequency of the ordinary telephone diaphragm. Hence alternators for large-power radio-telegraphic stations are now designed to give currents with a frequency of about 300 or 600 alternations per second, so that, when producing discharges of a condenser, the number of sparks per second may be at least 600, and fulfil the conditions for giving maximum sound in the telephone of the receiver per microampere.

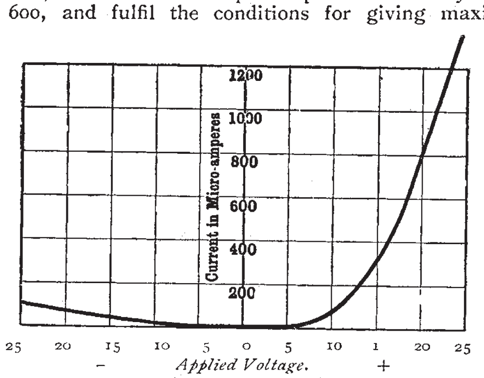

FIG. 16.—Characteristic Curves of Carborundum Crystal.

Another class of oscillation detector recently discovered comprises the crystal detectors, which depend on the possession by certain crystals of the curious property of acting as an electrical valve, or having greater conductivity in one direction than the other, and also on not obeying Ohm's law as conductors. It was discovered by General Dunwoody, of the United States Army, in 1906, that a mass of carborundum, which is a crystalline carbide of silicon formed in electric furnaces, can act as a detector of electric oscillations if inserted in the circuit of an antenna, the crystal mass being held strongly pressed between two spring clips, which are also connected by a shunted voltaic cell in series with a telephone. When feeble oscillations are set up in the antenna, a sound is heard in the telephone.

This property of carborundum has been carefully investigated by Prof. G. W. Pierce, of Harvard, and he showed that a single crystal of carborundum has remarkable unilateral conductivity for certain voltages when held with a certain contact pressure between metallic clips. Thus for a crystal held with a pressure of 1 kilogram, and subjected to an electromotive force of 30 volts, the conductivity in one direction through the crystal was 4000 greater than in the opposite direction (Fig. 16). The result of these experiments was also to show that the current voltage curve or characteristic curve of a carborundum crystal is not linear—that is to say, the crystal, as a conductor, does not comply with Ohm's law, for the resistance of the crystal decreases as the current is increased. Hence the conductivity of the crystal is a function of the voltage acting on it (Fig. 17). Accordingly, if we pass a current from a local cell through a crystal under a voltage, say, of 2 volts, a telephone being inserted in series with the cell, and if we apply an oscillatory voltage also to the crystal, which varies, say, between +0·5 and −0·5 volt, then the crystal is alternately subjected to a voltage of 2·5 and 1·5 volts, but the corresponding currents would be, say, 8·4 and 1·8 microamperes, as shown by an experiment with one particular crystal employed by Prof. Pierce. The mean current would then be 5·1 microamperes, whereas

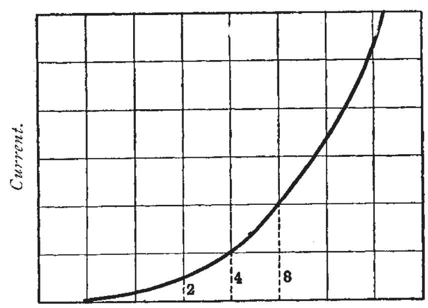

FIG. 17.

the steady voltage of 2 volts would only pass a current of 4 microamperes. Hence, apart from the unilateral conductivity, and merely in virtue of the fact that the characteristic curve is not a straight line, we find that such a crystal, or even a confused mass of crystals, can act as a radio-telegraphic detector.

There are, therefore, two ways in which a crystalline mass of carborundum can be used as a radio-telegraphic detector. It consists of a conglomeration of crystals arranged in a disorderly manner, or not so symmetrically as to neutralise one another's unilateral conductivity. Hence the mass of crystals, like the single crystal, possesses unilateral conductivity, and also a conductivity which is a function of the voltage applied to it. We may then use it without a local cell, and avail ourselves of its valve property to rectify the trains of oscillations in the antenna and convert them into short unidirectional trains which can affect a galvanometer or telephone; or, secondly, we may place the crystal between the ends of a circuit containing a telephone and a shunted voltaic cell, and then on passing oscillations through the crystal we hear sounds in the telephone, due to the fact that the conductivity is a function of the voltage, and is therefore increased more by the addition than it is diminished by the subtraction of the electromotive force of the oscillations to or from the steady voltage of the local cell. The telephone, therefore, detects this change in the average value of the current by a sound emitted by it. Prof. Pierce has discovered that several other crystals possess similar properties to carborundum—for example, hessite, which is a native crystalline telluride of silver or gold; an anatase, which is an oxide of titanium; and molybdenite, which is a suiphide of molybdenum. As regards the origin of this curious unilateral conductivity, it seems clear that it is not thermoelectric, but at present no entirely satisfactory theory of the action has been suggested.

A number of forms of oscillation detector have recently been invented which depend on the curious fact that a slight contact between certain classes of conductors possesses a unilateral conductivity, and can therefore rectify oscillations One such detector, now much used in Germany, consists of a plumbago or graphite point pressed lightly against a surface of galena. It has been found by Otto von Bronk that a galena-tellurium contact is even more effective. To the same class belongs the silicon-steel detector of Pickard. If such a contact is inserted across the terminals of a condenser placed in the receiving circuit, and if it is also in series with a telephone, the trains of oscillations are rectified or converted into more or less prolonged gushes of electricity in one direction through the telephone. These, coming at a frequency of several hundred per second, corresponding to the spark frequency, create a sound in the telephone, which can be cut up by the sending key into Morse signals. According to the researches of Prof. Pierce and Mr. Austin, it seems clear in many cases that this rectifying action is not thermoelectric, since the rectified current is in the opposite direction to the current obtained by heating the junction.

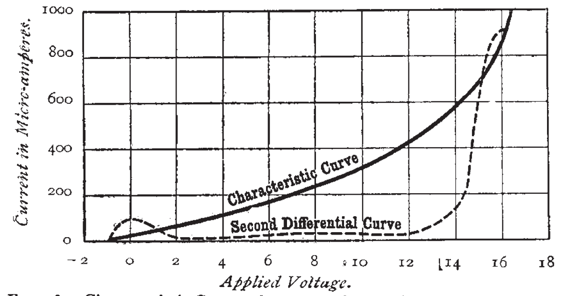

FIG. 18.—Characteristic Curve of Rarefied Gas Ionised by Hot Negative Electrode.

I may, then, bring to your notice some recent work on another form of radio-telegraphic detector, which I first described to the Royal Society about five years ago under the name of oscillation valve. It consists of an electric glow-lamp, in the bulb of which is placed a cylinder of metal, which surrounds the filament but does not touch it. This cylinder is connected to a wire sealed through the glass. Instead of a cylinder, one or more metal plates are sometimes used. The filament may be carbon or a metallic filament, and I found some year or more ago that tungsten in various forms has special advantages. The bulb is exhausted to a high vacuum, but, of course, this means it includes highly rarefied gas of some kind. When the filament is rendered incandescent it emits electrons, and these electrons or negative ions give to the residual gas a unilateral conductivity, as shown by me in a Friday evening lecture given here nineteen years ago. Moreover, the ionised gas not only possesses unilateral conductivity, but its conductivity, like that of the crystals just mentioned, is a function of the voltage applied to it. Hence, if we apply an electromotive force between the hot filament and the cool metal plate, we find that negative electricity can pass from the filament to the plate through the ionised gas, and that the relation between the current and voltage is not linear, but is represented by a characteristic curve bending upwards, which has changes of curvature in it (Fig. 18). The sharp bend upwards at one place implies a large increase in the current corresponding to a certain voltage, which means that, corresponding to a certain potential gradient, and therefore velocity of the electrons, considerable ionisation of the residual gas is beginning to take place. The current, however, would not increase indefinitely with the voltage, but would before long become constant or saturated.

It will be seen, therefore, that at points on the curve where there is a bend or change of curvature, the second differential coefficient of the curve may have a large value. Hence, if we consider the current and voltage corresponding to this point, it will be seen that any small increase in the voltage increases the current more than an equal small decrease in voltage diminishes it. If, then, we superimpose on a steady voltage corresponding to a point of inflexion of the curve an alternating voltage, the average value of the current will be increased. This, then, points out two ways in which this oscillation valve or glow-lamp can be used as a radio-telegraphic detector. First, we may make use of the unilateral conductivity of the ionised gas in the bulb and employ the glow-lamp with cylinder around the incandescent filament, as a rectifier of trains of oscillations to make them effect a galvanometer or telephone. This method was described by me in papers and specifications in 1904 and 1905. In that case the valve is arranged in connection with a receiving antenna, as shown in Fig. 19, and used with a galvanometer or telephone. Mr. Marconi subsequently added an induction coil and condenser, and employed in 1907 the arrangements shown in Fig. 20. In this case the trains of oscillations set up in the antenna could not by themselves affect a galvanometer or a telephone, but, when rectified by the valve, they become equivalent to an intermittent unidirectional current, and can then affect the telephone or a galvanometer, or any instrument for detecting a direct current.

On the other hand, we may take advantage, as I have more recently shown, of the non-linear form of the characteristic curve. In other words, of the fact that the conductivity of the ionised gas is a function of the voltage applied to it, and in the second method the valve and receiving circuits are arranged as shown in Fig. 21. In this case we have to apply to the ionised gas a unidirectional electromotive force which corresponds to a point of inflexion on the characteristic curve, and then to add to this voltage the alternating voltage of the oscillations set up by the incident electric waves in the receiving circuit. The result is to cause a change in the average value of the current through the telephone, and therefore to produce a sound in it, long or short, according to the number of trains of waves falling on the antenna. This last method, then, requires the application in the telephone circuit of an accurately adjusted steady electromotive force, not any electromotive force, but just that value which corresponds to a point on the characteristic curve at which there is a sudden change of curvature.

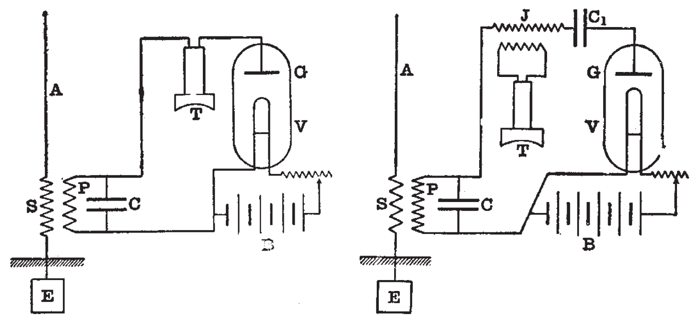

FIG. 19. FIG. 20.

Connections for Oscillation Valve used as Radiotelegraphic Detector.

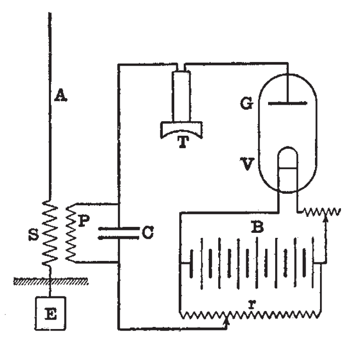

FIG. 21.—Connections for Oscillation Valve used as a Radiotelegraphic Detector.

At this point we may notice a broad generalisation which has already been made by H. Brandes, viz. that any materials such as the crystals mentioned, or ionised gases, which do not obey Ohm's law as regards the independence of conductivity on impressed voltage can be used as radio-telegraphic receivers. It is necessary to be able to test the relative sensibility of detectors to know whether any new form is an improvement. It is not always possible for an inventor to get these tests made at real wireless telegraph stations. Moreover, it is no use to test over short distances, because then all detectors appear to be equally good. I have found, however, that we can make these comparative tests very easily within quite moderate distances by employing closed sending and receiving circuits which are poor radiators. All the devices called wave detectors are really only oscillation detectors, and we can therefore test their value simply by ascertaining how feeble an alternating current or alternating voltage they will detect. If we, then, set up in one place a square circuit of wire a few feet inside, and complete the circuit by a condenser and a spark-gap, we can set up oscillations in it by means of an induction coil. I find that it is necessary to enclose the spark-gap in a cast-iron box, and to blow upon the spark with a jet of air to secure silence, absence of emission of electromagnetic waves direct from the spark balls, and constancy in the oscillatory circuit. I then set up, a few score or few hundred feet away, a similar tuned closed oscillatory circuit, and I connect the oscillation detector to be tested either in this circuit or as a shunt across the condenser. The closed receiving circuit is so constructed that it may be rotated round either of three axes. It is then generally possible to find some position of the receiving circuit such that no sounds are heard in a telephone connected to a highly sensitive detector associated with the circuit. This position is called the zero position. If the receiving circuit is rotated round some axis, it begins at a certain displacement to receive signals, and the angle through which it has to be turned is a measure of the insensibility of the particular oscillation detector being used. I find, for instance, that it is quite easy to take one of my oscillation valves, a magnetic detector, an electrolytic detector, a crystal detector, or any other type, and arrange these in order of their sensibility by means of the device described.

Sensibility is not, however, the only virtue which a wave detector should possess. It is important that it should be simple, easily adjusted, and not injured by the chance passage through it of any unusually large oscillatory currents. Another quality which is desirable is that it should be quantitative in its action, and that any change in the amplitude of the wave received should be accompanied by an equal change in the current which the detector allows to pass through the telephone. A quantitative oscillation detector, then, enables not merely signals, but audible speech to be transmitted. In other words, it can effect wireless telephony. The difficulties, however, in connection with the achievement of wireless telephony are not so much in the receiver as in the transmitter. We have to obtain, first, the uniform production of persistent electromagnetic waves radiated from an antenna, and next we have to vary the amplitude of these electric waves proportionately to, and by means of, the aërial vibrations created by the voice speaking to some form of microphone. We cannot employ an intermittent spark generator, because each spark would give rise to a sound in the telephone, and these sounds, if occurring at regular intervals, would produce a musical note in the telephone. If, however, we make the sparks run together into what is practically a high-voltage arc taking a small current, then, in an oscillatory circuit shunted across this arc, we have set up persistent high-frequency oscillations, as first achieved by Mr. Duddell.

We can greatly increase the energy of the oscillations by immersing the arc in a strong transverse magnetic field and also in a hydrocarbon gas, as shown by Poulsen, or we may employ a number of arcs in series. E. Ruhmer has lately also employed a high-tension arc between aluminium electrodes (Fig. 22), shunted by a condenser and inductance as a means of generating persistent oscillations. As an alternative, it is possible to create them by a mechanical method, viz. by a high-frequency alternator, subject, however, to certain limitations as to frequency. Both these types of generator have their advantages and practical objections. There is good evidence that radio-telephony has been accomplished over distances of 100 miles or more by each of these methods in the hands of experts, but what is now required is the reduction of the apparatus to such simple manageable and practical form that it can be applied in regular work. The wave-generating apparatus must be capable of producing uniform persistent oscillations of high voltage and frequency, not less than 30,000 or 40,000 per second, or at least above the limits of audition, and the amplitude of these oscillations must be capable of being varied by some form of speaking microphone placed in the oscillation circuit or in the radiating antenna, or in a secondary circuit coupled to it. No ordinary simple carbon microphone will safely pass sufficient current for this purpose. A type of multiple microphone has been used successfully, and also a duplex microphone, the invention of Ernst Ruhmer.

It is not, however, possible to speak of radio-telephony at the present time as having reached the same level of practical perfection as radio-telegraphy; but the possibilities of it are of such a nature that it will continue to attract the serious attention of inventors. This is not the place to enter into a full discussion of the causes which limit submarine telephony through cables, but there are well-known reasons in the nature of submarine cables as at present made which impose very definite limits upon it, owing to what is called distortion of the wave form. Electric wave telephony is free at least from this disadvantage, and if (as has been asserted) arc generators can be made self-regulating and capable of being worked for hours automatically, or even for ten minutes without being touched, then the remaining difficulties with the microphone are not insuperable.

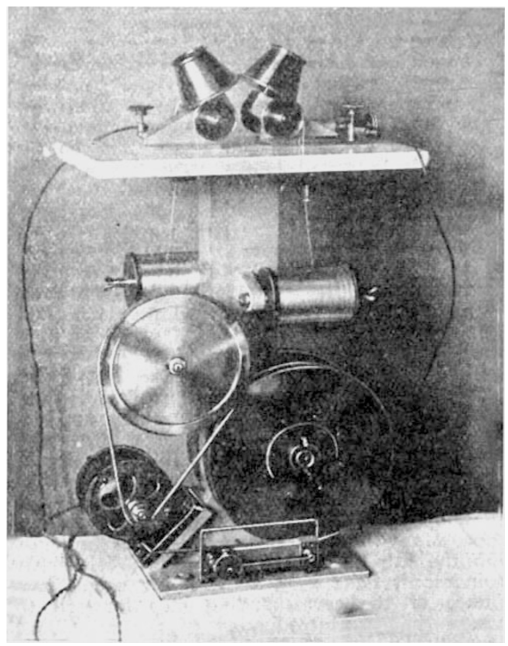

FIG. 22.—Ernst Ruhmer's High-tension Aluminium Arc for producing persistent Oscillations for Radiotelephony.

Time does not permit of the discussion of the many other points in connection with radio-telegraphy and telephony which have been the subject of recent work. Much attention has been paid lately to methods of cutting out atmospheric signals due to natural electrical discharges in the atmosphere, which are troublesome disturbers of the ætherial calm necessary for radio-telegraphy. Considerable thought and expenditure have been necessary to discover means for overcoming the difficulties of long-distance transmission by daylight, and also those arising from the cross-talk of other stations. Much also has been done in training skilled wireless operators both in the Navy and for the mercantile marine work. Radio-telegraphy, like aviation, is an art as well as a science, hence personal skill is a factor of importance in turning the flank of the difficulties of the moment. Nevertheless, the art and the science of radio-telegraphy are both progressing, and the splendid services already rendered by it in saving life at sea are at once a proof of present perfection and an evidence that the arduous labours of investigators and inventors have borne fruit in yet larger powers to command the great forces of nature for the use and benefit of mankind.

ILLUMINATING ENGINEERING.[1]

THIS society has been founded to bring together all those who are interested in the problems, practical and theoretical, of the *art of directing and adapting light, that prime necessity of* civilised, as well as of uncivilised, *existence, to the use and convenience of man.* To advance the subject of illuminating engineering, to investigate through all its lengthened breadth the facts within its domain, to increase and diffuse knowledge respecting them, and to unite those who are devoting their energies to these things, is the object of the society. The ascertained facts are few—all too few; their significance is immense; their economic and social value is great; but the ignorance respecting them generally is colossal.

For practically a century only have there been any systematic means of illumination in use in any civilised country. Before the year 1800 there were as means of illumination daylight, oil lamps, rush lights, tallow dips, and wax candles. Monarch and peasant, merchant-prince and workman, had alike to depend on individual sources of light at night. Only in the larger towns and cities was there any organised attempt to light the streets by oil lamps. In 1819 the authorities of the day stoutly resisted the proposal to light the then House of Commons by gas—nothing but wax candles could be admitted; but gas lighting was coming in, and Argand and colza oil lamps were the sole competitors until after 1850. Everything else dates since then—practically during the last half-century. For paraffin lamps were not widely spread until the 'sixties. Arc lighting, though tried for spectacular and lighthouse purposes from the 'fifties, did not come into public question until about 1879. Glow-lamps followed three or four years later. Still later came incandescent gas mantles and acetylene gas lights, while the newest things in both gas lighting and electric lighting are affairs of only a year or two ago. Many persons now realise the immense stride made in the introduction of the Auer (Welsbach) mantle for incandescent gas; very many fewer people realise the significance of the corresponding step forward that has been begun by the introduction of the metallic filament glow-lamp. We are on both sides in the very middle of an immense evolution in the art of illumination.

But whilst the means of illumination have thus been developing with amazing strides during a single generation, and the organised systems of distribution by municipal and urban and rural authorities, and by private corporations, have ramified throughout the community and brought supplies of gas and of electricity—shall I also say of oil?—to our doors, there has been another and very different development going on. I refer to the growth of that branch of the science of optics which deals with the measurement of luminous values. Photometry has been growing into an exact science by the explanation of its laws and the improvement of the instruments of measurement. It was not until 1760 that the first real discussion of photometric principles was made known. In that year Lambert, in his "Photometria," laid down the fundamental laws, and likewise in the same year Bonguer gave to the world his "Traité d'Optique," wherein a primitive photometer was described. Rumford's shadow photometer was invented in 1794, and Ritchie's in 1824. Then comes a long gap. Save for Bunsen's over-rated grease-spot instrument, there was no important advance in photometry until the 'eighties, when there were produced many novel forms, some of them, including the now well-known forms of L. Weber, Lummer-Brodhun, and Rood, capable of yielding results of much higher precision in the comparison of different sources of light; also in the 'eighties we meet for the first time with special forms of photometer of the kind destined to play a very important part in the work of our society, many photometers measuring the values, not of the brilliancy of a source of light, but the illumination of a surface.

Our primary concern is the adequate and proper illumination of things; and as we have to reduce the present chaos to an exact science, our first business is to secure some common agreement as to the measurement of illumination and the establishment of reasonable rules as to the amounts of illumination required in different cases.

Foremost, then, in the programme of work for our society we put the question of the units of measurements and the promulgation of the proper definitions of them. We must secure agreement—national and, if possible, international—as to what shall be taken as the unit of light and what as the unit of illumination at a surface.

Happily, the long-standing controversy as to the former appears to be settling itself by at least a preliminary agreement between the standardising laboratories of the great nations. One "candle" is no longer to be a vague and indefinite thing. The new definition provisionally agreed upon is an ideal unit, in terms of which one can describe the several standards in use in different countries. If this provisional *entente* can but be ratified by a little international common sense, we shall have henceforward an international "candle" such that it is the same in England as in America, equal to the *bougie décimale* accepted in France, and related to the Hefner-candle of Germany in the precise proportion of ten to nine.

But we have still to find agreement on the standard of illumination. Here in England, and in the United States, we have already grown accustomed to describe amounts of illumination of surfaces in terms of a British unit—the "candle-foot"—not perhaps a very happy term—one that we would readily exchange for a better—meaning, thereby, the intensity of the illumination at a surface situated at the distance of one foot from a light of one "candle." The source being assumed here to be concentrated at a point, the law of inverse squares holds good.

Adopting the candle-foot as the unit of illumination, one may readily state certain facts with definiteness. All competent authorities are agreed that at night, for the purpose of reading, an illumination is required not less than one candle-foot, some authorities saying 1½ candle-foot. The facts appear to be that reading is impossible with an illumination of one-tenth candle-foot, difficult and fatiguing with one of one-fifth candle-foot, comfortable with from 1½ to 3 or 4 candle-foot, but that if the illumination exceeds 6 or 8 candle-foot, the glare of the page is again fatiguing and dazzling. The page should neither be under-illuminated nor over-illuminated. Something depends, it is true, on the size of the print. Under a feeble illumination of, say, ½ candle-foot, a type of pica size printed in a fount of bold face properly inked is legible when one of long-primer size, printed in a weak way, would be practically illegible. Something also depends on the state of the eye as affected by the general illumination of the surroundings. Very seldom does one find in any ordinary room an artificial illumination exceeding 3 candle-foot. By day, on a writing-table placed near a north window—or near any window not receiving direct sunlight—the illumination may exceed 3, and may even attain 4 or 5 candle-foot.

Until a unit of illumination was thus agreed upon, it was impossible to render any reasonable certainty to estimates of the amount of illumination in any case of dispute. What is the meaning of the term well-lit as applied to any room, building, factory, workshop, or school? Formerly the term was entirely vague. To-day the answer can be given in numerical terms. Formerly judgment had to be made by the unaided eye, and the eye is notoriously a bad judge. As between two different illuminations, the powers of discrimination of the eye are very limited. The eye can equate, but it cannot appraise. It can tell with fair accuracy whether two adjacent patches

[1] Abridged from the inaugural address delivered at the inaugural meeting of the Illuminating Engineering Society held on November 18, by Prof. Silvanus P. Thompson, F.R.S., president of the society.