The Construction and Use of Oscillation Valves for Rectifying High-Frequency Electric Currents

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and for light of wave-length $\lambda_0+\delta\lambda_0$

$$h(\theta+\delta\theta+\delta\phi)=\left\{\frac{\Delta}{\pi}-(2p-1)\right\}\frac{\lambda_0+\delta\lambda}{2}+\frac{\lambda_0}{2\pi}\frac{d\Delta}{d\lambda_0}\delta\lambda$$

whence
$$=\left\{\frac{\Delta}{\pi}-(2p-1)\right\}\frac{\lambda_0}{2}+\frac{\lambda_0}{2\pi}\frac{d\Delta}{d\lambda_0}\delta\lambda,$$

$$h(\delta\theta+\delta\phi)=\frac{\lambda_0}{2\pi}\frac{d\Delta}{d\lambda_0}\delta\lambda.$$

Hence for coincidence of the bands due to the monochromatic constituents λ_0 and $\lambda_0+\delta\lambda$, we must have

$$\frac{d\Delta}{d\lambda_0}=\frac{2\pi h}{\lambda_0}\frac{d\phi}{d\lambda_0},$$

which gives the best thickness of the plate.

Also $\frac{d\Delta}{d\lambda}$ and $\frac{d\phi}{d\lambda}$ must have the same sign: whence $\frac{d\Delta}{d\lambda}$ being negative, the angle of incidence must increase on the positive side of the normal with decreasing wave-length.

X. *The Construction and Use of Oscillation Valves for Rectifying High-Frequency Electric Currents.* *By* J. A. FLEMING, *M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London**.

ATTENTION was directed by the author in 1890 to the fact that if two carbon filaments are sealed into a single vacuous glass bulb so as to make an incandescent lamp with two separate carbon loops, the resistance between these filaments, though infinite when the carbon is cold, becomes quite small as soon as the loops are made incandescent †. Moreover, if a metal plate is sealed into an incandescent lamp it was shown that the space between the metal plate and the incandescent carbon filament possesses a unilateral

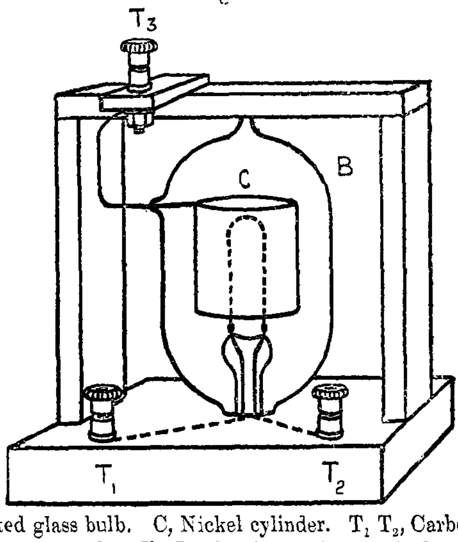
* Read March 23, 1906.

† See J. A. Fleming, "On Electric Discharge between Electrodes at Different Temperatures in Air and High Vacua," Proc. Roy. Soc. Lond. vol. xlvii. p. 122 (1890); also "Problems on the Physics of an Electric Lamp," Proc. Royal Institution, vol. xiii. part 34, p. 45 (1890).

conductivity, negative electricity being able to pass freely from the hot carbon to the plate, but not in the opposite direction *. More recently the author discovered that such an arrangement may be used as a valve to permit the passage of one constituent current only of a high-frequency current or to rectify an electric oscillation †. The reason for this action is now recognized to be the copious emission of negative ions or electrons from the incandescent carbon. This operation has been studied quantitatively by the present writer and many other observers.

For the purpose of rectifying electrical oscillations and thus be able to detect them by an ordinary galvanometer,

Fig. 1.



B, Exhausted glass bulb. C, Nickel cylinder. T_1 T_2, Carbon filament terminals. T_3, Insulated cylinder terminal.

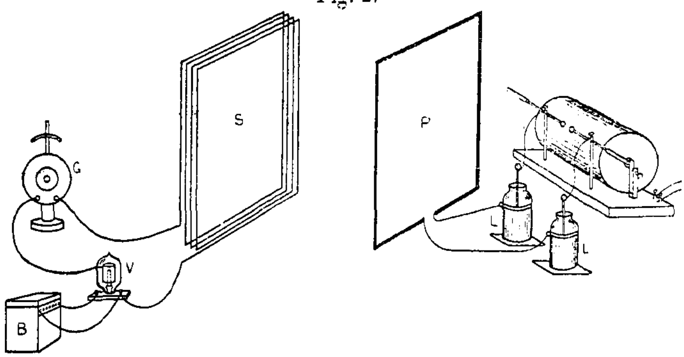
these *oscillation valves* are now made as follows :—A carbon-filament glow-lamp is constructed, the carbon loop of which is upheld in the centre of a highly exhausted glass bulb (see fig. 1). Around the loop is fixed a small cylinder

* See J. A. Fleming, "On a Further Examination of the Edison Effect in Glow-Lamps," Phil. Mag. July 1896.

† See also Proc. Roy. Soc. Lond. vol. lxxiv. p. 476, 1905, "On the Conversion of Electrical Oscillations into Continuous Currents by means of a Vacuum Valve."

of nickel, C, which is connected to a platinum wire sealed through the side of the bulb. The valve is used as follows:—The carbon loop is made incandescent by a suitable battery of secondary cells, a sliding rheostat being added to adjust the voltage on the terminals of the lamp. The circuit in which oscillations are to be detected is joined in series with a dead-beat mirror-galvanometer, and the valve connected with the circuit by wires joined respectively to the terminal of the nickel cylinder and the negative terminal of the carbon loop. The oscillation valve is most conveniently mounted for this purpose on a special form of stand (see fig. 1). In using the valve the carbon filament must be brought to bright incandescence, about equal to that which in a carbon glow-lamp would correspond to a so-called "efficiency" of 3 watts per candle. So used, the valve enables us to employ a sensitive

Fig. 2.



P, Primary oscillation circuit. S, Secondary oscillation circuit. G, Galvanometer. V, Valve. B, 12-volt battery for incandescing filament of valve.

mirror-galvanometer of the ordinary type to detect the presence of electric oscillations in a circuit and to institute comparative measurements.

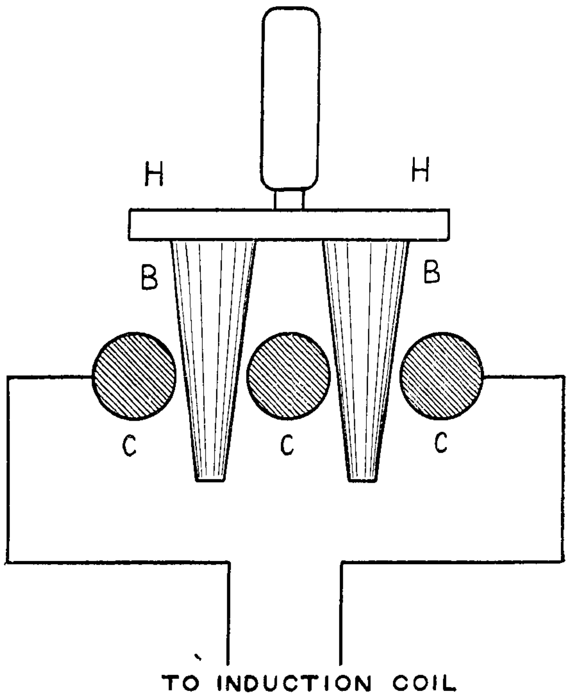
Thus, for instance, we form an oscillatory circuit (see fig. 2) by connecting a Leyden jar in series with a square coil of wire of a few turns P, and join the condenser and inductance across a spark-ball discharger connected to the secondary terminals of an induction-coil. At a certain distance we place another square coil of wire S in series with a galvanometer G and oscillation valve V. We then find that when oscillations are set up in the primary circuit, we obtain a steady deflexion of the galvanometer indicating that its coils are being traversed by a series of discharges in the same direction, all those in the opposite direction being practically stopped.

The author has already described the methods by which the amount of rectification produced by the valve can be ascertained (see Proc. Roy. Soc. vol. lxxiv. p. 484, 1905). Perfect rectification does not exist, but, as shown, the number expressing the percentage which the actual unilateral electric flow is of that which would flow if the unilateral conductivity were perfect, can be ascertained by sending the current which passes through the vacuous space of the valve through a calibrated galvanometer and electrodynamometer placed in series with each other. In valves as described this rectification may amount to 90 per cent.

We may use the above arrangements to investigate the effect of different kinds of discharge-balls and different lengths of spark. If we employ a fairly long spark in the primary condenser-circuit we may find that we obtain a very small effect on the galvanometer in the secondary circuit, but if we shorten the spark-gap until the spark at the balls is hardly visible, the galvanometer deflexion is generally increased. The reason for this is partly because the oscillations are damped out much more by the long spark than by the short one, and partly because with a short spark the condenser discharges occur more frequently. Hence, although in the latter case the condenser is charged to a less voltage owing to the lower discharge potential, the decreased damping and greater charge frequency causes the galvanometer to be traversed by a larger quantity of electricity per second, and therefore to give a greater deflexion.

In the same manner, we can exhibit the difference in the damping due to variations in the material of the spark-balls. Thus, using iron, brass, and zinc spark-balls of the same diameter and a spark-length of 0·1 mm., the galvanometer deflexions in one case were respectively 40, 57, and 70 scale-divisions, thus showing the smaller damping of zinc spark-balls. The writer has found by this means that carbon in the state used for arc-lamp carbons presents many advantages as a discharge surface. All who have experimented much with Hertzian oscillators know how the state of the polish of the surface of the metal balls (generally brass) affects the electric wave-producing power. It can be shown by the use of an oscillation valve that for quantitative work a discharger made of carbon rods, as follows, presents many advantages:—A row of arc-lamp carbons C, C, C (see fig. 3) are fixed like posts in a piece of ebonite and another row of slightly conical

Fig. 3.



carbon rods B, B are inserted transversely between them, the distances between the rods being fixed so that very small air-gaps are left between carbon and carbon. We thus construct a multiple spark-gap of carbon surfaces which has small damping and great constancy. By enclosing the rods in a non-oxidizing atmosphere we can prevent the rods burning away. Another advantage of the arrangement is the ease with which new surfaces can be brought into use.

We can also investigate by the same means whether the use of spark-balls immersed in oil presents any advantages. Also the same arrangements may be used to exhibit the screening action of conductors for high frequency magnetic fields. For if we interpose between the primary and secondary circuits a sheet of tinfoil or zinc, we see a notable decrease in the galvanometer deflexion, thus making the screening action of the metal very evident. Employed in this manner, it enables us to show strikingly the rapid rate at which the field due to a current in a square or circular circuit decreases with distance from the circuit, and therefore to illustrate one of the disadvantages under which wireless telegraphy by electromagnetic induction labours when compared with space telegraphy by electric waves. When using the valve to detect the oscillations in an antenna produced by the impact of Hertzian waves, an oscillation transformer is inserted in the circuit of the receiving antenna, and its secondary circuit is connected through a valve with a dead-beat mirror-galvanometer. We are thus able to receive signals over short distances by the direct effect of the rectified oscillations themselves on the galvanometer.

The action of other substances besides incandescent carbon as a cathode in a vacuum-value has also been studied. It has been found by G. Owen* and by A. Wehnelt† that glowing metallic oxides, including the rare oxides employed in the manufacture of the Nernst lamp-glowers, copiously emit negative ions when incandescent both at atmospheric and at reduced pressures. Wehnelt found that the incandescent oxides of calcium, barium, and strontium produce an abnormally powerful electronic discharge, and, following the recommendations of the author, he has proposed to employ vacuum-tubes with one electrode covered with such oxides and heated, as rectifying valves for alternating currents.

As far back as 1890 the writer showed in a lecture experiment at the Royal Institution that the so-called Edison effect, that is the passage of negative electricity across space

* See G. Owen, Phil. Mag. vol. viii. p. 230 (1904). "On the Discharge of Electricity from a Nernst Filament."

† See A. Wehnelt, Phil. Mag. vol. x. p. 80 (1905). "On the Discharge of Negative Ions by Glowing Metallic Oxides and Allied Phenomena."

from an incandescent carbon filament to a metallic plate near it, could take place at atmospheric pressure if the plate was very near the filament. It is easy to show a similar experiment with a Nernst electric glow-lamp. If a Nernst lamp is supported with the bare glower horizontal and placed within a few millimetres of a vertical insulated metal tube kept cold by being filled with water, it is found that negative electricity will pass freely across the glower to the cold metal, but not in the opposite direction. Hence if the glower and metal tube are inserted as a gap in an electric circuit containing a sensitive galvanometer, and if secondary oscillations are created by induction in this circuit, we find that the galvanometer gives a steady deflexion showing the passage of a continuous current through it, and therefore of the unilateral conductivity of the space between the glower and the metal tube.

The distance over which this transference of electricity can take place depends very much upon the temperature of the glower, and the amount of rectification of the alternating current obtained upon success in keeping down the temperature of the metallic electrode. This is best achieved by circulating water through it.

It follows as a consequence from the above facts, that there is a considerable emission of negative ions or electrons from the incandescent portion of the lime cylinder used with the oxy-coal gas-burner to produce the lime-light, and that the space near the incandescent portion of the lime cylinder as well as the space near the Nernst lamp-glower is highly conductive by reason of the presence there of negative ions emitted from the oxide surface.

In the practical construction of oscillation valves, the advantage of placing the heated and non-heated electrodes in a vacuum is that the plate which acts as an anode can be placed at a greater distance from the incandescent surface and thereby kept cool, since the electrons ejected from the heated surface are projected to a much greater distance when the atmospheric pressure is reduced. Although platinum coated with calcium or barium oxides undoubtedly emits a much larger electronic current per square millimetre than carbon at the same temperature and under the same surrounding conditions as to gas pressure, I find that for rectifying electric oscillations the carbon-filament oscillation-valve as I have designed it, affords more conveniently all that is required. There are some advantages in employing a thick carbon filament and constructing it to be worked at about 12 volts and take a fairly large current of 2 or 3 amperes. For one thing, the filament is much less likely to be destroyed by over-heating in working, and hence the valve lasts longer. In some cases an advantage may ensue from working valves in parallel, that is joining up a number of such carbon-filament valves with their carbon filaments in parallel on the same heating battery, connecting together the insulated metal cylinders contained in each bulb together, and then using the multiple arrangement as if it were a single valve.

When used, however, to rectify such oscillations as are employed in the receiving circuits of wireless telegraph apparatus, a single valve will do all that is required because the quantity of electricity which has to be carried is small and the electronic emission from even a 4-volt 1-ampere carbon filament is amply sufficient to carry the negative component of the feeble oscillations used across the vacuous space.

It should be noted that such oscillation-valves as are here described have quite a different range of use from other rectifying arrangements such as the Cooper-Hewitt mercury-vapour tube, and the electrolytic aluminium-carbon valve of Nodon and others.

The electrolytic valves produce no rectifying effects with high-frequency alternating currents, because the time element enters into the formation of the aluminic hydroxide film on which their action depends. On the other hand, the mercury-vapour tubes which have been proposed for use with high-tension alternating currents will not operate below a certain minimum potential-difference between the electrodes. The vacuum-valve as here described, however, will pass current unilaterally with a fraction of a volt difference of potential between the *incandescent* and the cold electrode, and there is no minimum potential difference below which they will not act; hence their use is conditioned solely by the sensitiveness of the galvanometer employed with them.

By its simplicity and ease of use the carbon-filament vacuum-valve recommends itself as a useful addition to our resources for experimental work in connexion with electric oscillations and electric-wave telegraphy.

Discussion.

Dr. R. T. Glazebrook expressed his interest in the paper, and hoped that Dr. Fleming would be able in a further communication to give numerical data so that the sensitiveness of the arrangement described could be compared with those of other rectifying devices.

XI. *On the Use of the Cymometer for the Determination of Resonance-Curves.* *By* G. B. Dyke, *B.Sc.**

Dr. Fleming has shown in his recent Cantor Lectures before the Society of Arts †, that by the introduction of a hot-wire ammeter into the circuit of his direct-reading cymometer, the effective or root-mean-square value of the oscillation current set up in the cymometer circuit can be measured. This instrument was originally designed for the determination of the wave-lengths used in wireless telegraphy by the direct inspection of a scale, and also for the measurement of capacities and inductances; but it has been found that a small addition renders the instrument also available for the determination of resonance-curves, and therefore of the decrement of oscillation-trains, and of oscillatory spark-resistances.

A direct-reading cymometer was used constructed as described by Dr. Fleming in a paper read before this Society on March 24th, 1905 ‡. The instrument consists essentially of a closed circuit containing a condenser and an inductance,

* Read March 23, 1906.

† Cantor Lectures, 1905. Dr. J. A. Fleming on "The Measurement of High Frequency Currents and Electric Waves."

‡ "On the Application of the Cymometer to the Determination of the Coefficient of Coupling of Oscillation Transformers," by Dr. J. A. Fleming. Proc. Phys. Soc. Lond. vol. xix. p. 603; and Phil. Mag. June 1905