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*Two Shillings and Sixpence Net*

THE
RADIO REVIEW

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# Ionic Oscillations in Three-Electrode Thermionic Valves.*

*By R. WHIDDINGTON, M.A., D.Sc. (Cavendish Professor of Physics, University of Leeds).*

IT is well known that if capacity inductance circuits of low resistance be associated with a valve in the manner shown in Fig. 1 oscillations may be set up in the anode circuit having a period very nearly equal to $2\pi\sqrt{LC}$ providing that:

(1) The resistance $R$ of the anode circuit is small.

(2) The "resistance" $\rho$ of the valve is great.

(3) The mutual induction $M$ between the grid and anode coils is only just great enough to maintain oscillations, a condition approximately realised when $M > 1/k\,(L/\rho + R\,.\,C)$ ? where $k$ is the so-called factor of amplification.

This method of producing oscillations has been very largely used for many purposes, particularly in wireless

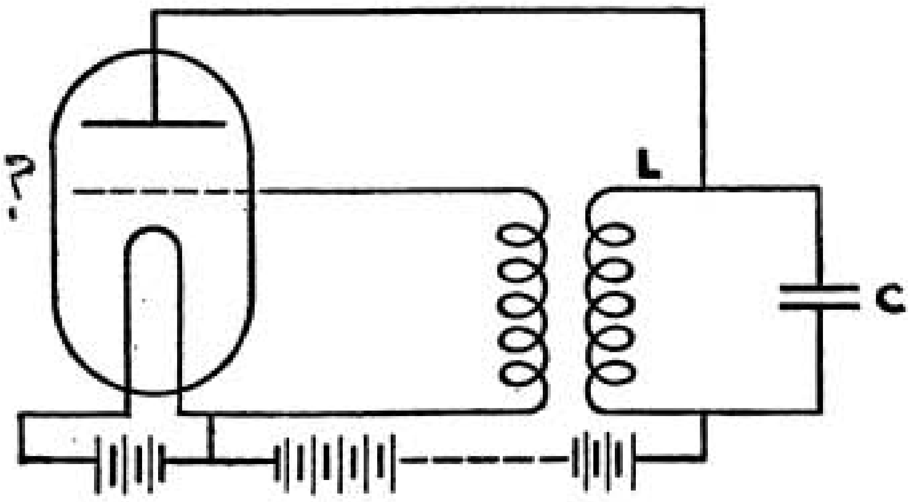

FIG. 1.

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* This article contains the text of a paper, entitled "A Wireless Method of Measuring the Ratio $e/m$," read before Section A of the British Association, together with subsequent additions made by the author.

telegraphy and telephony, and in modern practice is usually employed in conjunction with "hard" valves, that is to say valves from which gas and vapour have been removed to such a degree as to prevent the production of ions by collision.

The arrangement of Fig. 1 can however be used equally successfully and usually more efficiently with "soft" valves which contain sufficient quantities of gas or vapour as to permit of ionisation by collision.

It is the object of the present short paper to show that by employing a new and simple scheme of circuits a soft valve can be made to oscillate in a way involving very different principles to those obtaining in the arrangement of Fig. 1. The new arrangement is shown diagrammatically in Fig. 2.

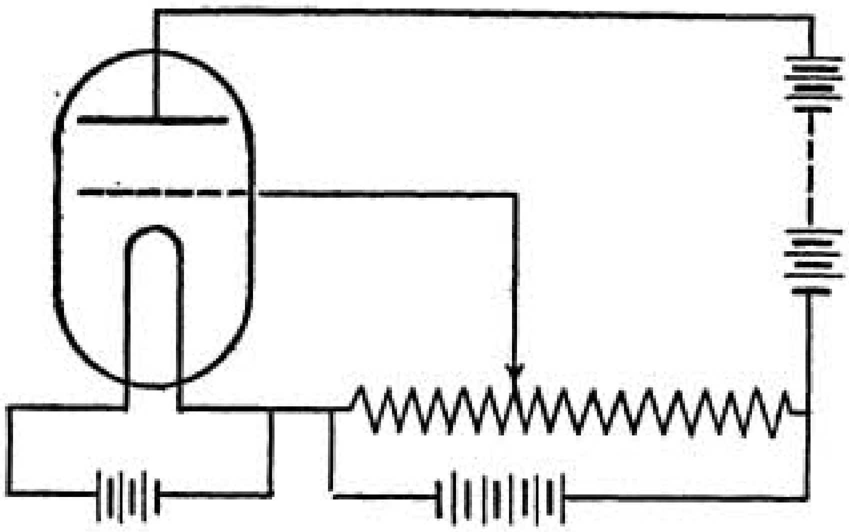

FIG. 2.

It is seen here that there are no capacity inductance circuits whatever, in effect simply two sources of potential, the one in the anode circuit being of fixed value, that in the grid circuit being variable. Experiment has shown that in an arrangement of this sort quite strong oscillations may be set up with a frequency which is determined almost entirely by the value of the grid potential and geometrical dimensions of the valve electrodes. In Fig. 2 the variable grid potential is represented by a potentiometer, which in practice was non-inductive and consisted in fact of a soft lead pencil split lengthways and fitted with a small metal sliding contact.

The oscillations were detected and their frequency measured by means of a heterodyne wave-meter placed in the vicinity, there being always sufficient energy radiated from the self-oscillating valve to be appreciable up to a few yards away.

It will be convenient at this stage to outline a simple theory which accounts, broadly speaking, for the observed phenomena.

An assumption that has to be made at the outset is, that although the filament as a whole is emitting electrons continuously according to the accepted exponential temperature law, yet there are often one or more spots which are emitting with exceptional power.

Such spots in the case of a tungsten filament are probably of chemical origin and may be due to the presence of local impurity. They would certainly be very sensitive to small temperature changes. It is further necessary to suppose that the bombardment by positive ions of the filament in the neighbourhood of such an emitting spot would greatly increase the local electronic emission so long as the bombardment lasted.

Very direct evidence of the existence of such selectively emitting spots on a tungsten filament is afforded in the experience of manufacturers of valves. It is customary in the factories to "clean up" the anode by passing a comparatively heavy thermionic discharge through the valve when on the pump. During this process the dissipation of energy at the anode is so regulated that the metal of the anode is maintained at a red heat, when it is often observed that one or more points on the anode are very much hotter than the main surface. This fact can only be explained on the assumption that there is exceptionally powerful emission from the corresponding points on the filament.

Now consider one such spot on the filament. If a burst of electrons be emitted they will proceed towards the grid with a speed $u$ given by $\frac{1}{2}\, m\, u^2 = e.V$ so that $u^2 = 2V.e/m$ where $e/m$ is the charge to mass ratio for the electron and $V$ is the value of the positive grid potential with respect to the particular point on the filament considered.* The electrons will thus take a definite and calculable time to travel from filament to grid under the moderate potential applied. On passing through the grid however the electrons emerge into the strong electric field of the anode and assume ionising speed. The negative ions follow the electrons to the anode but the positive ions pass back through the grid towards the filament with speed

$$u_1^2 = 2\, V.e/m_1$$

where $e/m_1$ is in this case the charge to mass ratio of the ion concerned.

There will thus be a cloud of positive ions focussed on the filament and bombarding the original electron emitting spot. This bombardment by producing a new burst of electrons sets up a self-sustaining current oscillation, whose period is determined

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* It is assumed as an approximation that the filament is screened from the anode by the grid. This is very nearly true for the fine-meshed grid of the valve used in the present experiments.

(for any particular valve) solely by the charge to mass ratio of the ions present and the potential applied to the grid.

The following table shows what frequency and wave-length of oscillations would be expected from the above general explanation for the particular case of a valve of the type actually used in the experiments, having a fine-meshed cylindrical grid 6 mm. in diameter down the axis of which passed the filament.

The frequencies corresponding to the singly charged ions of hydrogen and mercury moving under the influence of 1 volt applied to the grid are there evaluated.

| Charged Particle. | $e/m$ (approx.) | $u$ (cms./sec.) | $n$ (cycles/sec.) | Wave-length (metres). |
|---|---|---|---|---|
| Electron . | $1{\cdot}7 \times 10^7$ | $6{\cdot}0 \times 10^7$ | $4{\cdot}0 \times 10^8$ | 0·77 |
| Hydrogen . | $10^4$ | $1{\cdot}4 \times 10^6$ | $1{\cdot}0 \times 10^7$ | 30 |
| Mercury . | 50 | $1{\cdot}0 \times 10^5$ | $6{\cdot}6 \times 10^5$ | 450 |

In actual experiments it was found that the arrangement of Fig. 2 with an applied grid potential of 1 volt, radiated energy at a frequency between $7{\cdot}0 \times 10^5$ and $4{\cdot}0 \times 10^5$ cycles. On the preceding explanation therefore such oscillations are to be ascribed to mercury vapour. It is to be noted however that the frequencies tabulated above are calculated on the basis of singly charged monatomic ions. If in the case of mercury vapour polyatomic ions are concerned a different frequency will be associated with each ion, the frequencies for singly charged ions consisting of two, three, and four atoms respectively would be $1/\sqrt{2}$, $1/\sqrt{3}$, $1/\sqrt{4}$ times $6{\cdot}6 \times 10^5$ (the frequency corresponding to the monatomic ion).

These expected frequencies are tabulated below, while in the second column are given the frequencies actually obtained experimentally. It will be seen that there is a remarkable agreement between the expected and observed frequencies.

| Number of Atoms in Molecule. | Theoretical Frequency (1 Grid Volt). | Observed Frequency (1 Grid Volt). |
|---|---|---|
| 1 | $6{\cdot}6 \times 10^5$ | $6{\cdot}4 \times 10^5$ |
| 2 | $4{\cdot}7 \times 10^5$ | $4{\cdot}6 \times 10^5$ |
| 3 | $3{\cdot}8 \times 10^5$ | $3{\cdot}5 \times 10^5$ |
| 4 | $3{\cdot}3 \times 10^5$ | — |

Oscillations in addition to the above have been detected and measured, they are believed to be due to the carbon dioxide ion but have not yet been investigated in detail.

Referring back to the formula it will be seen that the square of the speed of the ions, that is, the square of the oscillation frequency, should be proportional to the potential applied to the grid. This prediction is amply borne out in practice; curves plotted between $n^2$ and $V$ yielding in all cases so far investigated excellent straight lines. These lines cut the axis of $V$ at points determined partly by the position of the emitting spot on the filament and partly by the natural emission velocity of the electrons.

A typical curve * found by plotting $n^2$ against $V$ is shown in Fig. 3, an obvious straight line giving a value of $n = 6{\cdot}4 \times 10^5$ for a grid potential of 1 volt. That the line produced passes through the origin is probably only accidental.

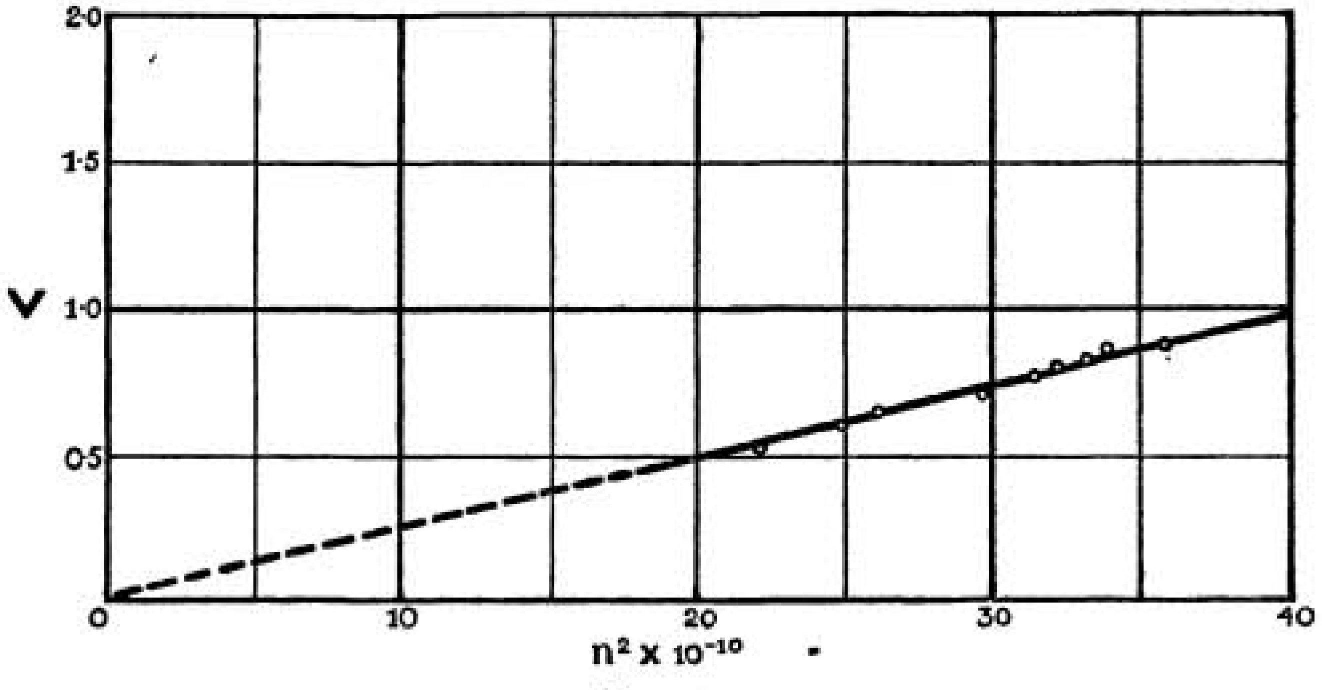

FIG. 3.

It can be seen at once that, if the electrons have a negligible speed of emission, the value of $V = V_o$ for which $n^2 = 0$ must determine the position of the emitting spot on the filament.

In fact if $v$ = the potential fall along the hot filament
$L$ = the length of the filament

and if the potentiometer of Fig. 2 is connected to the negative end of the filament, then

$V_o/v.L$ = the distance of the spot from the negative end of the filament.

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* The value of $e/m$ of the ion responsible for the oscillation determines the slope of the curve.

It is clear also that these straight lines should always cut the $V$-axis at positive values of $V$. In practice this has not always been found to be the case, a fact which it is believed may be more apparent than real and due to the confusion of harmonics with the fundamental oscillation.

This short paper does not in any way aim at completeness; it is intended merely to introduce what is believed to be a new and at first sight rather an astonishing oscillating valve circuit.

The method opens up new fields for research, such for example as the development of a method of determining $e/m$, and the production of extremely short wireless waves, which it is hoped will be dealt with in future papers.

Some of the work above described was carried out at the Air Force Wireless Experimental Establishment, Biggin Hill, where I was assisted in these experiments by Miss B. Summerhayes, B.Sc., and Lieutenant H. Richardson, R.A.F., B.Sc.

# On the Goniometric Functions Applicable to Directive Aerials.

*By A. BLONDEL.*

(*Continued from page* 10.)

## THE APPLICATION OF THE "ZERO METHOD," OR THE SINGLE FRAME METHOD, TO DIRECTION FINDING.

IF it is desired to employ a single-frame arrangement to determine the direction of incoming waves, the frame should be turned until the sound in the telephones just disappears; the angle $\psi_1$ between a horizontal line perpendicular to the plane of the frame and the north as given by the compass is noted. The frame is then turned in the opposite direction until a second position is found where the sound disappears. Let $\psi_2$ be the new angle between the line perpendicular to the frame and the north. The two directions obtained in this manner are not coincident, owing to lack of sensitiveness of the telephone and ear, but they correspond, one to a small positive value of the resultant electromotive force, and the other to a small negative value obtained by reversing the signs of $E_1$ and $E_2$. The corresponding phase angles $\phi_1$ and $\phi_2$, in the case of the type D arrangements, are given by the following equations :—

$$\left.\begin{array}{r} a[2e_0 \sin\phi_1]^2 = \epsilon' \\ a[2e_0 \sin(-\phi_2)]^2 = \epsilon' \end{array}\right\} \quad . \quad . \quad . \quad (5)$$

assuming that the detector gives a response proportional to the square of the resultant E.M.F., $a$ being a co-efficient of proportionality.

Hence, $$\phi_1 = \sin^{-1}\left(\sqrt{\frac{\epsilon'}{a}} \times \frac{1}{2e_0}\right) \quad . \quad . \quad . \quad (6)$$

In a more general case, using the function $F$ to represent the response of the detector, the above equations become

$$F[2e_0 \sin\phi_1] = \epsilon' . \quad . \quad . \quad . \quad (7)$$

$$F[2e_0 \sin(-\phi_2)] = \epsilon' . \quad . \quad . \quad . \quad (8)$$

In all cases we have $\phi_1 = \phi_2$, that is to say, the required direction is the bisector of the angle $\psi_1 - \psi_2$. But the size of this angle and the accuracy of measurement vary with $\phi_1$. In fact, writing $H$ for the inverse function of $F$, the following equations may be deduced

$$\psi_1 - \psi_2 = \phi_1 - \phi_2 = 2 \sin^{-1} H\left(\frac{\epsilon'}{2e_0}\right) . \quad . \quad (9)$$

where $$\phi_1 = \sin^{-1} H\left(\frac{\epsilon'}{2e_0}\right).$$

Also, since $\theta = \sin^{-1}\frac{\lambda\phi_1}{2\pi x}$, the error in the angle $\theta$ has the following value, corresponding to an error $d\epsilon'$ in determining the audibility limit,

$$d\theta = \frac{d\phi_1}{\sqrt{\left(\frac{2\pi x}{\lambda}\right)^2 - \phi_1^2}} = \frac{\frac{d}{d\epsilon'} H\left(\frac{\epsilon'}{2e_0}\right) d\epsilon'}{\sqrt{\left(\frac{2\pi x}{\lambda}\right)^2 - \phi^2}\sqrt{1 - \left[H\left(\frac{\epsilon'}{2e_0}\right)\right]^2}} \quad . \quad . \quad . \quad (10)$$

In the case of an energy integrating detector, this expression reduces to

$$d\theta = \frac{d\epsilon'}{\sqrt{\left[\left(\frac{2\pi x}{\lambda}\right)^2 - \phi^2\right]\left[(2e_0)^2 - \epsilon'^2\right]}} . \quad . \quad (10a)$$

It will be seen that the possible error $d\theta$ depends, not only on the angle $\theta$ itself (which enters into the expression for $\phi_1$) and on the minimum response $\epsilon'$, but also on the E.M.F., $2e_0$, induced by the waves, and, consequently, on the distance of the frame aerial from the transmitter and on the power of the latter. The definiteness of the measurement is obviously greater when the received waves are weaker.

Similar formulæ can be obtained for the S type loops by replacing $\sin\phi$ by $\cos\phi$; but, like the preceding expressions, they only permit numerical calculations to be made if the formulæ (5) and (6) are applicable.

From the preceding remarks it follows that the efficacy of the simple type D frame can be augmented by increasing the power of the transmitting station and the sensitiveness of the receiving detectors, so that angles greater than 30° to 40° are not obtained on either side of the mean position. Measurements made with larger angles must be looked upon as less reliable.

The single-frame arrangement has the advantages of simplicity and of ease of application in all practical cases. There is little risk, in general, of its giving false directions through bad insulation. In such cases it may cease to be usable, either through giving rise to no measurable effect on the detector, or for yielding a constant E.M.F. in every position. In either case the operator is warned that there is something wrong. A single aerial of the S type presents equally serious defects. On the one hand, as has been seen above, it only gives good results when $\frac{x}{\lambda}$ is very near $\frac{\lambda}{4}$, in fact, for small values of $\frac{x}{\lambda}$ the effect of the waves on the frame becomes almost independent of the orientation of the loop. Further, the sensitiveness, which is zero when $\theta = 0$, also becomes zero when $\theta = 90°$. The limits of utility are, therefore, far more restricted than in the case of the type D arrangement. Type S is, therefore, only of theoretical interest, and is not likely to be used in practice.

### Application of the Comparison Method.

Suppose for simplicity that the current induced in the local circuit is proportional to the resultant induced electromotive force and that the detector by complete rectification gives a response proportional to the amplitude of this current, then the equations can easily be written for all direction-finding arrangements by the comparison method with several loops.

For example, taking the case of two identical loops perpendicular to one another and coupled differentially by transformers, having variable transformation ratios $M$ and $N$, to a single circuit containing the detector, the comparison method becomes a *compensation method* by opposing the effect of the two loops, so as to reduce the indication of the measuring instrument to zero. Hence the relation

$$M \operatorname{gon} \theta - N \operatorname{gon} \left(\frac{\pi}{2} - \theta\right) = 0.$$

But, in practice, using a telephone instead of a galvanometer, the measurement is made by determining two values of the coefficients of mutual induction $M$ and $N$ when the sound disappears in the telephone. Hence assuming firstly the response of the detector proportional to the square of the acting electromotive force, we have

$$\left.\begin{aligned} M \operatorname{gon} \theta - N \operatorname{gon} \left(\frac{\pi}{2} - \theta\right) &= \sqrt{\frac{\epsilon'}{2ae_0}} \\ M' \operatorname{gon} \theta - N' \operatorname{gon} \left(\frac{\pi}{2} - \theta\right) &= -\sqrt{\frac{\epsilon'}{2ae_0}} \end{aligned}\right\} \quad . \quad . \quad . \quad (11)$$

where $a$ is a coefficient of proportionality and $\epsilon'$ a very small quantity corresponding to the threshold value of the sound in the telephones.

These quantities may be eliminated by adding the two equations whence,

$$\frac{\operatorname{gon} \theta}{\operatorname{gon} \left(\frac{\pi}{2} - \theta\right)} = \frac{N + N'}{M + M'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

In the case of the well-known apparatus, called by its inventors the "radiogoniometer," the two transformers are replaced by a single apparatus comprising two fixed primary circuits at right angles, and a secondary circuit which can be rotated about their common axis.

If we call $\psi$ the angle between the electrical axis of the movable coil and that of one of the fixed circuits, we have

$$M = \cos \psi\,; \; N = \sin \psi$$
$$M' = \cos \psi'\,; \; N' = \sin \psi'$$

from which we obtain,

$$\frac{\operatorname{gon}\theta}{\operatorname{gon}\left(\frac{\pi}{2}-\theta\right)}=\frac{\sin\psi+\sin\psi'}{\cos\psi+\cos\psi'}=\tan\frac{\psi+\psi'}{2} \quad . \quad (13)$$

In the particular instance when the frame width $x$ is very small in comparison with the wave length, the functions $\frac{2\pi x}{\lambda}\sin\theta$ and $\frac{2\pi x}{\lambda}\cos\theta$ are practically equal to the angles, so that the last term of the above equation reduces simply to $\tan\theta$, wherefore substituting $\beta$ for $\frac{\psi+\psi'}{2}$, we have $\theta=\frac{\psi+\psi'}{2}=\beta$.

Firstly let us take the case of Type D arrangement:

If we plot, as in Fig. 9, the values of $\theta$ from 0° to 90° as abscissæ, and the values of $\beta$ as ordinates, where

$$\beta=\tan^{-1}\left(\frac{\frac{2\pi x}{\lambda}\sin\theta}{\frac{2\pi x}{\lambda}\cos\theta}\right)=\theta,\ \textit{nearly} \quad . \quad . \quad . \quad . \quad (14)$$

we obtain a straight line.

But this is only the case for long wave lengths. When shorter wave lengths of the order of 100 metres are used, $\beta$ is replaced by a more complicated function :—

$$\beta_D=\tan^{-1}\frac{\operatorname{gon}\theta}{\operatorname{gon}\left(\frac{\pi}{2}-\theta\right)}=\tan^{-1}\frac{\sin\left(\frac{2\pi x}{\lambda}\sin\theta\right)}{\sin\left(\frac{2\pi x}{\lambda}\cos\theta\right)} \quad . \quad . \quad (15)$$

Fig. 9 gives the values of $\beta_D$ as a function of $\theta$ and conversely, for $\frac{x}{\lambda}=\frac{1}{4},\frac{1}{8},\frac{1}{16}$. The difference between $\beta$ and $\beta_D$ is negligible when $x=\frac{\lambda}{16}$, it reaches a maximum of 7° 30′ when $x=\frac{\lambda}{4}$ approximately, and becomes zero in every case, whatever the value of $x$, when $\beta=0°$, 45° and 90°.

To employ a radiogoniometer accurately, it is necessary to plot a correction curve similar to the preceding, giving $\theta$ in terms of $\beta$, and *vice versâ*, for each value of $\frac{x}{\lambda}$ that is used, or else to employ a double-entry table.

If we use type S arrangement instead of type D, the angle $\beta$ is given by an analogous expression, the sines being replaced by the cosines

$$\beta_S = \tan^{-1} \frac{\cos\left(\frac{2\pi x}{\lambda}\sin\theta\right)}{\cos\left(\frac{2\pi x}{\lambda}\cos\theta\right)} \quad . \ . \ . \ . \ . \ . \ . \ . \quad (16)$$

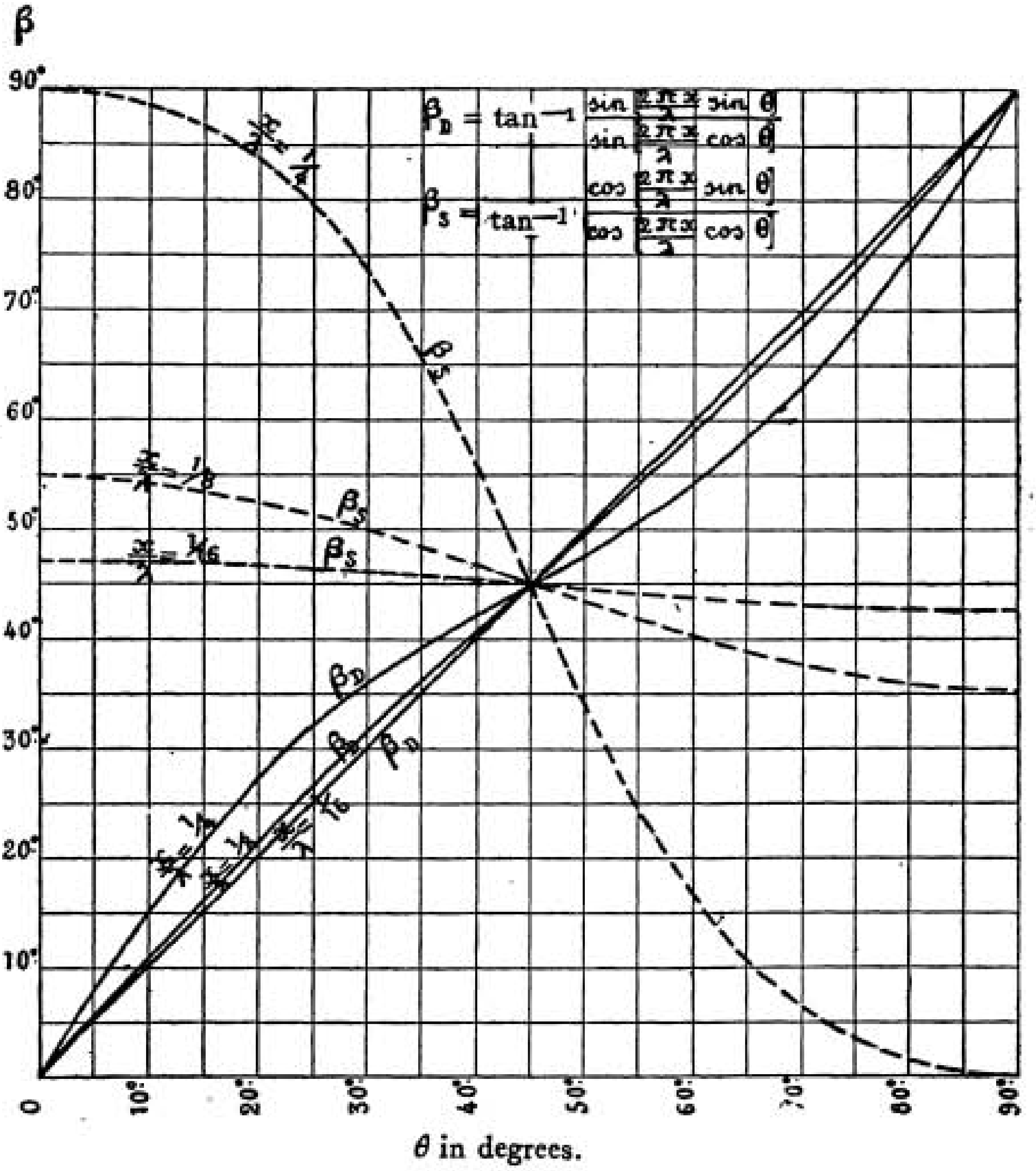

FIG. 9.

By plotting the curves of $\beta_S$ for different values of $\frac{x}{\lambda}$, Fig. 9, we see that they are of a different type from those of $\beta_D$. When $\frac{x}{\lambda} = \frac{1}{4}$ the curve for $\beta_S$ is the inverse of that for $\beta_D$—*i.e.* $\theta$ is replaced by $\left(\frac{\pi}{2}-\theta\right)$. But as $\frac{x}{\lambda}$ decreases, the value of $\beta_8$ tends to become constant, instead of being proportional to $\theta$. The sensitiveness therefore falls off as the width of the loop becomes less than a half wave length.

For that reason there is no further interest in considering the type S arrangements for direction finding; the same argument applies even more, if frame arrangements with slanting aerials are used.

Instead of operating by *compensation* as above, we may utilise *alternate* measurements, as I indicated in 1910,* by arranging the two loops to influence the same receiving circuit or telephones in turn, and altering the mutual inductances $M$ and $N$ until the two sounds become equal—thus making use of the *differential* sensitiveness of the ear instead of its ultimate threshold sensitivity. The preceding equations remain valid (with another $\epsilon'$ of course), if the detector gives a response proportional to the amplitude or the square of the amplitude, of the electromotive force in the loop, or even if it follows some other function of the voltage.

In the last case, theoretically the most complex, each of the expressions gon $\theta$ would be replaced by the unknown and more complex function $F(e_0 \operatorname{gon}\theta)$. This, however, does not hinder the solution of the equations for the compensation method, since, by writing $H$ for the inverse of the function $F$, the two expressions (11) can immediately be replaced by the following:

$$\left.\begin{aligned} M\operatorname{gon}\theta - N\operatorname{gon}\left(\frac{\pi}{2}-\theta\right) &= H\left(\frac{\epsilon'}{2e_0}\right) \\ M'\operatorname{gon}\theta - N'\operatorname{gon}\left(\frac{\pi}{2}-\theta\right) &= -H\left(\frac{\epsilon'}{2e_0}\right)\end{aligned}\right\} \quad . \; . \quad (17)$$

Adding these two expressions, the unknown function on the right hand side is eliminated, and the following equation obtained,

$$\frac{\operatorname{gon}\theta}{\operatorname{gon}\left(\frac{\pi}{2}-\theta\right)} = \frac{N+N'}{M+M'} = \tan\beta,\ \text{say} \quad . \; . \; . \quad (18)$$

All the results previously found therefore remain without alteration. In the particular case, for the radiogoniometer,

$$\tan\beta = \tan\frac{\psi+\psi'}{2}.$$

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* A. Blondel, *loc. cit.*

In the case of the alternate measurement method the function $H$ cannot be introduced, so that equation (11) must be replaced by the following :

$$\left.\begin{aligned} F\,(2e_o\,M \operatorname{gon}\theta) - F\left[2e_o\,N\left(\frac{\pi}{2}-\theta\right)\right] &= \epsilon' \\ F\,(2e_o\,M' \operatorname{gon}\theta) - F\left[2e_o\,N' \operatorname{gon}\left(\frac{\pi}{2}-\theta\right)\right] &= -\epsilon' \end{aligned}\right\} \quad . \quad (19)$$

When the detector is not a crystal but an energy integrating one $F$ indicates a square, and we obtain :

$$\frac{\operatorname{gon}\theta}{\operatorname{gon}\left(\frac{\pi}{2}-\theta\right)} = \sqrt{\frac{N^2+N'^2}{M^2+M'^2}}$$

which is comparatively simple. But if $F$ is any unknown quantity, the solution of (19) cannot be obtained immediately but a previous knowledge is required of the function $F$ and of the variation of $e_o$ with the distance from the transmitter.

The comparison method then, is preferable to the alternate measurement method. Moreover it should be noted that it gives a more uniform degree of accuracy when $\theta$ varies. Indeed, assuming that the measurement of $\theta$ is accomplished directly by a galvanometer, as may be done with the radiogoniometer, we have, as above,

$$M \operatorname{gon}\theta - N \operatorname{gon}\left(\frac{\pi}{2}-\theta\right) = 0 \quad . \quad . \quad . \quad . \quad . \quad (20)$$

Any variation $d\theta$ of the angle $\theta$ then makes this expression equal to a small quantity $d\alpha$ instead of zero. The relative accuracy is then :—

$$\frac{d\alpha}{d\theta} = M\frac{d \operatorname{gon}\theta}{d\theta} - N\frac{d \operatorname{gon}\left(\frac{\pi}{2}-\theta\right)}{d\theta} \quad . \quad . \quad . \quad (21)$$

When $M$ and $N$ are equal respectively to $\cos\psi$ and $\sin\psi$, as above, and when the distance between the antennæ is sufficiently small to allow the use of the simplest form of the goniometric function $\left[\operatorname{gon}\theta = \frac{2\pi x}{\lambda}\sin\,\theta;\ \operatorname{gon}\left(\frac{\pi}{2}-\theta\right) = \frac{2\pi x}{\lambda}\cos\theta\right]$, the second term of equation (21) reduces to

$$\frac{2\pi x}{\lambda}\left(\cos^2\theta + \sin^2\theta\right) = \frac{2\pi x}{\lambda} \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

and is therefore a constant.

If the detector integrates the energy proportional to the square of the first term of (20), the accuracy of measurement is given by

$$2\,\frac{d\alpha}{d\theta}\left[M \operatorname{gon}\theta - N \operatorname{gon}\left(\frac{\pi}{2}-\theta\right)\right] = 8\left(\frac{\pi x}{\lambda}\right)^{2} \operatorname{gon}(\theta-\psi)\,. \quad (21a)$$

If $M$ and $N$ can be varied independently the relative accuracy remains proportional to the expression (21), but increases with the absolute values of $M$ and $N$, which are assumed always to satisfy equation (19). This shows that it is always advisable to increase as much as possible the mutual inductance of the transformer supplied by the loop receiving the weakest electromotive force.

On the contrary in the comparison system using alternate measurements, gon $\theta$ must be replaced by $F$ (gon $\theta$), a function dependent upon the mode of operation of the detector; and the sensitiveness is no longer constant. However, if the detector is a simple energy integrator, $F(\operatorname{gon}\theta) = (\operatorname{gon}\theta)^2$ and (20) becomes

$$M^2 \operatorname{gon}^2\theta - N^2 \operatorname{gon}^2\left(\frac{\pi}{2}-\theta\right) = 0 \quad . \quad . \quad . \quad (20a)$$

## NON-VERTICAL AERIALS.

We have assumed up to the present that the antennæ or sides of the loops are vertical, with the exception of the horizontal parts which serve merely for connections.

In cases where the shape of the loop is more complicated, the function gon $\theta$ will be replaced by a more complicated expression.

The only condition desirable for each such system of connected aerials, if they are of complicated shape, is that they shall be symmetrical at least about a vertical line in their plane midway between them.* Let us therefore consider two symmetrical aerials, and that $(x, z)$ are the co-ordinates of any point in one of them, $z$ being the height measured from the horizontal plane passing through the lowest point of the aerial, or, more generally, from any horizontal reference plane. The co-ordinates of a point at the same height on the second aerial will be $(-x, z)$. The equation of each antenna in the plane of the loop can therefore be expressed in the form $x = f(z)\ -x = -f(z)$.

*(To be concluded.)*

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* This condition is not, however, absolutely essential, since it is always possible to integrate the electromotive force of the two antennæ separately, by referring their phase angle to a vertical reference axis. But this results in a rather troublesome complication especially when the damping is considered. (See below.)

# An Investigation of the Internal Action of a Triode Valve.

*By W. H. ECCLES, D.Sc., M.I.E.E.*

(*Continued from page* 20.)

## THEORY OF THE GRID.

### *Triode with Plane Electrodes.*

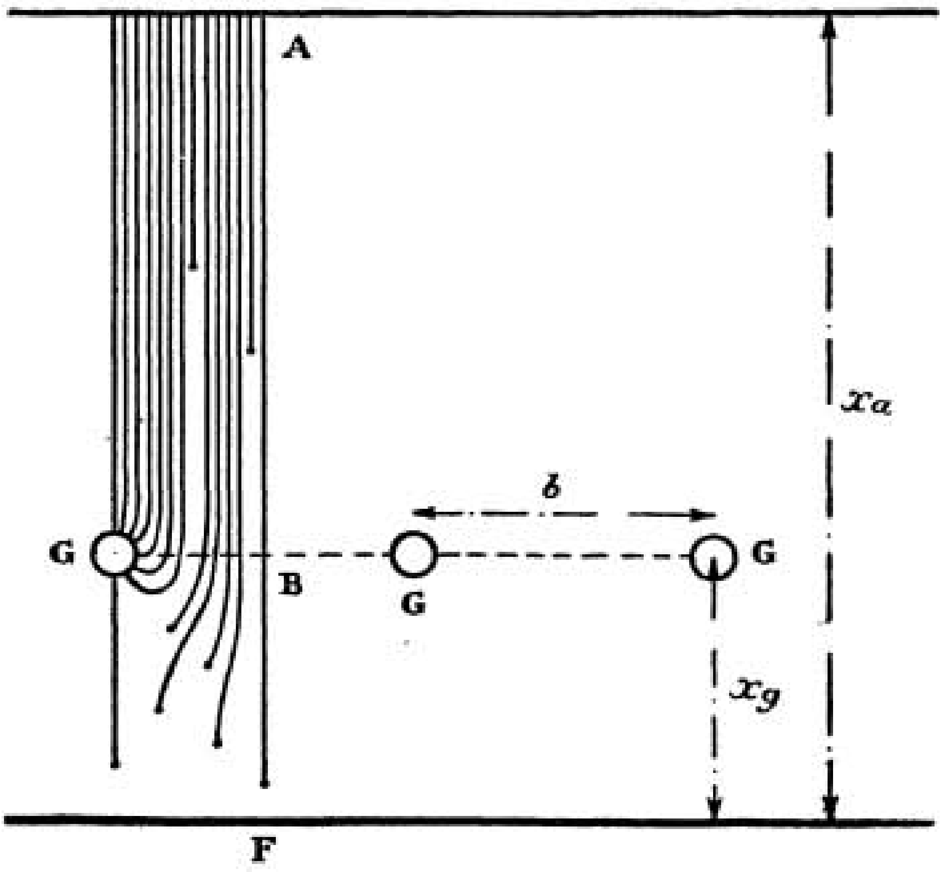

FIG. 7.

We shall first suppose the cathode and anode to be parallel planes of infinite extent and the grid to consist of a number of equidistant straight parallel wires with their axes in a plane parallel to the electrodes. The cathode will be supposed to be emitting the electrons uniformly over its surface. We begin by endeavouring to picture the instantaneous state of the electric field between the electrodes. The form of the lines of force is suggested in Fig. 7. Since the triode is usually used with the anode at much higher potential than the grid and the cathode, the Faraday lines are portrayed as starting on the anode A and ending on the grid G and on the electrons of the space charge. Near the anode the density of the lines is uniform and the lines are perpendicular to the anode. They remain nearly parallel till near the grid wires, and here the radial field due to the charge on the grid combines with the parallel field to give the curved lines. Passing into the region between the grid G and the cathode F the field tends to become uniform again, but is clearly much weaker on account of many of the lines having been disposed of. None of the lines reach the cathode, because the field, as we have already seen, must be zero at or near the cathode; that is to say, all the lines that penetrate the shield formed by the grid end upon flying electrons. In the figure there is marked a region B wherein the grid exerts very little influence. We shall make this a kind of resting place in our calculation of the voltages between different points in the field.

Let $x_a$ represent the distance of the anode from the cathode, $x_g$ the distance of the plane of the grid from the cathode, $b$ the distance between consecutive grid wires, $r$ the radius of each grid wire, and $v_a$, $v_b$, $v_g$ the potentials of the points A, B, G relative to the cathode F. Among the lengths $r$ will be supposed small compared with $b$, and $b$ small compared with $x_a$ and $x_g$. We shall now estimate the voltages between the points A and B, B and G, B and F, and shall make these obey the condition that all the Faraday lines leaving A end upon the grid and upon electrons. In order to do this without great labour it is necessary to make some simplifying approximations at the very beginning. First we shall assume that the electric field is practically constant all the way from A to B; then, if $\sigma_a$ be the number of lines starting from the square centimetre of anode, the field is $(4\pi/\kappa)\sigma_a$, where $\kappa$ is the inductivity (S.I.C.) of the vacuum, and the P.D. between A and B is

$$v_a - v_b = 4\pi\sigma_a (x_a - x_g)/\kappa.$$

Next let the charge on every centimetre of each wire of the grid be $Q$, then, since there are $1/b$ wires per centimetre, the amount of electricity per square centimetre on the grid is $Q/b$. Now, in estimating the P.D. between B and G, we may suppose a unit test charge of electricity moved from B to G under the electric forces due to the whole of the grid wires, and calculate the work done. The contribution of each grid wire to the voltage is of the form

$$\frac{2Q}{\kappa} \log \left(\frac{\text{initial distance}}{\text{final distance}}\right),$$

where the distance is to be measured from the centre of the wire concerned. The sum of all such logarithms is of the form

$$\frac{2Q}{\kappa}\log\frac{\beta}{r}$$

where $\beta$ is a geometrical constant that can be determined by calculation for any number of wires, if required. For one wire $\beta$ is clearly $\frac{1}{2}b$, for two wires, one on each side of B, $\beta = \frac{1}{4}b$, and so on. We obtain, therefore,

$$v_b - v_g = \frac{2Q}{\kappa}\log\frac{\beta}{r}.$$

The next step is to evaluate the voltage between B and F. We do this by aid of the electron current equation given on p. 13, which states that when an electronic current of density $i$ is flowing between two parallel plane areas at one of which the voltage and the electric field are zero, the P. D. is

$$v_b = (i/A)^{\frac{2}{3}} x_b^{\frac{4}{3}}.$$

The last of the equations to be formed is, as already explained,

$$\begin{aligned}\sigma_a &= Q/b + \text{all space charge}\\ &= \alpha Qb/, \text{ say,}\end{aligned}$$

where $\alpha$ is a quantity to be determined by experiment, and obviously approaches unity when the space charge, that is to say, the electron current, is very small. Experiment shows that for most types of triode $\alpha$ is nearly equal to unity for a large range of values of grid voltages and anode current, but the mode of derivation shows that it should tend to increase as the electron current increases.

We now have four equations amongst the seven variable quantities, and can, therefore, eliminate three of them, say $\alpha_a$, $Q$ and $v_b$. From the first equation we obtain $\sigma_a$, from the second, $Q$; substituting these in the fourth equation, we have

$$v_a - v_b = \frac{2\pi\alpha\,(x_a - x_g)}{2b\log\beta/r}\,(v_b - v_g)$$

or

$$v_a + gv_g = (1 + g)v_b,$$

where we have put, for brevity,

$$g = \frac{2\pi\alpha\,(x_a - x_g)}{b\log\beta/r},$$

and where the logarithm is natural.

Now using the third equation we obtain

$$v_a + gv_g = (1 + g)\,(i/A)^{\frac{2}{3}}\,x_g^{\frac{4}{3}},$$

or
$$i = A\frac{(v_a + gv_g)^{\frac{3}{2}}}{(1+g)^{\frac{3}{2}}\,x_g{}^2}.$$

This formula for the planar triode is not of immediate utility, because very few, if any, instruments have been made with the cathode consisting of a heated plane surface. Even in those cases where the anode and the grid are planes the cathode is usually a filament, which may in large lamps be wound to and fro between the grid so as to form a number of V's; and to this the formula is not genuinely applicable. The same method may, however, be applied to the cylindrical triode, and to this we now turn.

### The Cylindrical Triode.

The cathode will be taken to be a straight filament or a curled filament with straight axis and of small over-all diameter, while the anode will be taken to be a circular cylinder co-axial with the cathode. All the electrodes are supposed to be of infinite length. The grid will be taken to be a co-axial intermediate helix with equidistant spires or a collection of equal parallel equidistant co-axial circles. In Fig. 8 a sectional view is given, and A is the anode, F the cathode, G the grid. When, as is usual, the anode is at higher potential than the other electrodes, the Faraday lines starting from the inside surface of the anode form a converging radial electric field in which every line of force ends upon the grid or upon an electron in the space charge conveying the current. Let the radius of the grid wire be $r$, the distance between consecutive turns $b$, the radius of the grid helix $x_g$, and the radius of the inner surface of the anode $x_a$. Also let the charge per unit length of the anode be $Q_a$, and that upon unit length of the wire of the grid $Q$. It follows that the charge per unit length of the grid helix is approximately

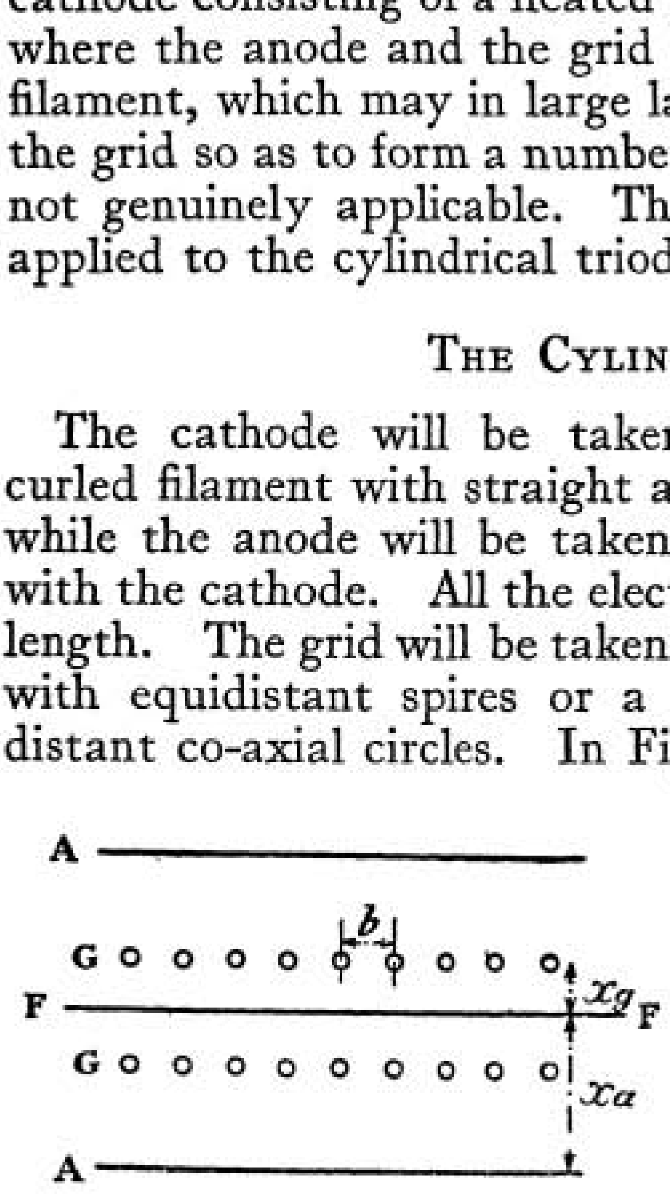

Fig. 8.

$$2\pi x_g Q/b$$

The analysis now follows closely that used in the case of the planar triode. But the potential between A and B is due on the present occasion to a radial field, and the P.D. is therefore a logarithm; that is to say,

$$v_a - v_b = \frac{2Q_a}{\kappa} \log \frac{x_a}{x_g}.$$

The next equation is, by reasoning the same as before,

$$v_b - v_g = \frac{2Q}{\kappa} \log \frac{\beta}{r},$$

and then from the properties of the electron current flowing between cylinders we have

$$v_b = (j/2\pi A)^{\frac{2}{3}} x_g^{\frac{2}{3}}.$$

The condition that the lines of force leaving the anode all end on the grid and on the space charge may be written

$$\begin{aligned} Q_a &= 2\pi x_g Q/b + \text{space charge} \\ &= 2\pi\alpha x_g Q/b, \text{ say,} \end{aligned}$$

where $\alpha$ is a parameter to be determined by experiment, usually not much greater than unity.

From the first, second and fourth equations we get

$$v_a + g v_g = (1 + g)\, v_b,$$

where

$$g = \frac{2\pi\alpha x_a}{b} \cdot \frac{\log (x_a/x_g)}{\log \beta/r}.$$

On substituting for $v_b$ we obtain finally

$$j = 2\pi A \, \frac{(v_a + g v_g)^{\frac{3}{2}}}{(1 + g)^{\frac{3}{2}} x_g}$$

where $A = 2{\cdot}33 \times 10^{-6}$ in practical units.

In those cases where the radius of the filament or of the curled filament exceeds about one-tenth of the radius of the grid it is necessary to apply to the formula just obtained the correction given in the table on p. 18.

As an example a particular receiving triode of which measurements have been taken may be quoted here. In this triode $x_a = 0{\cdot}503$ cm., $x_g = 0{\cdot}23$ cm., $b = 0{\cdot}169$ cm., and we may take $\beta = b/2\pi$ for theoretical reasons. Then on substituting in the formula we obtain

$$g = 6{\cdot}71 a.$$

Now, experiment showed that $g$ is actually equal to 6·9; hence we conclude that the quantity $a$ is equal to about 1·03.

Again, the formula for the current yields for an anode voltage of 60 and grid voltage zero the value

$$j = 1{\cdot}31 \text{ mA},$$

if no account be taken of the radius of the cathode. In fact, the cathode is a curly filament of about 0·54 mm. radius. The correction factor is seen from the table on p. 18 to be about 1·1, which gives

$$j = 1{\cdot}44 \text{ mA}.$$

Actually, the measured current was 1·65 mA. This is not a closely accordant result, but is not unsatisfactory when regard is had to the number of circumstances neglected (such as the finite length of the electrodes) in the derivation of the formulæ.

## SOME CONSEQUENCES OF THE FORM OF THE CURRENT EQUATION

In the preceding paragraphs, where we have been dealing with the scalar electric potential in a purely theoretical manner, we have used the letter $v$ in reference to absolute values of the potential. In what follows we shall extend the results into relations wherein experimental voltages due to batteries are solely concerned, and shall therefore use the letter $e$ instead of $v$.

In some respects the most remarkable feature of the mathematical results now reached is the fact that the current through the triode is expressible as a function of $e_a + ge_g$. Of course, it was obvious without any investigation that the current must be expressible in the form

$$i_a = F(e_a, e_g);$$

but the elucidation of the mode of association of the variables $e_a$ and $e_g$ is of considerable mathematical and physical importance. This point has not waited for theoretical discovery, however; it was found empirically by Langmuir (*Proceedings of the Institute of Radio Engineers*, p. 278, 1915), who showed that the lower parts of the characteristic curves of his pliotrons followed the equation

$$i_a = A'(e_a + ge_g)^{\frac{3}{2}}.$$

H. J. van der Bijl has also given experimental evidence of the truth of the theorem in the case of triodes of his own design in the *Proceedings of the Institute of Radio Engineers*, April, 1919. The latter has shown, besides, that the lower values of the currents in his tubes follow the equation

$$i_a = A'(e_a + ge_g + e_o)^2.$$

It is possible to find any number of equations of the type $i_a = A'(e_a + ge_g + e_o)^n$ by choosing suitable pairs of values of the parameters $e_o$ and $n$, but Langmuir's equation has the advantage of possessing a physical reason for the appearance of the index $\frac{3}{2}$, namely, the space charge phenomenon. The form $F(e_a + ge_g)$ includes both of the above formulæ, and has infinite other possibilities, and it appears to be applicable over a greater range than Langmuir's equation, which cannot hold good so far as the point of inflection in the familiar characteristic curves of $i_a$ plotted with values of $e_g$ as abscissæ. But before discussing these and before exhibiting some practical applications it is necessary to point out some of the mathematical consequences of the form of the function.

In the first place it is evident that many of the statements on pp. 20, 67, 69, concerning the general theory of electric shielding apply immediately to the electron current that passes through the tube when the circuit is completed outside and a suitable voltage applied. Within limits any desired current smaller than the saturation current can be produced by a wide variety of values of $e_a$ and $e_g$; if, for example, $g = 20$, 100 volts on the anode with the grid at zero voltage is equivalent to 120 volts on the anode with $-1$ volt on the grid, and to 80 volts on the anode with $+1$ on the grid. In fact, we may say that a principal function of a triode is to multiply the grid voltage by $g$, transfer it to the anode circuit, and superpose it on the anode voltage. We shall call this total voltage the "lumped voltage" and give it the symbol $e_l$. The current equation is then

$$i_a = F(e_l).$$

The lumped voltage may now be taken as a new independent variable and the current curves plotted with values of $e_l$ as abscissæ.

Let us take the family of curves in Fig. 9 and transform them to the new variable. It is first necessary to find $g$ from the curves. An easy way is to draw first any line PQRS to mark points of equal currents on the different curves of Fig. 9; then set up ordinates $p_op$, $q_oq$, etc., to represent to scale the anode voltage of the respective curves, and draw the best straight line through the points p, q, etc., to cut the axis in z. Since this line relates to constant current, the value of $e_a + ge_g$ must be constant along it, so that a fall in $e_a$ is made up by $g$ times the increase of $e_g$. Thus the gradient of the line, reckoned on the voltage scales, is the value of $g$. For example, supposing the final line goes through p and that the length $p_0$ z represents 20 volts on the grid, the value of $g$ is 250 volts ÷ 20 volts = 12·5.

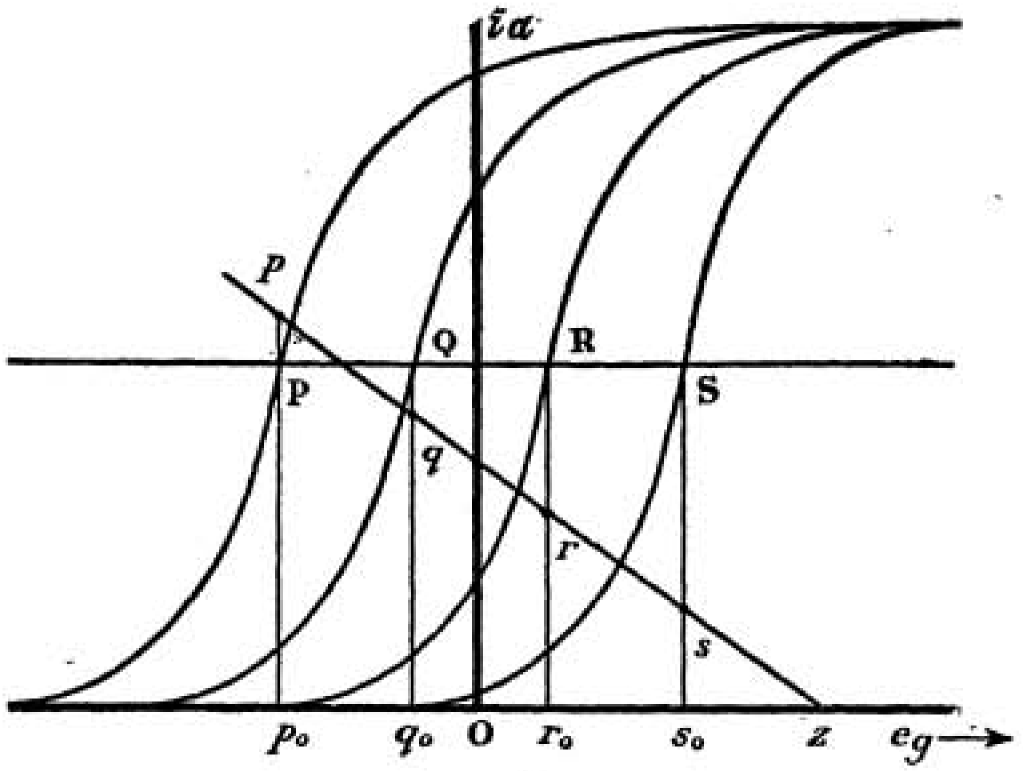

Fig. 9.

The next step consists in calculating the value of $e_a + ge_g$, that is, $e_l$, for a number of points on the curves of the family, either arithmetically or graphically. The latter method is shown in Fig. 10, where one of the curves is taken aside for the sake of clearness. First the sloping line through O is drawn parallel to the line through z in Fig. 9. The ordinates of this line are $g$ times the corresponding grid voltage. Then a line is drawn through q with constant ordinates equal to the anode voltage of the curve, and ordinates are drawn through any points such as Q, T. Evidently

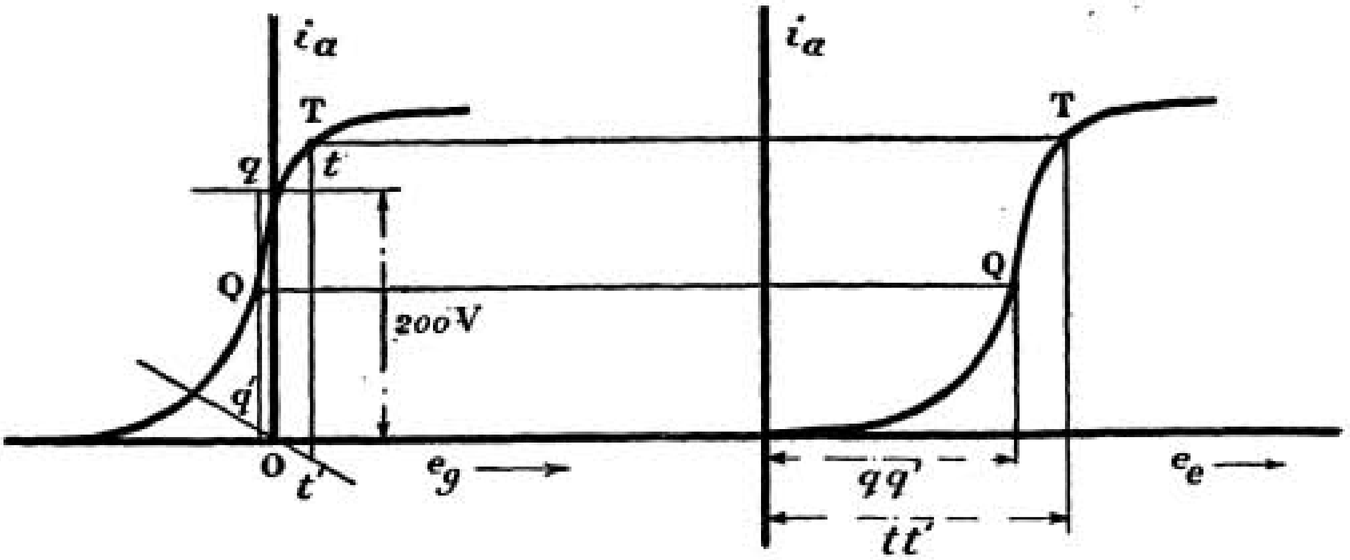

Fig. 10.

the intercepts between the voltage lines, such as qq′ and tt′, are the algebraic sum of $e_a$ and $ge_g$, and therefore give values of $e_t$. The curve sought is now obtained by co-ordinating values of current at Q, T, etc., with the new abscissæ qq′, tt′, etc.; this is carried out on the right-hand side of Fig. 10.

When this process is applied to all the curves of the family in Fig. 11 the result is the nearly perfect single curve of Fig. 12. In this one curve is contained all the information given by the original family of curves. It may be called the lumped characteristic curve of the triode for the particular filament current in use. It is found that the nearly straight portions of the $i_a e_g$ curves of most forms of triode coincide perfectly in the lumped characteristic, but the knees fit together less closely. Also, below a certain

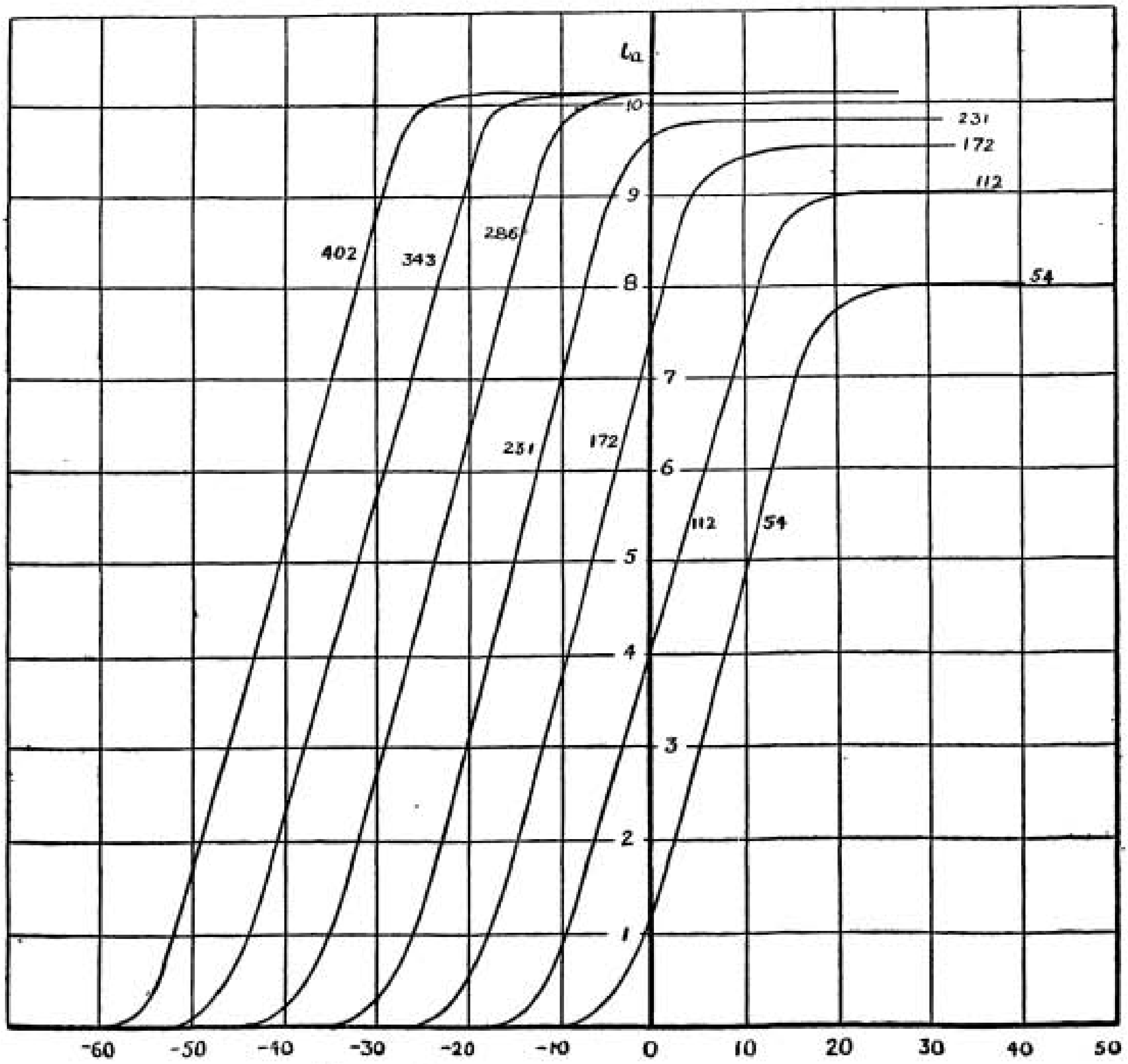

Fig. 11.

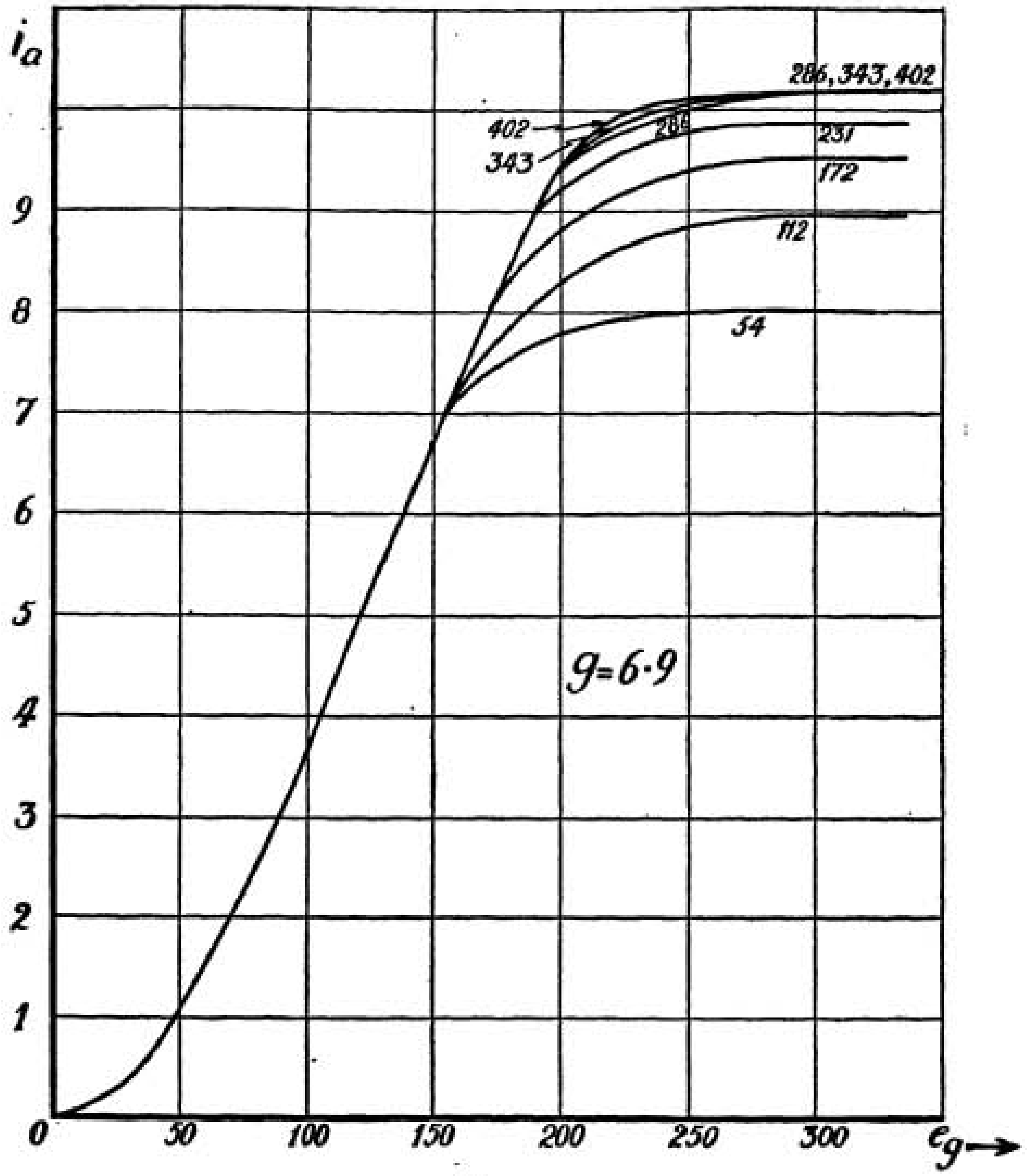

FIG. 12.

anode voltage the saturation currents take lower and lower values, with the result that we obtain the forked portion of Fig. 12.

A further mathematical consequence of the form of our equation is that a simple relation exists between the partial differential coefficients of $i_a$ with respect to $e_a$ and $e_g$ regarded as independent variables. From

$$i_a = F(e_l)$$

we derive

$$\frac{\partial i_a}{\partial e_a} = \frac{di_a}{de_l} \cdot \frac{\partial e_l}{\partial e_a} = \frac{di_a}{de_l}$$

since

$$e_l = e_a + ge_g.$$

Similarly
$$\frac{\partial i_a}{\partial e_g} = \frac{di_a}{de_l} \cdot \frac{\partial e_l}{\partial e_g} = \frac{di_a}{de_l} g.$$

Hence
$$\frac{\partial i_a}{\partial e_g} = g \frac{\partial i_a}{\partial e_a}.$$

We shall, for brevity, write $h_a$ for the partial differential coefficient with respect to $e_a$, and $h_g$ for that with respect to $e_g$. In this notation the letter $h$ is meant to suggest "increase of anode current," and the suffix $a$ to suggest "per unit increase of anode voltage," and a similar interpretation is given to $h_g$. In passing, we may remark that this notation is in systematic accord with the use of $g_a$ and $g_g$ for similar partial differential coefficients of grid current with respect to the two voltages, which arise in the course of any complete discussion of the properties of triodes. The differential co-efficient $h_a$ is, plainly, the gradient at any point of the lumped characteristic curve, and $h_g$ is the gradient at any point of any of the $i_a e_g$ characteristic curves. We see that the latter gradient is $g$ times the former whenever the current is a function of $e_a + g e_g$; but this conclusion is not necessarily true when the current does not possess this property.

In the particular form presented by Langmuir's equation
$$i_a = A' e_l^{\frac{3}{2}}$$
we have
$$h_a = \frac{di_a}{de_l} = \frac{3}{2} A' e_l^{\frac{1}{2}}.$$

This indicates that $h_a$ would increase continually as $e_l$ increases if the equation were obeyed. As a fact, experimental curves prove that though $h_a$ does at first increase in accordance with the formula yet it is practically constant over a relatively large range, departing further from Langmuir's equation as saturation is approached. It may be mentioned that it is possible to find empirical formulæ to fit the whole curve with moderate success. For example, some triodes are suited by the formula
$$i_a = i_1 \left[1 + \tanh \{ h_a (e - e_1)/i_1 \} \right],$$
where $e_1$ and $i_1$ refer to the lumped voltage and the current at the mid-point of the curve; but though such empirical equations may be useful for the purposes of design, they have no physical meaning and explain nothing.

(*To be concluded.*)

# The Transmission of Electromagnetic Waves Around the Earth.

### By *THE EDITOR.*

OUR experimental knowledge of the variation of the strength of the received signal as the distance from the transmitting station is increased is due almost entirely to the work carried out in 1910 and 1913 by the Radio Department of the United States Navy under the direction of Dr. Louis Austin. Previous experiments had been made by Duddell and Taylor, but only over relatively short distances. The results obtained in the U.S. Navy experiments are usually expressed by the well-known Austin-Cohen formula. For relatively short distances over the sea, the received current varies inversely as the distance, as it would if the earth were a perfectly conducting plane and the atmosphere a perfect and limitless dielectric, but as the distances become greater the received current falls off more rapidly and an exponential factor has to be inserted in the formula for the received current. Austin found that although the transmission at night was usually better than that during the day, it was far more erratic and was therefore discarded in calculating the formula which best represented the observed results. Cohen found that the exponential factor that gave the closest approximation to the 1910 results was $\epsilon^{-\frac{0 \cdot 0015d}{\sqrt{\lambda}}}$ where $d$ is the distance, and $\lambda$ the wave length, both in kilometres. Although, owing to the difficulties of the measurement, to the variableness of the received signal even when the distance is unchanged, and to the limited range of distance, Austin's 1913 results when plotted leave one in some doubt as to the curve which best represents them. Cohen's exponential index gives good average results up to a distance of 2,000 miles. Turning to the mathematical investigation of long distance transmission, one finds that it is a problem of such enormous difficulty as to call for prolonged research on the part of some of the leading mathematicians. The assumptions usually made have been that the earth is a perfectly conducting sphere, and the atmosphere a perfect dielectric of boundless extent. It is important that this problem should be solved and the results compared with the experimental observations in order to determine to what extent the transmission over great distances involves conditions of the earth or of the atmosphere other than those assumed in the mathematical investigations.

The late Henri Poincaré and Professor Nicholson published solutions in 1910; Professor Macdonald in 1914 and March and Rybczynski in 1912 and 1913 respectively. In 1915 Professor Love pointed out that the work of the two last named was fundamentally unsound. Unfortunately the results obtained by Nicholson and Macdonald were not in agreement and so the matter stood in a very unsatisfactory condition until 1918 when the problem was investigated by Dr. G. N. Watson. The results of his analysis are embodied in two papers of the greatest importance communicated to the Royal Society, one in 1918, entitled "The Diffraction of Electric Waves by the Earth," and the other in June of the present year, entitled "The Transmission of Electric Waves Round the Earth." In the September number of the *Philosophical Magazine* Dr. van der Pol gives a physical interpretation of the former paper and substituting suitable numerical values in the formulæ, compares the calculated results with the results of Austin's observations. A brief account of his work was given by Dr. Watson himself in a paper before *Section A.* of the British Association at Bournemouth.

In the first paper he solves the problem of the perfectly conducting earth and limitless ideal dielectric, and obtains a result in substantial agreement with Nicholson and Macdonald. He points out the causes of the discrepancies and the limits of the validity of the various assumptions. An investigation of the effect of the earth having resistance shows that any effect is very small, even for dry earth, with long wave lengths. Watson obtains for the index of the exponential factor $-\ 0{\cdot}00376d/\sqrt[3]{\lambda}$ and, moreover, finds that instead of being inversely proportional to $d\lambda$, the received current should be inversely proportional to $\sqrt{\sin\theta}\,\lambda^{7/6}$, where $\theta$ is the angle subtended at the centre of the earth by the distance $d$. Now, as Dr. van der Pol points out, some of the received currents measured by Austin over distances of about 6,000 miles are 2,000,000 times as great as the values calculated by Watson's formula. Hence, it must be concluded that long distance radio-telegraphy cannot be explained on the assumption that the earth is surrounded by a perfect dielectric of boundless extent. A great many phenomena of radiotelegraphy suggest that the upper atmosphere is ionised and acts as a partial conductor.

In his second paper, therefore, Dr. Watson has investigated the effect of a concentric conducting layer forming the upper limit of the atmosphere. His analysis leads to the striking result that Austin's experimental and empirical formula is obtained if the ionised layer has a well-defined lower surface at a height of about 100 km. and has a specific resistance of $6{\cdot}95 \times 10^5$ ohms per centimetre cube. With this reflecting upper layer the index of the exponential term in the formula for the received current contains the square root of the wave length, in agreement with the Austin-Cohen formula, whereas the pure diffraction theory leads to the cube root of the wave length.

The two papers of Dr. Watson mark an epoch in the study of long distance radiotelegraphy and may be regarded as bringing to a most satisfactory conclusion a discussion which has exercised the minds of many of the leading mathematicians.

# The British Association Meeting at Bournemouth.

(*Continued from page* 42.)

## A Method of Using Two Triode Valves in Parallel for Generating Oscillations.

*By W. H. ECCLES, D.Sc., and F. W. JORDAN, B.Sc.*

Paper read before Section G (Engineering) of the British Association Meeting.

IN the typical method of using a three-electrode tube or "triode" for generating electrical oscillations, the connections are as shown in Fig. 1. The oscillations in the closed inductance-capacity circuit, sometimes called a flywheel circuit, are sustained by unidirectional pulses of current through the anode circuit, that is, through that external circuit of the tube which begins at a terminal of the filament and ends at the anode. This circuit includes a high voltage battery, which is the ultimate source of the energy of the oscillations. The unidirectional pulses are produced in correct time phase by the action of the oscillations themselves on the grid circuit by means of the coupling between the coil in the closed circuit and a coil in the grid circuit.

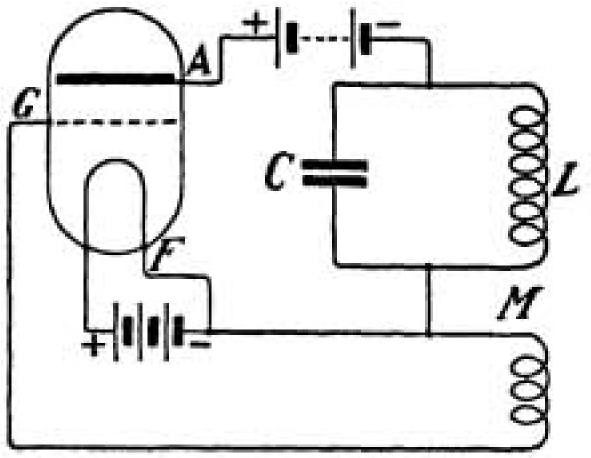

Fig. 1.

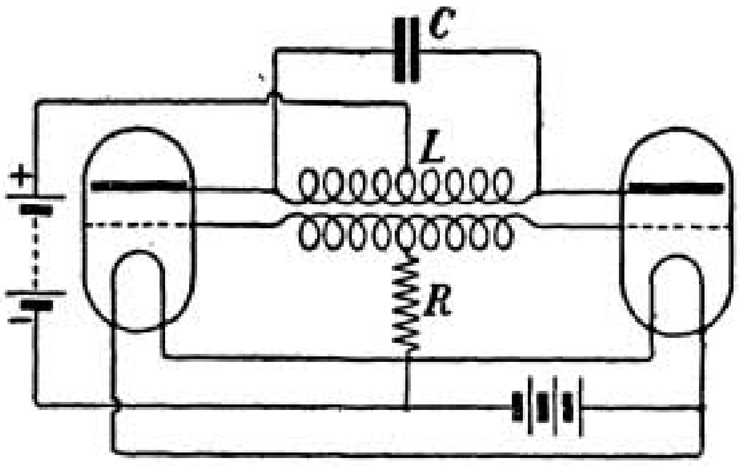

Fig. 2.

When two or more triodes are used they are in the prevailing practice connected in parallel. It is known that unless special care is taken in selecting the tubes and in adjusting their normal grid voltages this connection does not in general give an output double that of a single tube. Moreover, if the coupling is made too close, as is often the case, the variations of the grid voltage may be so great as to carry the representative point in the characteristic diagram on to the straight horizontal parts of the curves, with the consequence that harmonics are produced, accompanied by a lack of symmetry in the oscillations generated.

More symmetrical oscillations could be obtained if the flywheel circuit were acted upon by a triode and high-voltage battery symmetrically in every half-period. The improvement to be described consists in arranging two tubes so as to fulfil the last stated condition. One way of doing this is to join the grids of the two tubes by a coil which is linked by means of its mutual inductance to the oscillating circuit. This method of joining the grids is shown in Figs. 2 and 3. This mode of connection causes the potential of each grid, and, therefore, the resistance of each tube, to vary in opposite directions, that is, causes the resistance of one tube to increase, while that of the other diminishes—with a definite phase relation to the oscillations.

In Fig. 2 the anode circuits of the tubes are in parallel, and are connected in series with a high-voltage battery. They are associated with the flywheel circuit so that increase of one anode current applies to the flywheel circuit a stimulus in one direction,

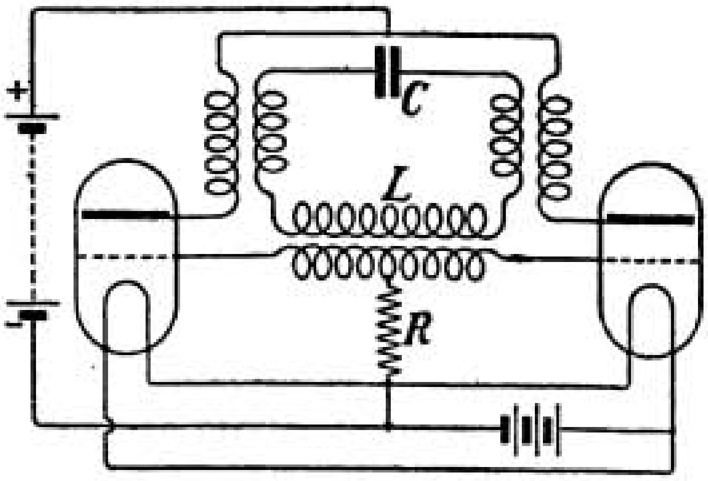

FIG. 3.

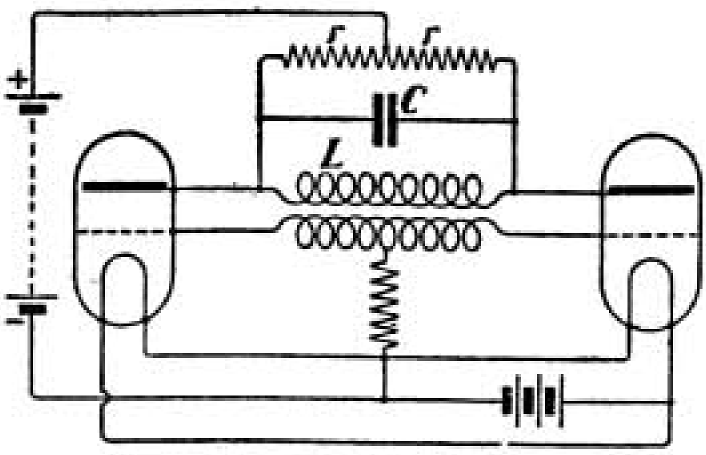

FIG. 4.

and increase of the other anode current applies a stimulus in the other direction. In the result the variations of both anode currents are effected in correct phase relation to maintain the oscillations of the flywheel circuit, an impulse being applied first by one tube and then by the other in successive half-periods.

In Fig. 2 the coupling between the two anode circuits and the oscillatory circuit is direct. Fig. 3 shows a method in which the anode current acts by mutual inductance on the oscillatory circuit. In both figures R is a large resistance which acts as a grid leak, and should be chosen so as to keep the grids at a voltage found advantageous by trial. A method in which resistance coupling is employed is indicated in Fig. 4. This has its advantages in certain laboratory applications. In Fig. 5 a method employing condenser coupling is shown. Here, again, R indicates a grid leak. The condensers $C_1$ and $C_2$ need not be of any particular capacitance; they are chosen by trial, and their variation has very little effect upon the frequency of the oscillations.

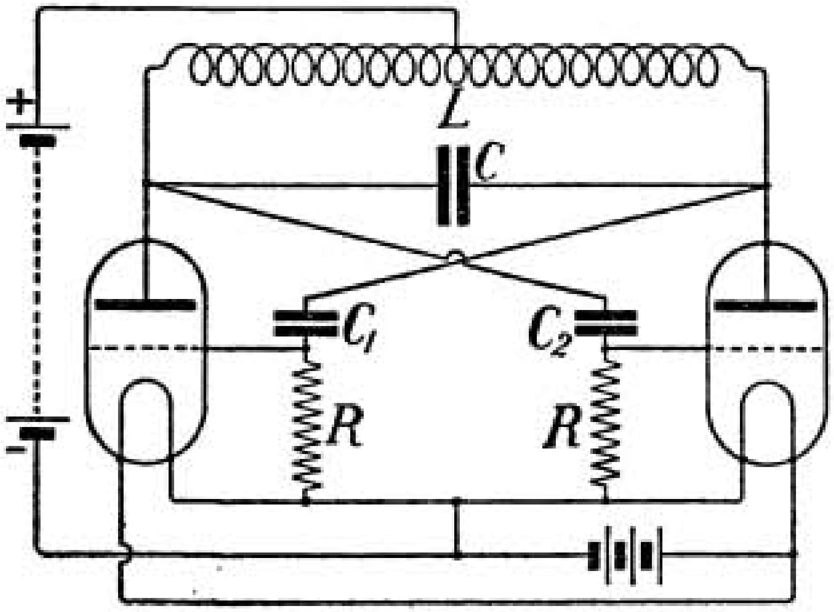

FIG. 5.

It is clear that, instead of using two triodes, the symmetrical action could be obtained by using one tube possessing, for example, a single plate, two grids and two filaments, or, alternatively, a single filament, two grids and two plates.

It is found that these cross-coupled circuits oscillate more freely than single circuits. They can be operated, for example, by using four or five volts only in the anode circuit with ordinary receiving B.T.-H. triode valves.

The devices just described were the subject of a patent, number 6,090/1918, taken out by the Admiralty, and the description is now published by permission.

# The Three-Electrode Thermionic Valve as Alternating Current Generator.*

*By Professor C. L. FORTESCUE.*

## 1. INTRODUCTORY.

THIS paper deals mainly with work done during the war in the W/T Department of H.M. Signal School, at Portsmouth, which constitutes the instructional and experimental centre for all matters pertaining to naval wireless telegraphy. The paper has been prepared in collaboration with the Superintendent of Signal Schools and his staff, has been submitted to the Admiralty, and is now published with the Board's approval.

Thermionic valves were used in the Naval Service for the generation of high-frequency currents of small amplitude for reception by the "heterodyne" or beat method in 1914. De Forest's "Audion" valves were used, and the circuits were made up from existing Naval Service apparatus. Later sets used for the same purpose were made by the Marconi Company, the valves employed being those designed by Captain H. J. Round. In both cases the maximum high-frequency current was in the neighbourhood of 50 milliamperes.

During the spring of 1915 experiments were carried out with a transmitting valve of Captain Round's design. This valve was of the same general construction as those used with the small heterodyne sets. The filament consisted of a fine platinum wire coated with lime; the grid was made of nickel wire gauze, and a nickel positive electrode was supported by its natural springiness against the glass walls of the tube. The vacuum was not high, and no appreciable bombardment of the electrodes was carried out during the exhausting process, this being impossible owing to the large positive electrode being in contact with the glass walls of the tube. With this tube a high-frequency power of from 40 to 50 watts could be obtained. Experiments under actual signalling conditions were carried out, and some

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* **Paper read before Section G, of the British Association, slightly abbreviated.**

surprisingly long ranges were obtained. On one occasion one of H.M. destroyers received comfortably readable signals when off the coast of Northumberland, and when the high-frequency current in the aerial in H.M.S. *Vernon* at Portsmouth was only 0·6 amperes.

Considerable difficulties were, however, experienced on account of the lack of proper heat treatment of the valve in the course of the exhaustion, and the valves were not regarded as being sufficiently reliable to enable them to be used in ship installations.

At about this time the French, too, were experimenting with valve transmission, with a view to the development of wireless telephony.

Towards the end of 1915 some transmitting valves of the "Oscillion" type were obtained from America by the Admiralty. These valves were exhausted to a higher degree than the Marconi valves, and gave correspondingly better results. But the uncertainty of the supply, and the still far from perfect results obtained, made it evident that the requirements of a naval W/T set using transmitting valves could not yet be met.

In the spring of 1916 a "Pliotron" valve, made by the American General Electric Company, was purchased by the Admiralty for experimental work. This valve, which was similar in construction to those described in the *General Electric Review* of May, 1915, and September, 1916, had been very thoroughly exhausted. It was normally worked with the tungsten positive electrode at a bright red or even yellow heat, and but for one small defect was probably the equal of any valve made up to the end of 1918. High frequency currents of from 8 to 10 amperes were obtained in an aerial of about 5 ohms resistance, and with only about 2,000 volts available for the supply to the positive electrode. Had a higher voltage supply been available there is little doubt but that the high-frequency power generated could have been doubled. On the only trial carried out for maximum range under signalling conditions communication was established between H.M.S. *Vernon* at Portsmouth and H.M. W/T station at Gibraltar. This was in June, 1916, and at the time was second in range obtained with an oscillating valve only to the famous wireless telephone trial between Arlington, U.S.A., and the Eiffel Tower.

It was recognised that, although the "Pliotron" valves as then developed could not be manufactured on a scale sufficiently large to meet naval requirements, the elements of successful development were present, and exhaustive trials and experiments were continued by the Experimental W/T Staff of H.M.S. *Vernon*. The results of these experiments, together with the information already published in the technical and scientific journals (principally American), enabled a fairly complete theory of the action of both the circuits and the transmitting valves to be worked out. This theory has formed the basis of all the subsequent designs.

Early in 1917 the first attempts were made to manufacture transmitting valves in this country to meet naval requirements. These attempts were undertaken by the General Electric Company at their lamp works at Hammersmith, in collaboration with the Naval Experimental W/T Staff.

Previous to this, although the advantages of valve transmission were fully realised, there had been no demand for additional lines of communication, the requirements of which could not be met by the existing arc or spark installations; nor was there any demand for the replacement of the latter by valve transmitters. Consequently, although the necessary conditions were investigated as fully as possible, no earlier steps were taken to start British firms on the manufacture of the larger valves, their staffs being already fully engaged on war work.

By a fortunate coincidence, however, the construction of these valves just preceded an urgent demand from the Grand Fleet for a valve transmitting set. The designs were worked out, and eight sets were put in hand in the W/T workshops in H.M.S. *Vernon*. The first two of the sets were despatched to the Grand Fleet on the night of Good Friday, 1917, within six weeks of the demand for the sets arising. Some two months elapsed, during which lengthy trials were carried out. On the strength of these trials it was decided to fit similar sets in a considerable number of ships. Contracts were placed with various instrument-making firms, and within one month the first of these sets was on its way north, not complete in every detail certainly, but sufficiently complete for satisfactory service.

Meanwhile numerous experiments were conducted by the W/T staff of the Admiral Commanding Reserves with Marconi valves installed in W/T stations located round the coasts of the British Isles. These experiments gave useful information, and showed that results could be obtained even with valves that were only partially exhausted. In particular they demonstrated the advantage of working with high voltages for the supply to the positive electrode.

The success of the first valve transmitting sets in the Grand Fleet led quickly to a demand for other sets of greater power. In the autumn of 1917 a larger set was designed to work from the power supply of existing spark apparatus. The trials of this set were carried out during the winter of 1917—1918, the details of the design being finished early in 1918. The apparatus was being fitted in ships as it became available throughout the whole of the summer of last year. To a great measure the success of this set was due to the type of aerial tuning inductance employed. This coil was designed by the W/T staff at Portsmouth primarily for use with Poulsen arc sets. The work previously carried out by this staff in connection with the design of inductances may be said, in fact, to have contributed more to the success of the valve sets than any other single item, except perhaps the design of the valves themselves.

Whilst the parts of this more powerful set were being manufactured yet higher power sets were being experimented with for use on board ship and in the Admiralty shore stations. Outputs and ranges almost equal to those of the smaller Poulsen arcs were obtained, and the many advantages of the valve transmitter pointed to the certainty of it replacing the arc in the near future for all purposes except in the very highest-powered land stations.

Valve transmitting sets also had their application in the other services—the Army and the Air Force. The direction and the nature of these applications have already been described by Colonel Cusins, R.E., and by Major

Erskine-Murray before the Wireless Section of the Institution of Electrical Engineers.

A similar development was of course also taking place in France and in America. Valves of very considerable power were being experimented with in France in 1917 under the direction of General Ferrié. In America the development was more in the direction of quantity production of relatively small power tubes for short range telegraphy and telephony work.

Wireless telegraphy and telephony do not constitute the only spheres of utility of the three-electrode valve as an alternating current generator. For laboratory and testing purposes it is rapidly taking the place of all other sources of alternating current where frequencies above about 200 cycles per second are required.

The successful application of the valve transmitters to naval wireless was largely due to the valuable assistance of the following permanent and temporary members of the Naval Experimental W/T Staff, viz., Messrs. W. A. Appleton, B. S. Gossling, H. A. Madge, H. Morris-Airey, and C. M. Sleeman; of Captain J. A. Slee, C.B.E., R.N., formerly on the staff of the Admiral Commanding Coastguard and Reserves; of Captain H. J. Round, M.C., formerly attached to Army Signals, and of Dr. G. B. Bryan, the Assistant Professor of Physics, R.N. College, Greenwich.

## 2. THE ACTION OF THE THREE-ELECTRODE VALVE AS AN ALTERNATING CURRENT GENERATOR.

The conditions necessary for a three-electrode valve to act as a generator of alternating currents have been investigated by others besides the workers at H.M. Signal School, Portsmouth, notably, Hazeltine * in the *Proceedings of the Institute of Radio Engineers*, has given a very complete investigation of the requirements. Vallauri † has also worked out the critical condition for a few particular cases. Recently Eccles has shown, before the Physical Society of London, a method of investigating the problem by a graphical method.

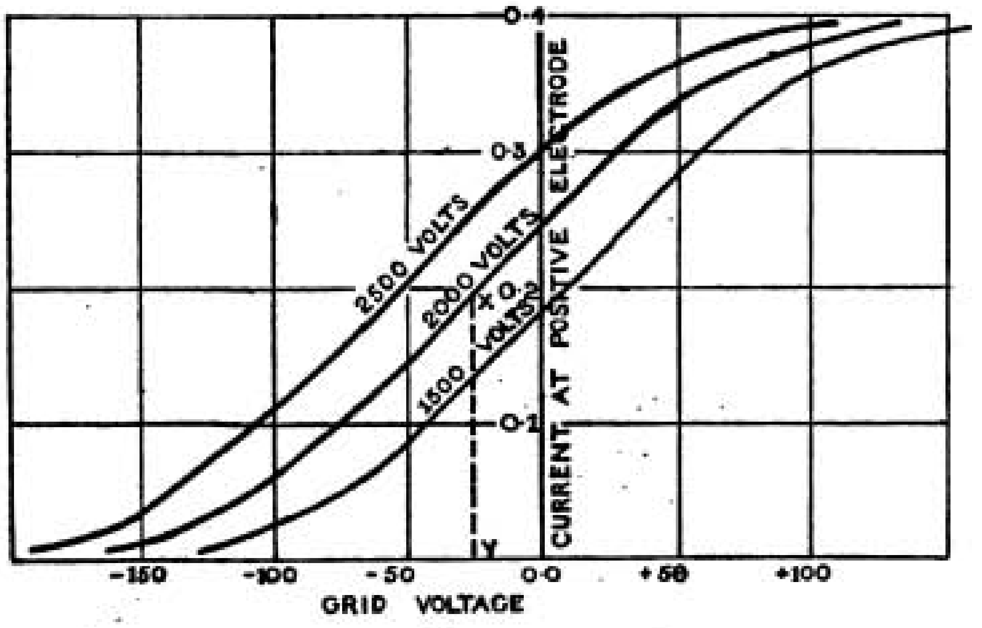

FIG. 2.

The principles of the action of the three-electrode valve itself have already been described on many occasions. For the purpose of generating alternating currents a highly exhausted valve is generally used. Fig. 1 shows the construction of such a valve.

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* *Proc. Inst. Radio Engineers*, April, 1918.

† *L'Elettrotecnica*, January 25th and February 5th, 1917.

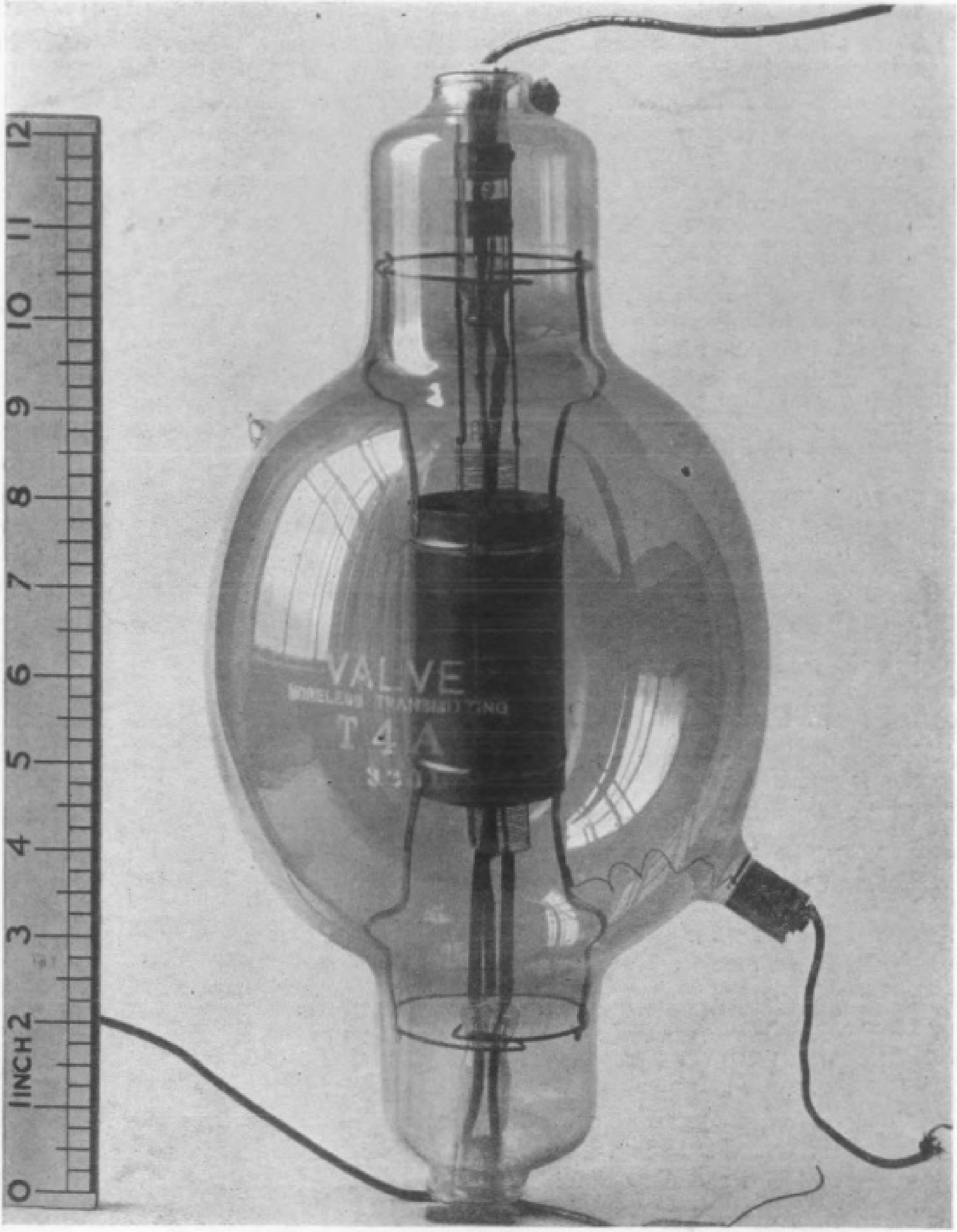

FIG. 1.

Characteristic curves showing the control exercised by the grid electrode in a valve of this type are shown in Fig. 2. From these curves it is observed that, with the grid 100 volts or more negative to the filament, it is only with high voltage on the positive electrode that the current at this electrode is appreciable. As the grid becomes more positive, the current at the positive electrode gradually increases to a more or less clearly defined maximum value. After this maximum has been reached any further increase of the positive voltage of the grid will lead to a decrease of the current at the positive electrode, because of the diversion of an appreciable portion of the electron stream to the grid itself.

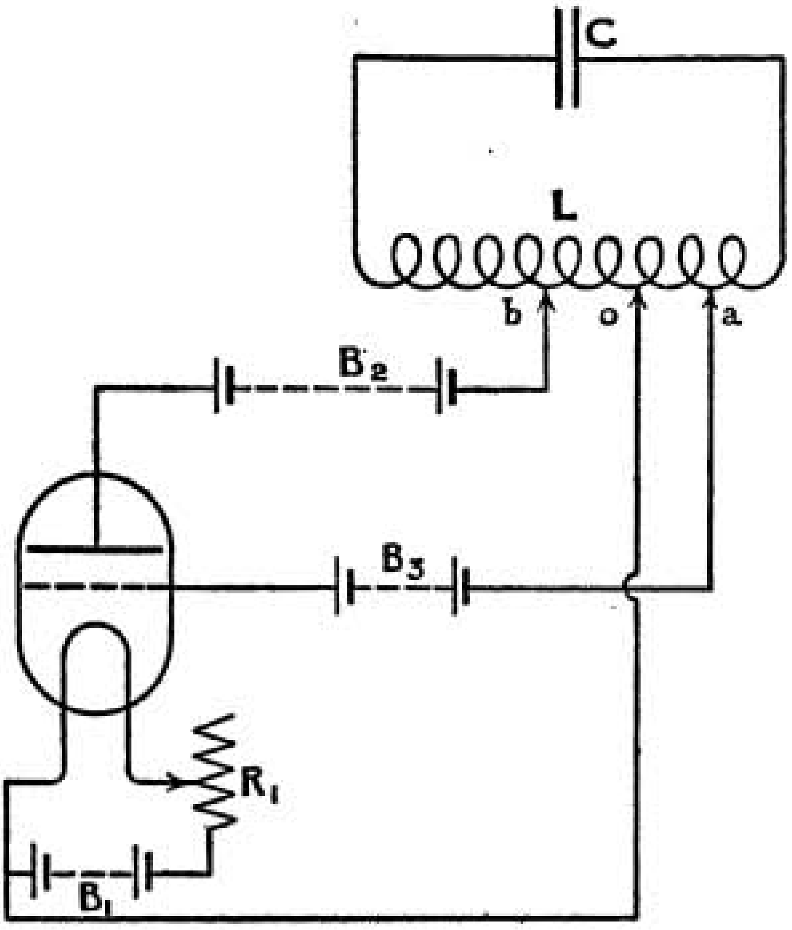

FIG. 3.

There are many ways of connecting up a three-electrode valve of this kind to an inductance-capacity circuit so as to maintain oscillations. One of the simplest is that shown in Fig. 3. Here *C* is the condenser and *L* is the inductance. The filament of the valve is heated by a battery $B_1$, the heating current being controlled by the resistance $R_1$. The filament is directly connected to a point *O* on the inductance. The positive electrode is connected to a point *b* on the inductance through a battery or other source $B_2$. The grid is connected to a point *a* on the inductance, on the opposite side of the point *O* to that of the point *b*, with a battery $B_3$ in series.

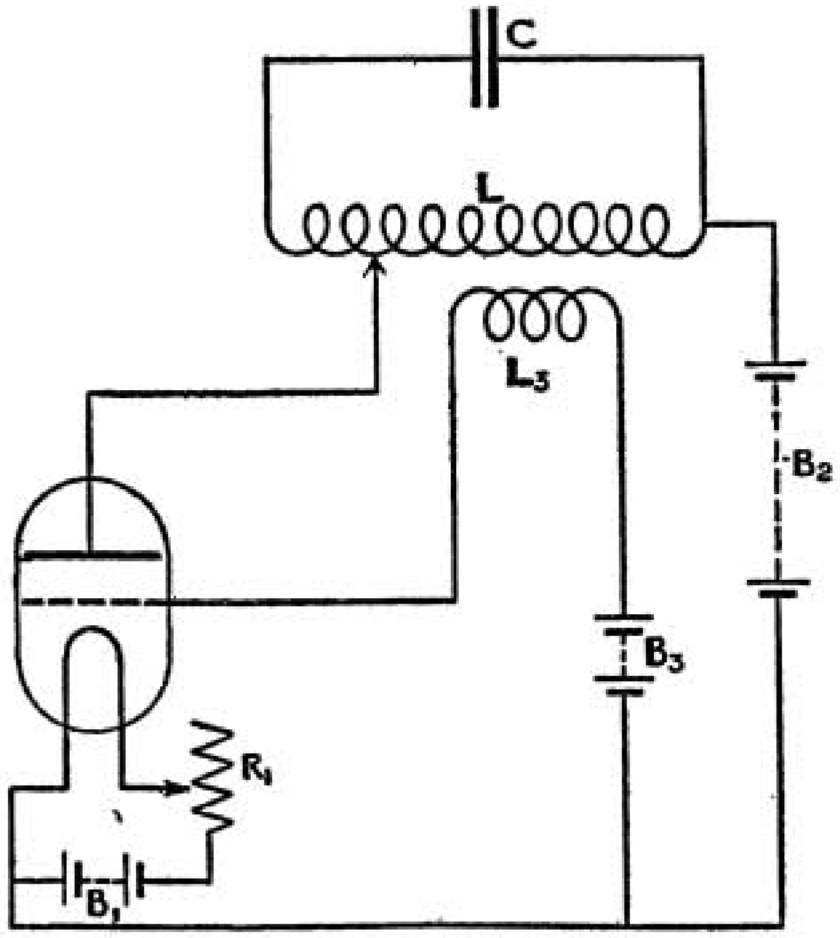

FIG. 4.

The filament current and the voltages of the batteries $B_2$ and $B_3$ are adjusted so that the steady conditions correspond to a point *X* on the curves of Fig. 2.

Assuming that there is no time lag in the adjustment of the electronic stream to the changes of grid voltage, as should be the case theoretically for all frequencies up to ten million or more per second, then this arrangement of a valve with a capacity-inductance circuit becomes an alternator of frequency depending upon the natural frequency with which the current in the circuit $LC$ will oscillate. By adjusting the capacity and the inductance to suitable values this frequency can have any desired value from at least ten million cycles per second downwards to frequencies of 250 cycles per second, or even less, if somewhat bulky apparatus is not objected to.

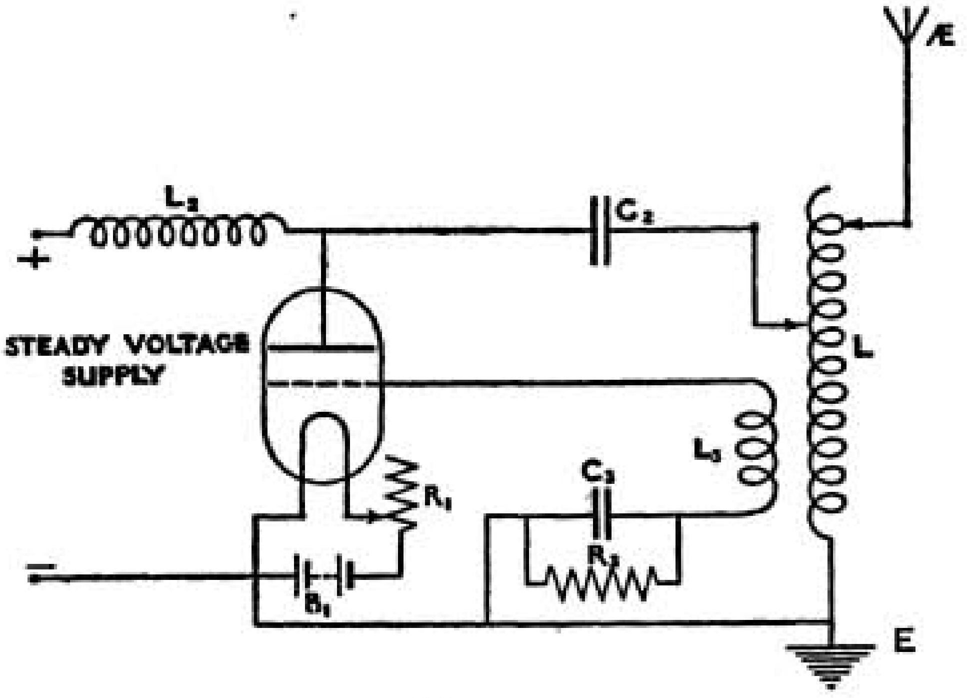

Fig. 5.

The circuit arrangement of Fig. 3 is but one of many possible ones. For instance, Fig. 4 shows a very commonly used circuit. Here the grid is influenced by the induced E.M.F. in the coil $L_3$ instead of by the induced E.M.F. in a part of the main coil $L$, as in Fig. 3. Fig. 5 shows a very convenient circuit arrangement for a valve transmitter for wireless telegraphy. This arrangement is in principle the same as Fig. 4. The addition of the condensers $C_2$ and $C_3$, and of the inductance $L_2$, are for reasons of practical convenience rather than difference of principle.

(*To be concluded.*)

# A New German Association for Applied Physics.

At a meeting held in Berlin on June 6th it was decided to found a new Association for Applied Physics. It is proposed to (1) hold meetings at which papers will be read; (2) issue a periodical with abstracts and original papers; (3) issue an index similar to the *Chemical Zentralblatt;* (4) hold an Annual Convention in different towns; (5) consider educational matters and the foundation of scholarships. The first council includes, among others, Profs. Warburg, Kurlbaum, Gerdien, and Wagner. —*Jahrbuch der Drahtlosen Telegraphie, August,* 1919.

# Review of Radio Literature

## 1. Abstracts of Articles.

NOTE.—*It is intended to devote the space in this section of the* RADIO REVIEW *to as complete a review as possible of the published literature of radiotelegraphy and telephony, and kindred matters. The more important of these papers and articles will be given in abstract, while, for the remainder, references will be given, accompanied by one or two lines to indicate the contents of the article. In this way it is hoped to obtain a complete monthly record of the progress of the science, and of the latest developments and inventions relating thereto, that should be of considerable value to all research workers and students of the subject.*

### 19. ON MEASUREMENT OF SIGNAL STRENGTH. W. H. Eccles. (*Proceedings Inst. Radio Engineers*, 7, p. 267, June, 1919.)

Considerable use has been made of the "shunted-telephone" method of measurement of received signal strength, but confusion has sometimes arisen between the audibilities $A = \frac{R+S}{S}$ and $A' = \frac{Z+S}{S}$, calculated from the results obtained. ($R$ and $Z$ = telephone resistance and impedance respectively, corresponding to note frequency in use, and $S$ shunt resistance.)

The author develops the vector diagrams for the circuit, and deduces curves showing the relation between $A$ or $A'$ and the current "strength-ratio," $a = \frac{\text{Detector Current}}{\text{Telephone Current}}$. From a consideration of the conditions obtaining when the method is used for the comparison of signal strengths of the same note frequencies, it is shown that the quantity $a \cos \phi$ is proportional to the square of the aerial current, provided that the efficiency of the detector remains constant. From the vector diagrams it is then seen that this quantity

$$a \cos \phi = \frac{a^2 (S^2 + Z^2) - S^2}{2aZS}.$$

For small values of $S$ (loud signals) this reduces approximately to $a \cos \phi = \frac{aZ}{2S}$, and for faint signals to $a \cos \phi = \frac{(a^2-1) S}{2aZ}$. It appears from experimental curves given by Van der Pol that, taking the power ratio, $a \cos \phi$, as the measure of the signal strength, the detector appears not to be losing its efficiency with weak signals as rapidly as has usually been supposed.

An alternative method of measuring the signal strength is also described, in which a local buzzer of adjustable pitch is employed to provide a comparison signal of known and adjustable intensity. The method is also applicable to C.W. reception. L. W. AUSTIN, in the discussion on the paper, supplies additional information relative to the use of the telephone resistance or impedance in the calculation of the audibility factors.

### 20. A NEW METHOD OF USING CONTACT DETECTORS IN RADIO MEASUREMENTS. L. W. Austin. (*Proceedings of the Institute of Radio Engineers*, Vol. VII., p. 257, June, 1919.)

An arrangement of crystal detector for radio-frequency measurements is described. The crystal detector, in series with a galvanometer, is shunted by a non-inductive resistance. This complete unit may be calibrated against a small low-reading hot-wire instrument by reducing the value of the non-inductive shunt. The complete shunted detector can then be used for other shunt values by dividing the sensibility by the shunt ratio. A table of sensibility and maximum working current is given for various shunt resistances.

### 21. MEASURING THE CAPACITY OF VACUUM TUBES. (*Everyday Engineering Magazine*, 7, p. 299, August, 1919.)

A simple method is described in which the grid-filament capacity is measured, under working conditions of the tube, by determining the wave length of a closed circuit with and without the valve in parallel with the tuning condenser.

### 22. COUPLING FOR RADIO CIRCUITS. E. Bellini. (*British Patent* 126978, February, 1916.) *

The coupling of two oscillatory circuits is dealt with, and the advantages are pointed out of a combined magnetic and electric coupling in order to secure oscillations of a single frequency.

### 23. COUPLING FOR WIRELESS TELEGRAPH APPARATUS. J. Bethenod. (*British Patent* 128575, March, 1918.)

This patent relates to a special means of coupling a high frequency alternator to a transmitting aerial. The alternator is provided with a number of separate windings which are coupled to the aerial circuit by separate transformers. These transformers may have iron cores in certain cases.

### 24. APPLICATIONS OF THE VALVE. (*La Nature*, 47, pp. 117—126, August, 1919.)

The latest developments of valve apparatus are considered in three classes: Complete stations; Amplifiers; and apparatus for special research or investigation. In the first, and second, descriptions of some French Army C.W. sets are given, while the third deals with laboratory apparatus.

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*** See footnote, p. 49.**

*French Army Radio Sets.*—The most generally used set since 1917 (type C.A.) has a three-valve transmitter and a crystal or valve receiver. One valve of the transmitter acts as a hetorodyne when receiving. Twelve watts are used for filament heating and about 20 watts (at 350 volts) for the plate circuits. Using an umbrella aerial 27 metres high a range of 250 km. has been obtained. Total weight of set with cells = 160 kg. Weight of set alone 50 kg.

The most recent combined transmitting and receiving sets have six valves, three used for transmission and three for reception; while among receiving sets three valves are generally used, one detecting and two low frequency amplifying; or with four valves, one for H.F. amplification, one detecting, and two low frequency amplifiers. For a 1 kw. radiotelephone set, six large valves are used, with a H.T. voltage of 1,000 and a filament voltage of eight. The microphonic control is effected on the grids of the transmitting valves, through a two-valve low frequency amplifier. For speech communication with aeroplanes a range of 120 km. has been obtained with this set and a telegraphic range of 1,000 km.

Under the heading of amplifiers descriptions are given of high and low frequency amplifiers using four, six or eight valves with inductive or resistance capacity couplings.

*Wavemeter standardisation.*—In connection with the standardisation of wavemeters, the arrangement devised by H. Abraham is described (see Radio Review, Abstract No. 1). Two valves $V_1$ $V_2$ are used, fed from common filament and plate circuit batteries as indicated in Fig. 1. The coupling between the valves is provided by the two variable condensers $C_1$ $C_2$. By adjusting these condensers the fundamental frequency of the oscillations can be controlled. Harmonics up to the 150th can be obtained, enabling absolute frequency determinations to be made up to a frequency of 150,000 ($\lambda = 2,000$ metres) by direct comparison with a tuning fork of frequency 1,000.

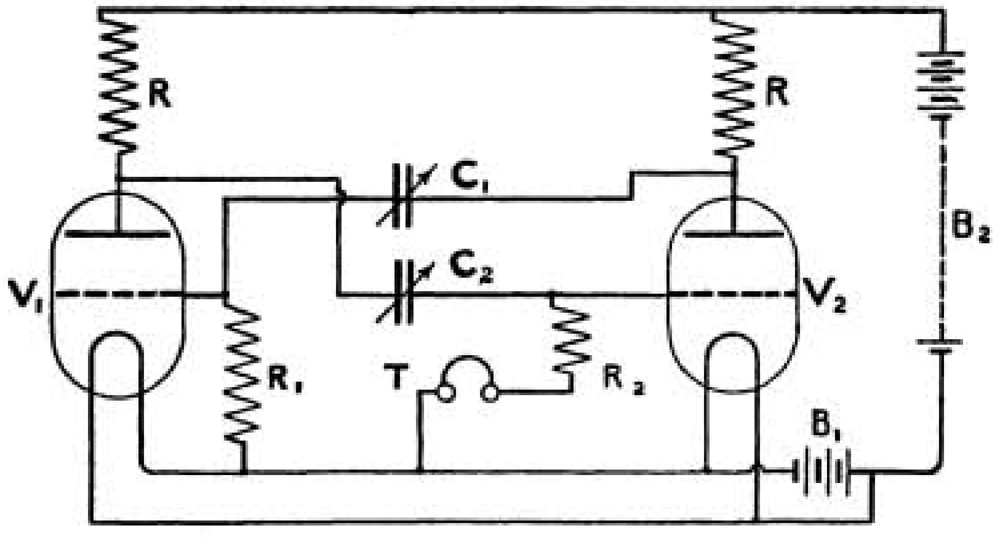

Fig. 1.

*Interference prevention.*—An arrangement for this purpose attributed to Lieutenant Levy, consists of a double application of the heterodyne principle. The incoming oscillations from the receiving aerial are first heterodyned to a frequency of 10,000, and this resultant frequency again heterodyned to a musical frequency of about 700. The effect of atmospherics can by this means be greatly reduced.

25. Apparatus for the Radio Laboratory. M. B. Sleeper. (*Everyday Engineering Magazine*, 7, pp. 357—359, September, 1919.)

Constructional details are given for a laboratory wavemeter with views of the complete instrument, and calibration curves.

26. Air Fans for Driving Electric Generators of Aeroplanes. G. F. Gray, J. W. Reed, and P. N. Elderkin. (*Journal of the Franklin Institute*, 188, p. 270, August, 1919.)

The authors describe the method employed by the radio development section of the United States War Department in testing air fans for driving the electric generators used for radio communication on aeroplanes. The various types of fans are discussed at some length and also the difficulties met with in designing a fan to run at constant speed with widely varying aeroplane speeds.

27. Research Work of the General Electric Company in the Great World War. J. R. Hewett. (*General Electric Review*, 22, p. 601, August, 1919.)

This article describes in detail the work of the General Electric Company, U.S.A., and includes references to and photographs of high-frequency machines and other radio apparatus of recent design. The 200 kw. 25,000 cycle high-frequency alternator of the Alexanderson type installed at the New Brunswick (N.J.) radio station, is described and illustrated. The various continuous wave valve transmitting sets used with the United States Army in France are also described. An interesting oscillogram is given of the control current of the Alexanderson magnetic amplifier microphone and the resultant current in the New Brunswick aerial taken during a conversation between the U.S. Naval Secretary and President Wilson over a range of 500 miles. This article includes photographs of some of the latest types of American " pliotrons," but very little detail of the internal structure can be distinguished.

28. Special Type of Quenched Spark Radio Transmitter. D. G. McCaa. (*Proceedings of the Institute of Radio Engineers*, 7, pp. 409—415, August, 1919.)

A quenched spark transmitter is arranged with a double aerial system, so that the capacity in the highly-damped primary circuit is that between one of the aerials and earth. Experiments are described and oscillograms given showing the spark frequency and radiation characteristics.

29. Discharge-Gap Apparatus. Société Française Radio-Electrique. (*British Patent* 126030, December, 1915.) *

This particular apparatus for the production of electric oscillations consists

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* See footnote on p. 49.

of an evacuated vessel containing a heated filament for cathode, and an anode of mercury or amalgam, capable of emitting vapour.

### 30. IMPROVEMENTS IN WIRELESS SIGNALLING SYSTEMS. The General Electric Company (U.S.A.). (*British Patent* 128682, January, 1918. Patent accepted July 3rd, 1919.)

In wireless signalling systems using continuous waves, amplitude pulsations of the oscillations in the aerial are produced by a series of alternating currents of different frequencies of a lower order than the wave frequency. In the arrangement described in this specification the aerial is excited by a high frequency alternator which is controlled by a magnetic "microphone," or magnetic amplifier. This magnetic amplifier is provided with direct current excitation and in addition with currents drawn from any one of a number of alternators of different frequencies driven from the same shaft as the main high frequency alternator. Multiplex telegraphy may be accomplished in this manner by simultaneous sending with three or more different note frequencies. At the receiving station separate circuits are employed tuned to the different note frequencies in order to obtain the requisite selectivity.

### 31. THE VALVE AS OSCILLATION GENERATOR. (*Popular Science Monthly*, 95, p. 142, October, 1919; *New York World*, July 8th, 1919; *Wireless World*, 7, pp. 456—457, November, 1919.)

An important judgment was given in the U.S. District Court, New York, in July, to the effect that Claim 1 of the U.S. Patent No. 803684, held by Dr. J. A. Fleming, and describing his well-known valve, is to be held as covering its use not only as a radio detector, but also as an oscillation generator.

### 32. A TRANSMITTER DESIGNED TO RADIATE WAVES OF LOW DECREMENT. C. L. G. Fortescue. (*Wireless Age*, 6, p. 22, August, 1919.)

The use of a special tuned circuit upon the step-up transformer of a spark transmitter is claimed to enable waves of lower decrement to be radiated.

### 33. RADIOTELEPHONE DEVELOPMENT IN THE ARMY. N. H. Slaughter, G. F. Gray and J. W. Stokes (Signal Corps, U.S.A.). (*Electrical World*, 74, pp. 340—343, August, 1919.)

A general description of the apparatus developed by the Signal Corps for radiotelephone communication with aircraft. The development of the sound proof helmet for receiving, and microphone transmitters unresponsive to engine noises, are dealt with, and details are given of constant voltage wind-driven generators with vacuum tube regulation.

34. **WIRELESS TELEPHONY.** (*Post Office Electrical Engineers' Journal*, 12, p. 101, July, 1919.)

This article deals with demonstrations of wireless telephone apparatus by the Marconi Company. Besides other information as to the working of the sets, it contains the wiring diagrams of the transmitter and receiver, which have not previously been published. The transmitting valve is excited from an alternating current supply through a rectifying valve (Fig. 2), while the receiver comprises three radio frequency amplifying valves and one detecting valve (Fig. 3).

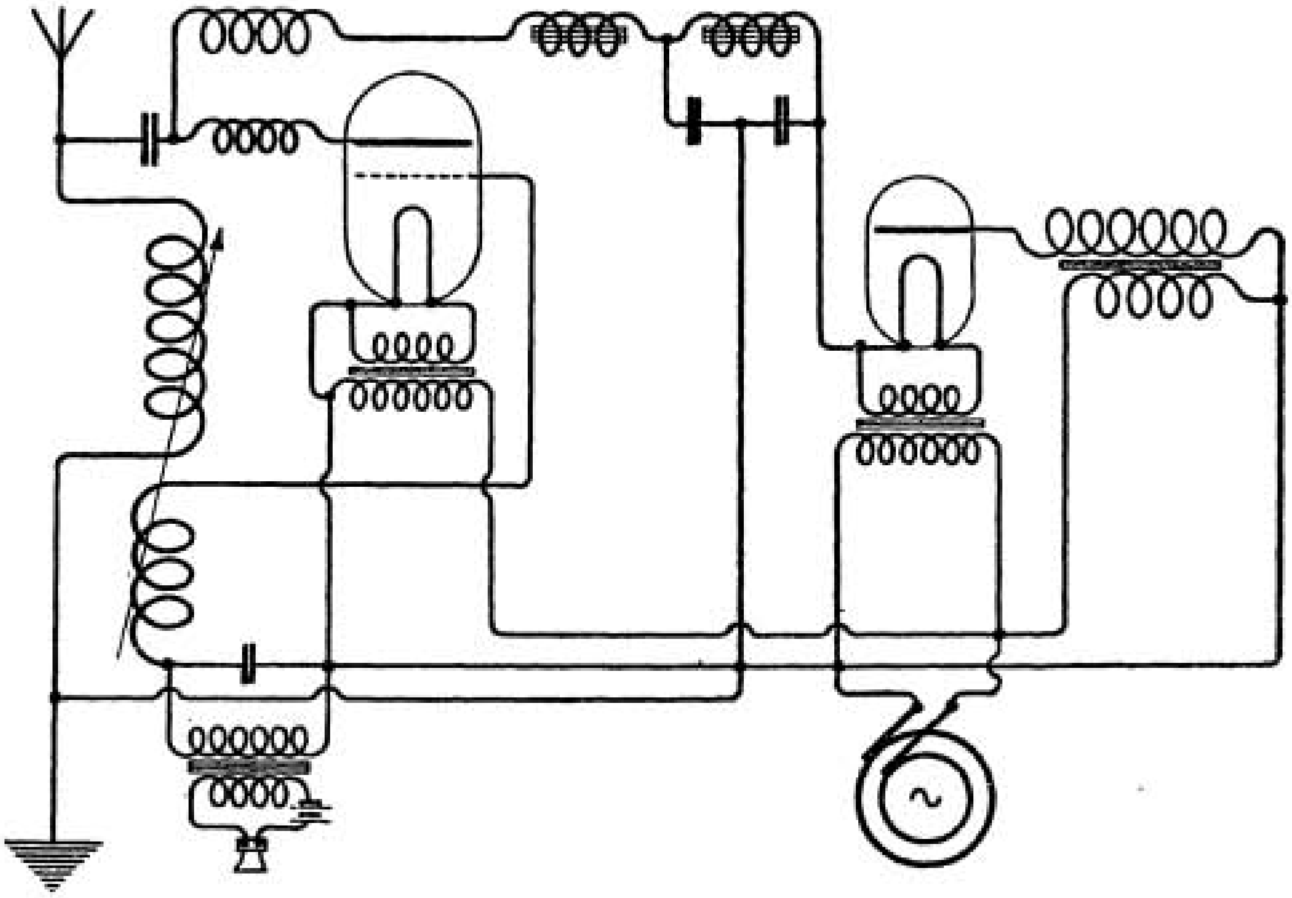

FIG. 2.

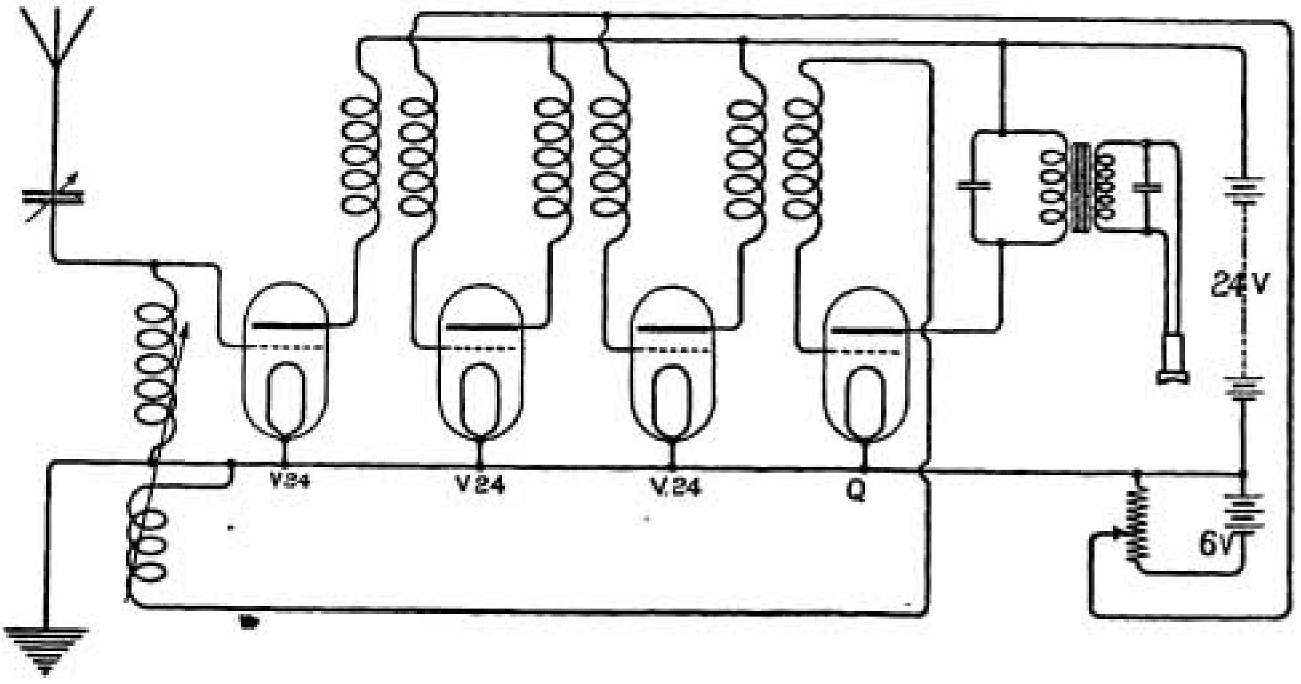

FIG. 3.

### 35. Modulating Apparatus for High Frequency Electric Signals. The Western Electric Company (U.S.A.). (*British Patent* 130219, October, 1918. Patent accepted July 31st, 1919.)

An arrangement is described for the modulation of a radio transmitter (such as for speech transmission, etc.) in such a manner that radiation takes place only when the modulating current is acting and not continuously. One such arrangement is shown in Fig. 4. *G* is the source of H.F. oscillations of the "carrier" frequency. This is coupled through $T_1$ to the common grid circuits of modulating valves $V_1$, $V_2$. The plate circuits of these valves are coupled through $T_3$ to the output circuit. The two primaries of $T_3$ produce opposing effects on the output circuit so that normally no radiation takes place. When modulating current is supplied through $T_2$ the potentials of the grids of $V_1$ and $V_2$ are varied in opposite sense, so that the oscillatory currents through the primaries of $T_3$ no longer balance, and radiation takes place.

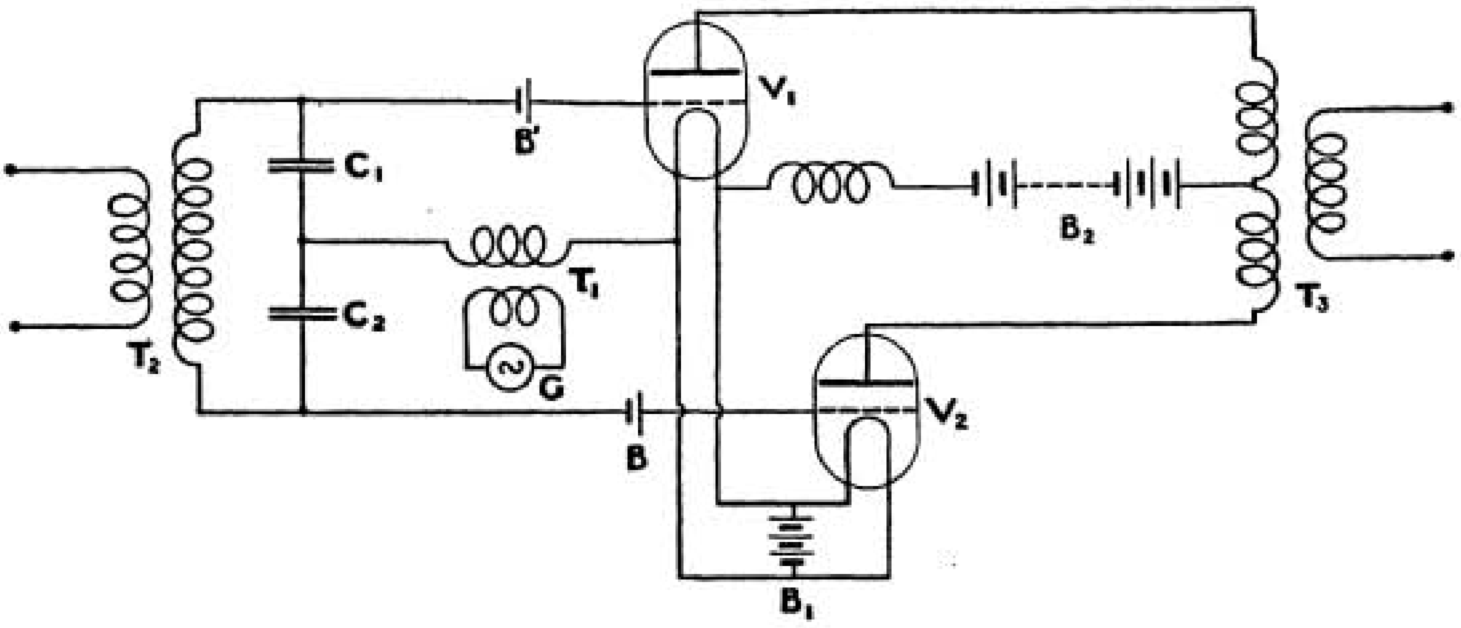

Fig. 4.

In an alternative arrangement the two valves may be replaced by a differential microphone controlled electromagnetically by the modulating current.

### 36. Improvements in Vacuum Tubes. G. A. Bauvais. (*British Patent* 130039, August, 1917. Patent accepted July 31st, 1919.)

During the exhaustion of a valve the spiral grid is heated by passing current through it, and the plate is heated by electronic bombardment, using the grid as cathode. In the use of the tube current may also be passed through the grid wire so that the potential difference between any point on the grid and the adjacent part of the cathode is the same at all points along the grid.

### 37. IMPROVEMENTS IN VACUUM TUBES. G. A. Bauvais. (*British Patent* 130040, August, 1917. Patent accepted July 31st, 1919.)

This patent describes the use of screens round the supports for the anode and grid in order to prevent deposition of a conducting film on the leading-in seals. Cooling of the electrodes in a high voltage valve may be promoted by making the surfaces large and by covering them with a material of high emissivity.

### 38. VACUUM TUBES. H. Pilon. (*British Patent* 125945, April, 1918.)

This patent deals with constructional details of vacuum valves, the special feature claimed being the shaping of the anode, so that the filament is in equilibrium under the resultant electrostatic forces.

### 39. IMPROVEMENTS IN VALVES FOR WIRELESS TRANSMISSION SYSTEMS. C. Hiatt, W. J. Davis, and Edison Swan Electric Company. (*British Patent* 129051, April, 1918. Patent accepted July 10th, 1919.)

The construction of anodes for valves is described. In the particular form dealt with the anode plate has an extension integral with it which may either be embedded directly in the glass stem of the bulb, or pressed round a post similarly mounted. The object of the invention is to obtain an arrangement such that the supports for the anode become heated by conduction from the anode plate during the exhaustion of the tube, thus increasing the facility with which the occluded gases may be removed.

### 40. ARTOM'S VISUAL RECEIVER FOR DIRECTIVE WIRELESS TELEGRAPHY. (*Wireless Age*, 6, p. 21, August, 1919.)

An arrangement is described for automatically indicating the direction of the received waves on the scale of the instrument. A special form of moving coil galvanometer is employed, energised from the rectified current derived from the two directional aerials, so arranged that its pointer indicates the required wave direction on the galvanometer scale.

Special constructions of vacuum valves are also described, to facilitate the use of valve detectors for this purpose.

### 41. THE POSSIBILITIES OF CONCEALED RECEIVING SYSTEMS. A. H. Taylor. (*Proceedings of the Institute of Radio Engineers*, 7, p. 261, June, 1919.)

Experiments on various forms of frame aerials are described, and particularly the directive results obtainable with two frames at right angles. Less interference from atmospherics was generally found with this arrangement.

42. APPARATUS FOR THE CONCENTRATION OF ELECTRIC WAVES IN A SINGLE DIRECTION, OR UPON A FIXED POINT. L. Rota and E. Binetti. (*British Patent* 128624, August, 1917. Patent accepted July 3rd, 1919.)

The apparatus for transmitting and receiving electromagnetic waves in or from a predetermined direction consists of a series of cylinders, or prisms, with their axes lying along the required direction, the cylinders, etc., being connected to each other by transformers, and an end cylinder being connected to the oscillation producing or reception circuit. The specification provides for the enclosing of these cylinder " aerials " inside an additional set of tubes. These tubes may be connected to batteries through resistances and choking coils as necessary. The arrangement is claimed to ensure secrecy in working, and to prevent interference by atmospherics, or by signals intended for other stations, and to prevent absorption and dissipation due to atmospheric electricity.

43. AERIALS AND LIKE RADIATING AND RECEIVING CONDUCTORS. General Electric Company (U.S.A.). (*British Patent* 127675, May, 1916.)

A frame-aerial directive receiving arrangement, comprising a coil of large number of turns wound over damping copper sheets of low impedance. The energy of signals or atmospherics coming from other directions than in the plane of the coil is damped out by the copper sheets.

44. EXPERIMENTS ON GROUND AERIALS WITH THEIR RELATION TO ATMOSPHERICS. C. D. Herrold. (*Radio Amateur News*, 1, p. 11, July, 1919.)

This paper deals with extensive experiments on the various types of ground aerials. A double aerial, with the receiver in the centre, was found to give the best ratio of signal strength to atmospheric strength.

45. TRANSATLANTIC RADIO RECEPTION. C. A. Culver (U.S. Signal Corps). (*Journal of the Franklin Institute*, 187, pp. 529—579, 1919.)

This communication deals with the results of an investigation of the reliability of various receiving stations for transatlantic reception. Comparisons were made by the shunted telephone method using low horizontal aerials. Signal audibility was found proportional to the 1·2 power of the length of the horizontal aerial. Signal strength at different receiving stations was found to vary as between one station and another at the same time of day. The signals at a given station might show a comparatively satisfactory signal audibility for a short period of time, while at the same time signals from another transmitting station were below normal strength. Various devices for eliminating atmospheric interference were also tested but with negative results.

The experiments indicated that the strength of X's of local origin varied inversely with the velocity of the wind and the air temperature. A marked agreement was found between X-strength and the humidity of the air, while variations in the X-strength corresponded directly with changes in the value of the horizontal component, H, of the earth's magnetic field.

### 46. ELECTROMAGNETIC WAVES. T. J. I'a. Bromwich, D.Sc., F.R.S. (*Philosophical Magazine*, 38, p. 143, July, 1919.)

A mathematical paper devoted entirely to the development of electromagnetic theory.

### 47. TRANSMISSION OF ELECTRIC WAVES ROUND THE EARTH. G. N. Watson, D.Sc. (*Proceedings of the Royal Society*, 95A, pp. 546—563, July, 1919.)

A mathematical paper devoted to radio transmission theory. It investigates the consequences of the assumption that the earth is surrounded by a concentric conducting layer (Heaviside layer) at a considerable height, and of the ionisation theory of wave refraction and reflection. The conclusion shows that the ionisation theory is sufficient to explain the observed facts concerning the rate of decay of electric waves transmitted over large sheets of water, and confirms the theory put forward by Heaviside and Eccles. See also RADIO REVIEW, p. 78.

### 48. PROPAGATION OF ELECTROMAGNETIC WAVES ROUND THE EARTH. Balth. van der Pol. (*Philosophical Magazine*, 38, p. 365, September, 1919.)

A mathematical paper devoted to the theory of wave transmission round the earth. It deals with the theoretical solution of the problem of defraction round a sphere of electric waves emitted from a source close to the sphere, and of wave lengths small in comparison to the circumference. It is suggested that the daytime signal strengths should be considered as normal instead of the night-time ones. The object of this article is the comparison of the observed normal value with the magnitude to be expected according to the defraction theory. Numerical data are given by which it is shown that the actual value of the received wave amplitude according to Austin's measurements is about two million times larger than the value to be expected by the pure defraction theory. The cause for this discrepancy must be looked for higher up in the atmosphere. Eccles' theory of ionic defraction is therefore strongly supported by these conclusions. See also RADIO REVIEW, p. 78.

### 49. THE SCIENTIFIC PROBLEMS OF ELECTRIC WAVE TELEGRAPHY. J. A. Fleming, D.Sc. (*Journal of the Royal Society of Arts*, 67, pp. 597—605, 612—618, 625—631, August, 1919.)

These Cantor lectures give a general summary of radio transmission and reception methods.

50. A NEW TYPE OF RECEIVING TUNER. M. B. Sleeper. (*Everyday Engineering Magazine*, 7, p. 292—295, August, 1919.)

An article dealing with the uses of the "honeycomb" standard inductances manufactured by the de Forest Radio Co. (U.S.A.). These are multi-layer coils wound with spaced turns to reduce the self-capacity and high-frequency resistance. Wave-length curves are given for these coils used in combination with various capacities.

51. TELEPHONE RELAYS FOR WIRELESS. L. N. Brillouin and G. A. Beauvais. (*British Patents* 127013, 127014, March and November, 1916.)

This patent relates to multi-valve receiving amplifiers, in which the grid is worked at a positive potential with respect to the filament.

Less interference from strong signals and X's is claimed.

52. AN AMERICAN RECEIVER USED ON FRENCH SHIPS. (*Everyday Engineering Magazine*, 7, pp. 296—298, August, 1919.)

A general illustrated description is given of valve receiving sets used on certain French vessels. A single "French" detecting valve is employed.

53. WIRELESS SIGNALLING SYSTEMS. I. Shoenberg and Marconi's Wireless Telegraph Co., Ltd. (*British Patent* 127634, May, 1917.)

Relates to the use of A.C. for the heating of valve filaments.

54. THE PROBLEMS OF VACUUM TUBE CIRCUITS. L. M. Clement. (*Everyday Engineering Magazine*, 7, pp. 300—302, August, 1919.)

A consideration is given of the amplification obtainable with various arrangements of amplifying valves, using resistance, inductance, or inductive couplings.

55. IMPROVEMENTS IN VACUUM TUBES. H. W. Edmundson and W. T. Munro. (*British Patent* 127724, June, 1918.)

Describes a metallic screen round the anode of a valve to prevent heating of the glass stem and deposition of a conducting film on leading-in seals.

56. CASCADE AMPLIFICATION OF A SINGLE VACUUM TUBE. (*Wireless Age*, 6, p. 23, July, 1919.)

This article describes a valve developed by Alexander Nicholson. The filament surrounds the first control electrode, and a cylindrical plate or anode encloses the whole. Two other grids and anodes are mounted on the outside of the above construction. By this means a three-stage amplification may be obtained in a single tube.

### 57. The Application of Amplifiers to the Recording of Wireless Signals.

H. Abraham and E. Bloch. (*Comptes Rendus*, 169, pp. 282—285, August, 1919. *Revue Générale de l'Electricité*, 6, pp. 323—324, September, 1919.)

A frame aerial receiver is used in combination with two multi-valve amplifiers, of eight and three valves respectively. The first five valves are used for radio frequency amplification, the sixth as a detector, and the last two for low frequency amplification. To the end of this amplifier a special three-stage amplifier is connected, arranged with the grid of the last valve maintained normally at a negative potential, so that the plate circuit current is practically zero. The reception of the signal causes the plate current to jump to the saturation value, and so influences the recorder. This second amplifier thus takes the place of the usual relay.

Any ordinary Morse printer or recording galvanometer may be used. Medium strength atmospherics do not affect the recorder. Using a frame coil of forty turns 1·2 metres diameter, successful records of transatlantic signals have been obtained.

### 58. A Comparison of the Wave Form of the Telephone Current Produced by a Thermal Detector and by a Rectifier in Heterodyne Reception.

Balth. van der Pol, D.Sc. (*Proceedings of the Physical Society of London*, 31, pp. 290—298, August, 1919.)

A theoretical treatment is given of the wave form of the telephone current resulting from the heterodyne method of reception of wireless signals.

When a detector is used generating a potential difference at the telephone terminals proportional to the square of the aerial current, it is shown that the lowest frequency "harmonic" of the resultant current is

$$I_1 I_2 \cos (\omega_1 - \omega_2) t.$$

With a rectifying detector the theory becomes more involved, and the telephone current is $I_1 \cos \omega_1 t - I_2 \cos \omega_2 t$, with the condition that when this function is negative it is replaced by zero. The fundamental frequency of this function is $\frac{1}{2\pi}$ times the greatest common factor, $f$, (including fractions) of $(\omega_1 + \omega_2)$ and $(\omega_1 - \omega_2)$, so that $\omega_1 + \omega_2 = (p + q) f$ and $\omega_1 - \omega_2 = (p - q) f$ where $(p + q)$ and $(p - q)$ are the smallest integers, allowing $(\omega_1 + \omega_2)$ and $(\omega_1 - \omega_2)$ to be expressed in this form.

The relative magnitudes of the amplitudes of the different harmonics are wholly determined by the values of $p$ and $q$. The harmonics of the order

$$(p + q),\ 2(p + q),\ 3(p + q), \quad . \quad . \quad . \text{ etc.}$$

and

$$(p - q),\ 2(p - q),\ 3(p - q), \quad . \quad . \quad . \text{ etc.}$$

will have much greater amplitudes than the remaining harmonics.

It is further shown that the amplitude of the harmonic of order $(p - q)$ is, for practical cases, much larger than that of the fundamental, and that it is likely that the ear will take the harmonic of order $(p - q)$ as determining the pitch of the sound in the telephone receiver, as in the case of the thermal detector. Owing to the larger number of harmonics obtained with the rectifier, the thermal detector shows a theoretical advantage, from the point of view of interference from other wave lengths.

### 59. Improvements in Receivers for Wireless Signals. C. S. Franklin and Marconi's Wireless Telegraph Company. (*British Patent* 128673, September, 1917. Patent accepted July 3rd, 1919.)

The use of the heterodyne method of reception for very high frequencies presents difficulties through inability to maintain the required frequency difference between the local and the incoming oscillations. The arrangement described in this specification provides for the regular variation of the local frequency so that the heterodyne beat frequency passes through the whole range of periods up to about 150,000 per second, a considerable number of times per second. The local variation of frequency may be obtained by a small rotary condenser connected in parallel with the oscillation circuit. The frequency of the capacity variations of this condenser may be arranged to give a musical note, such as, for example, 1,000 variations per second. Alternatively, a rapid variation of the inductance of the circuit may be made to produce a similar effect.

### 60. Improvements relating to Wireless Signalling Systems. The General Electric Company (U.S.A.). (*British Patent* 129722, December, 1917. Patent accepted July 24th, 1919.)

The receiving conductor or " aerial " is formed as a frame coil which is placed in the vertical plane containing the receiving station and the desired transmitting station. The second coil is mounted perpendicularly to the main receiving coil, with the object of screening the receiving coil from the undesired waves emitted from an adjacent transmitting station. The main receiving circuit should be tuned to the wave length of the station from which the signals are to be received, while the second coil at right angles is tuned to the frequency of the interfering station which is to be cut out.

### 61. Improvements in Apparatus for Eliminating Interference. H. Richmond and Marconi's Wireless Telegraph Company. (*British Patent* 130107, April, 1918. Patent accepted July 25th, 1919.)

The wireless receiving apparatus adapted to prevent interference by signals from undesired stations comprises a pair of directive frame aerials mounted perpendicularly to one another. The plane of one of the aerials is arranged to include the station from which it is desired to receive signals. The energy received on this aerial is transferred to the receiving circuit and detector in the usual manner. The same receiving circuit is also coupled adjustably to the second frame aerial. Signals from an undesired station affect both aerials and by adjusting the couplings the undesired signals may be neutralised in the receiving circuit.

### 62. Improvements in Wireless Receiving Apparatus. R. A. Weagant, F. N. Waterman, and Marconi's Wireless Telegraph Company of America. (*British Patent* 129625, Convention date July, 1918. Application date for British Patent, May, 1919.)

The aerial arrangements dealt with in this Patent are described in Radio Review Abstract No. 18.

### 63. Thermionic Devices for Magnification Purposes. G. M. Wright and Marconi's Wireless Telegraph Co., Ltd. (*British Patent* 127651, May, 1917.)

This patent deals with the use of a succession of valves so arranged that the strength of atmospheric disturbances is reduced, while, at the same time, any desired magnification can be obtained. The circuit for two valves is shown in Fig. 5.

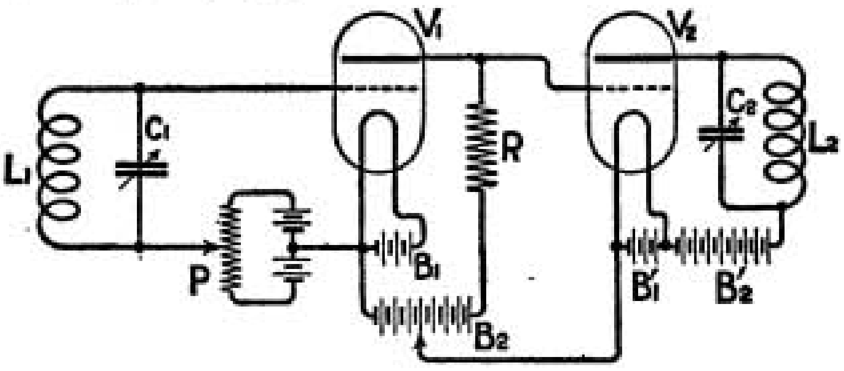

Fig. 5.

### 64. Duplex Wireless Signalling. General Electric Company (U.S.A.). (*British Patent* 127335, April, 1917.)

An arrangement for duplex wireless signalling employing separate transmitting and receiving aerials at each station. The effect of the emitted waves on the adjacent receiving aerial is neutralised by impressing opposite potential variations on the receiving aerial by coupling it electrostatically or electromagnetically to the transmitting aerial. Different frequencies may be used for transmitting and receiving.

### 65. Wireless Aerials for Aircraft. B. Binyon. (*British Patent* 127434, June, 1918.)

An easily detachable trailing aerial for aircraft is described. The aerial wire is contained inside the plummet which is dropped from the 'plane.

### 66. The Cabot Converter. C. F. Caines. (*Proceedings Inst. of Radio Engineers*, 7, p. 281, June, 1919.)

A description of the Cabot commutator converter for supplying high-tension direct current from a polyphase A.C. source. The theory of the commutation is given and specifications for a 1 k.w. transformer for use with this apparatus. Voltages up to 100,000 D.C. may be obtained.

67. Wireless Control of Torpedoes. A. E. Ericson. (*British Patent* 128295, July, 1917.)

Synchronously revolving commutators are used at the transmitter and receiver in order to determine the use to which any given impulse is put in controlling the torpedo.

68. Wireless Control of Distant Apparatus. H. J. G. Proumen and A. le C. de Lautreppe. (*British Patent* 127848, May, 1917.)

69. Radio Signalling. J. Stone-Stone. (*Proceedings of the American Institute of Electrical Engineers*, 38, p. 933, July, 1919.)

The Annual Technical Committee report, giving a brief summary of the year's radio progress.

70. Radiotelegraphy in Competition with Wire Telegraphy. R. B. Black. (*Proceedings of the Institute of Radio Engineers*, 7, pp. 391—407, August, 1919. *Telegraph and Telephone Age*, pp. 434 and 459—462, September, 1919.)

This paper deals with some of the obstacles encountered in overland radio service. The organisation and operation of the Pacific coast chain of duplex radio stations belonging to the Federal Telegraph Company is described in detail.

71. Radiotelegraphy by Infra-Red Rays. J. Herbert-Stevens and A. Larigaldie. (*Comptes Rendus*, 169, pp. 136—137, July, 1919. *Revue Générale de ÉI'lectricité*, 6, pp. 476—477.)

The results obtained in recent wartime experiments in infra-red phototelegraphy are described. A thermo-electric detector was used, with an arc or incandescent lamp for transmitter. Ranges up to twelve miles have been obtained.

# Correspondence.

## HARDENING AND SOFTENING OF IONIC TUBES.

To the Editor, the "Radio Review."

Sir,

The phenomena described by Professor C. L. Fortescue on page 35 of your October issue occur in all kinds of ionic tubes, and are of immediate importance to those who use the thermionic high-vacuum valve with either two or three electrodes. Dr. Bryan's explanation is given on the same page. I now write to offer another explanation.

Suppose the filament to be at its normal temperature in an ordinary commercial tube and suppose that the voltage applied is producing about half the saturation current. Doubtless some of the molecules present will be ionised by collision with the electrons, but in a steady state of affairs the electron flow will be sufficient to prevent the positive ions reaching the cathode in any considerable number. Now let an unusually high voltage be applied between the anode and filament without alteration of the temperature of the latter so that the saturation current is being taken. Then more positive ions will be formed because the collisions will be more vigorous, their speed will be greater, and there will be appreciable bombardment of the filament by positive ions. We may suppose that these ions become embedded in the filament to form what is called occluded gas.

Now suppose that the voltage applied between the anode and filament is reduced to an unusually low value so that the electron current is far below saturation. The space charge accumulates densely near the filament and the voltage gradient at the surface of the filament becomes negative. This is indicated by the curve marked *V* in Figure 3 on page 15, of my paper in your October issue. Hence the positive ions lying upon, or embedded in the filament tend to be drawn into the space charge. This is evident because the same space charge that pushes negative ions (electrons) back into the filament will encourage positive ions to leave it. And these positive ions if they enter the space charge in quantity lead to the flow of a greater current through the vacuum and make the valve, as we say, "soft."

In this explanation the assumption is made that the positive ~~electrons~~ ions occluded by the filament remain there unneutralised. This assumption seems reasonable when one recalls that according to the kinetic theory of matter the averaged velocity of, say, the hydrogen molecule in the incandescent filament is much greater than that of the metal molecule and is only fifty times smaller than the averaged velocity of the electrons in the metal. Even if the filament is allowed to cool and is then reheated the occluded gas may be expected to become ionised *in situ*. Hence the superior conductivity of gas liberated from a high temperature cathode over cold gas admitted into a tube.

This method of hardening has been used for several years in the manufacture of valves, each tube being treated individually. It seems worth mentioning that it should be possible to utilise these phenomena in the construction of what might be called an electric pump for the production of the highest vacuum. The pump would consist of a cathode of very large surface and an anode in a glass bulb with a side tube to which the vessels to be exhausted to the limit would be sealed. A high voltage between the anode and the cathode in the pump would ionise and deposit the gas coming from the vessel to be evacuated.

Yours faithfully,
W. H. ECCLES.

City and Guilds Technical College,
Finsbury, E.C. 2.
*October* 20*th*, 1919.