AMPLIFICATION OF THE PHOTOELECTRIC CURRENT BY MEANS OF THE AUDION.

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A METHOD has been outlined by Jakob Kunz[1] by means of which the photoelectric current may be amplified, thus making the photoelectric cell more useful as a photometer, especially in the region of ultraviolet light and also for technical purposes.

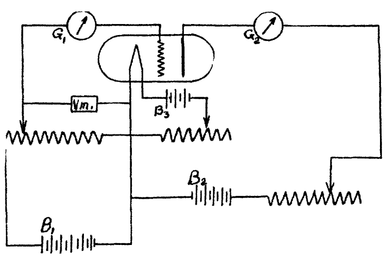

Fig. 1.

The amplification is produced by means of a vacuum tube with three electrodes, or the audion. In order to determine the best potentials to use in the primary and secondary circuits it is necessary to know the characteristic curves for the audions used. The characteristic curves of several audions have been determined by an arrangement of apparatus shown in Fig. 1, which is self explanatory. If we plot the grid potentials as abscissæ and the plate current as ordinates, the curve obtained is called the characteristic.

Due to the fact that the plate current as well as the grid current was so sensitive to small changes in the temperature of the filament, it was necessary to keep the heating current very constant. Large storage cells, well insulated from the ground, were used for this purpose. A large resistance was placed in the external circuit, so that a small variation in the resistance of the filament would not affect the current appreciably. The characteristic curves of three types of audions are shown in Figs. 3, 4 and 5. Audion no. 1 is an oscillion made by the DeForest Radio Telephone and Telegraph Co. Audion no. 2 of Fig. 4 is a W-type;

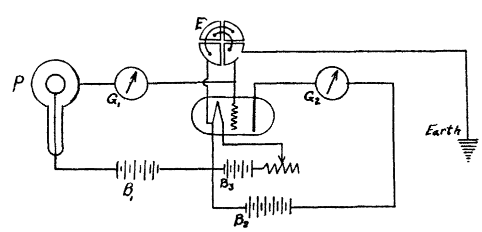

Fig. 2.

[1] PHYS. REV., Vol. X., No. 2, p. 205.

Audion no. 3 of Fig. 5 is a V-type instrument made by the Western Electric Co. It is noted that the plate current in the oscillion reaches its saturation value more abruptly than it does in either of the other two instruments. In the oscillion it is necessary to heat the filament to incandescence before the electrons are emitted, while in audion W and V the light from the filament was scarcely visible.

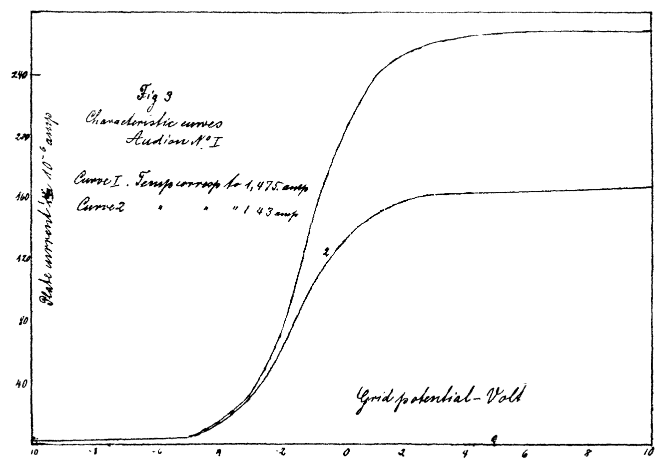

Fig. 3.

Audion no. 2, the W-type instrument, was used for the amplification of the photoelectric current, with an arrangement of apparatus shown in Fig. 2. Twenty-four volts were used in the secondary circuit and a hundred and twenty-five volts in the primary. The photoelectric cell used was a larger type of those made by Kunz in our laboratory. With 125 volts in the primary circuit, the drop of potential inside the audion was very small; measured with an electrometer it was found to be 0.56 volt for nearly the highest intensity of light incident on the photoelectric cell. Since the drop of potential between the grid and filament is very small in comparison to that across the terminals of the photoelectric cell, the photoelectric current is very nearly equal to what it would be if the audion were out of the circuit. The curve giving the relation between the intensity of light and the photoelectric current is shown in Fig. 6. It is unfortunately not a straight line. If this were a straight line and if the portion of the characteristic curve of the audion, used for the amplification, were straight, then we would expect a straight line relation between the intensity of light and the amplified current, and the amplification i_2/i_1, the ratio of the secondary to the primary current would be constant, represented by a straight line parallel to the hori-

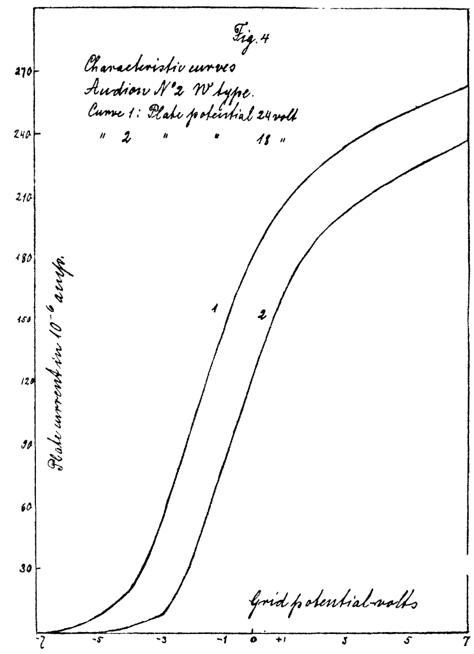
Fig. 4
Characteristic curves
Audion N°2 V type.
Curve 1: Plate potential 24 volt
" 2 " " 18 "
Plate current in 10⁻⁶ amp.
Grid potential-volts
1
2
270
240
210
180
150
120
90
60
30
-7
-5
-3
-1
0
+1
3
5
7

Fig. 4.

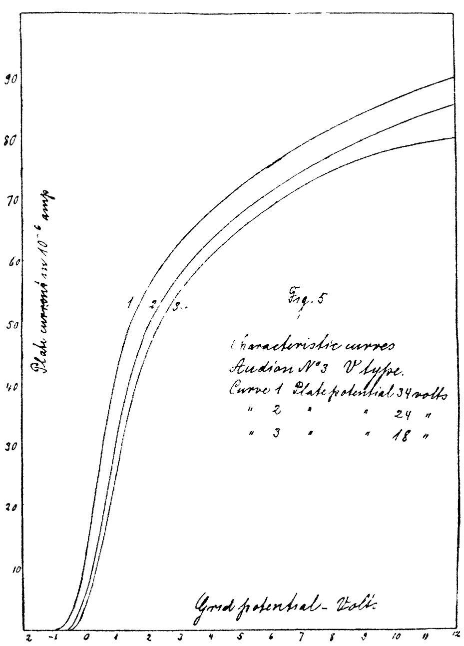
Fig. 5
Characteristic curves
Audion N°3 V type.
Curve 1 Plate potential 34 volts
" 2 " " 24 "
" 3 " " 18 "
Plate current in 10⁻⁶ amp
Grid potential - Volt.
1
2
3
90
80
70
60
50
40
30
20
10
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

Fig. 5.

zontal axis of Fig. 7. Instead of this straight line, the curve of Fig. 7 has been obtained for intensities varying from 3 to 30 candle meters. For the highest intensity the amplification is about 1750, for the smallest

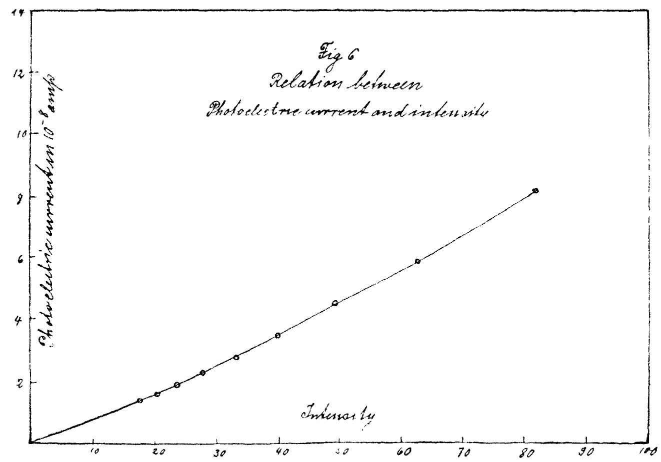

Fig. 6.

intensity it is over 5,000; above an amplification of 4,000 the points appear somewhat scattered around the curve, but this was only so because the primary current deflections of the Leeds and Northrup galvanometer,

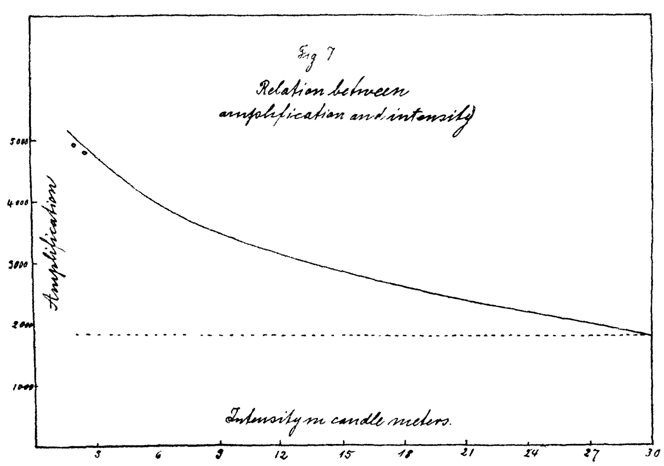

Fig. 7.

G_1 (with a figure of merit $3.74 \cdot 10^{-9}$ for the scale distance used), were very small. If the primary or photoelectric current i is zero, there is already a large current through the secondary galvanometer with a figure of merit $2.9 \cdot 10^{-6}$. It goes without saying that this "dark" current was subtracted from that current which was obtained in the galvanometer, G_2, when the photoelectric cell was under the action of light. The difference between the two deflections was proportional to the current i_2. The deflections of the galvanometers were very steady and could easily be repeated. Table I. gives the data that have been plotted in Fig. 7. A satisfactory theory of the audion, based upon the motion, accumulation and absorption of electrons has not yet been given. The current amplification can therefore not yet be determined theoretically. But we can find a simple expression for the amplification, namely, i_2/i_1 in the following way, which involves only Ohm's law and the experimental relation between the plate current and the grid potential; as long as we restrict the amplification to the straight portion of the characteristic $i_2 = Cp_1$, we get the following equations.

$$i_1 = \frac{E_1}{R_0 + R_1} = \frac{p_1}{R_1},$$

$$i_2 = \frac{E_2}{R_2 + R_3} = \frac{p_2}{R_2} = Cp_1 = Ci_1R_1,$$

$$\frac{i_2}{i_1} = C \cdot R_1.$$

The amplification is therefore constant if C and R_1 are constants, that is, if the straight part of the characteristic is used and if the resistance R_1 between the filament and the grid is constant. For large amplifications C and R_1 have to be large.

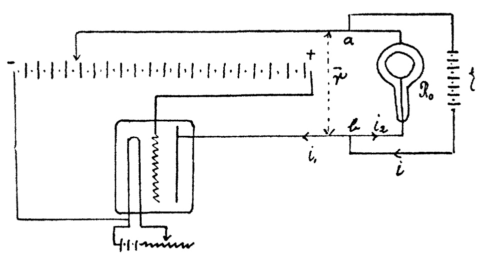

Fig. 8.

A different principle has recently been indicated by A. W. Hull,[1] of the General Electric Company, for the amplification of small currents. By a proper choice of the potentials, the electrons emitted from the incandescent filament pass through the grid and strike the plate where they are reflected. A system of this kind, shown in Fig. 8, presents a negative resistance $\bar{r}$ between the points a and b. If we place a photo-electric cell with the positive resistance R_0 in parallel with $\bar{r}$, then we get;

[1] P. I. R. E., February, 1918.

TABLE I.

Increase in d_2.	i_2 Amperes.	d_1.	i_1 Amperes.	Amplification.	Intensity in Candle Meters.
73.5	213.0×10^{-6}	35.0	131.0×10^{-9}	1600	33.0
64.8	188.0	23.5	87.7	2100	24.0
56.5	164.0	17.0	63.5	2600	18.5
49.0	142.0	12.9	48.2	2900	14.8
41.0	119.0	10.0	37.4	3270	12.0
35.5	101.5	8.1	30.2	3400	9.9
31.4	91.0	6.8	25.4	3570	8.3
28.0	81.2	5.7	21.3	3800	7.1
23.8	69.0	4.8	17.9	3840	6.1
22.5	65.2	4.1	15.3	4250	5.3
19.5	56.6	3.5	13.1	4320	4.7
17.5	50.7	3.1	11.6	4370	4.2
16.5	47.8	2.8	10.5	4570	3.7
15.1	43.7	2.5	9.4	4680	3.3
13.0	37.7	2.1	7.9	4800	3.0
12.0	34.8	1.9	7.1	4890	2.7
10.9	31.6	1.8	6.7	4720	2.5
11.5	33.3	1.7	6.4	5100	2.3
10.0	29.0	1.6	6.0	4840	2.1
10.0	29.0	1.5	5.6	5200	1.9

"W" type audion, no. 2. Lamp current, 3.75 amperes; candle power, 3.0. Heating current, 0.665 amperes. B^1 equaled 125 volts. B^2 equaled 25 volts. Figure of merit of G^1 3.74×10^{-9}. Figure of merit of G^2 2.9×10^{-6} when shunted with 1.7 ohm resistance. Ratio of figure of merit of G^2 to that of G^1 equaled 775.

$$i = i_1 + i_2 = E\left(\frac{R_0 + \bar{r}}{R\bar{r}}\right),$$

and

$$i_1 = \frac{E}{\bar{r}}, \quad i_2 = \frac{E}{R},$$

hence the amplification

$$\frac{i_2}{i} = \frac{\bar{r}}{R_0 + \bar{r}}$$

may be made very large by making r and R_0 nearly equal in absolute values.

One application of the amplification of photoelectric currents in wireless telegraphy may be pointed out. J. Kunz and J. Kemp[1] have at first used the photoelectric cell as receiver in wireless telegraphy. Their method has been modified by H. Behnken[2] who showed that the photoelectric cell with a string electrometer forms a constant detector of high sensitiveness, especially useful for photographic registrations. With

[1] Jahrbuch d. drahtlosen Telegraphie, 6, 405, 1913.

[2] Verhdlg d. deutschen phys. Ges., 16, p. 668, 1914.

the amplification of the weak currents here involved it should be possible to increase the usefulness of the photoelectric detector. It was intended to continue this investigation with ultra-violet and interrupted light, with alternating currents, and with a differential galvanometer in the secondary circuit.

SUMMARY.

It has been shown that photoelectric currents can be amplified by means of the audion from 1,600 to 5,000 times. The weaker the light the smaller the primary photoelectric current and the larger the amplification. With different audions amplifications of 18,000 have been obtained.

In conclusion the writer wishes to express his appreciation to Jakob Kunz for suggesting the problem and directing the work.

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