

June 10, 1930.

C. W. CARTER, JR
THERMIONIC VACUUM TUBE

1,762,212

Filed Dec. 20, 1924

2 Sheets-Sheet 1

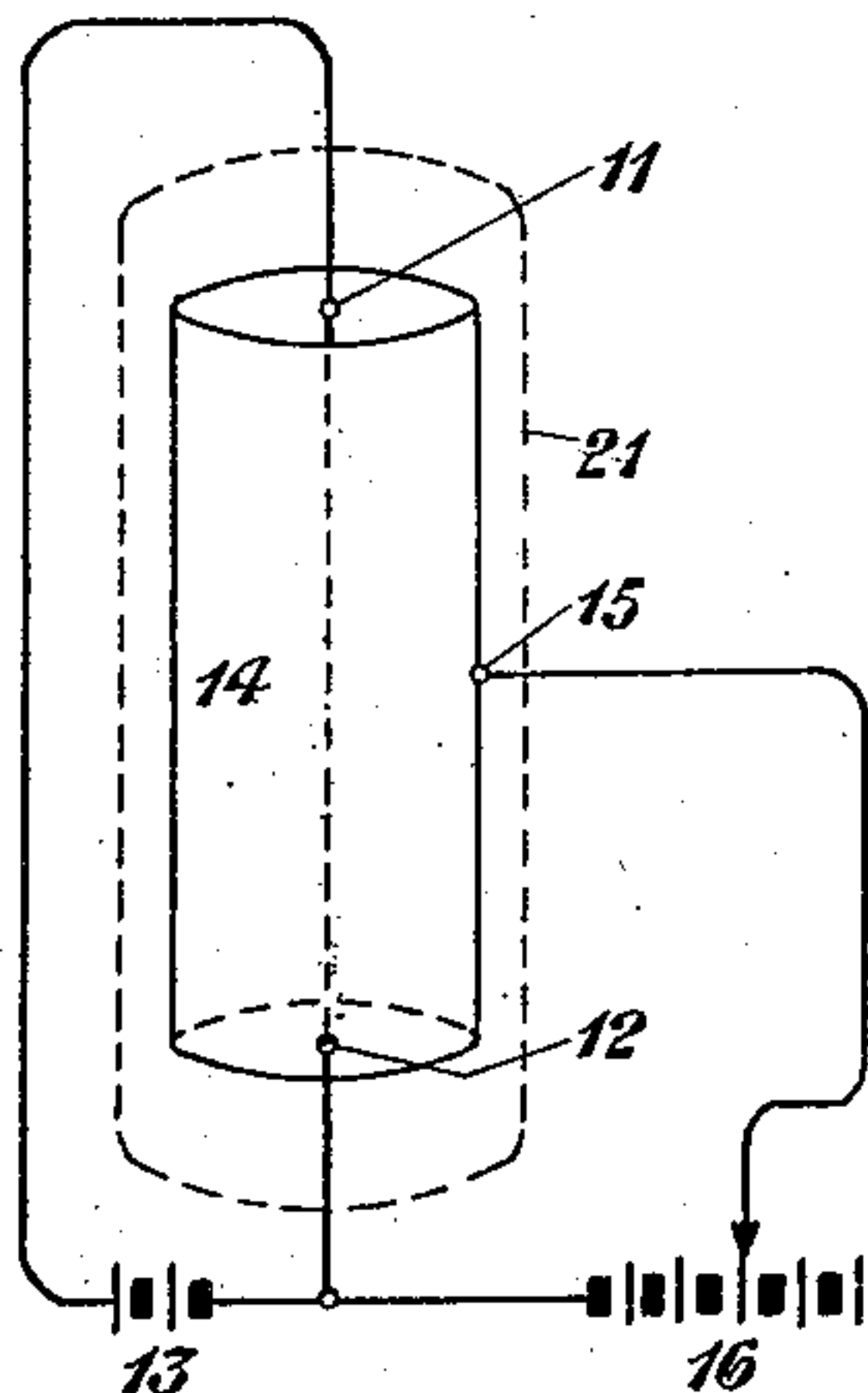


Fig. 4

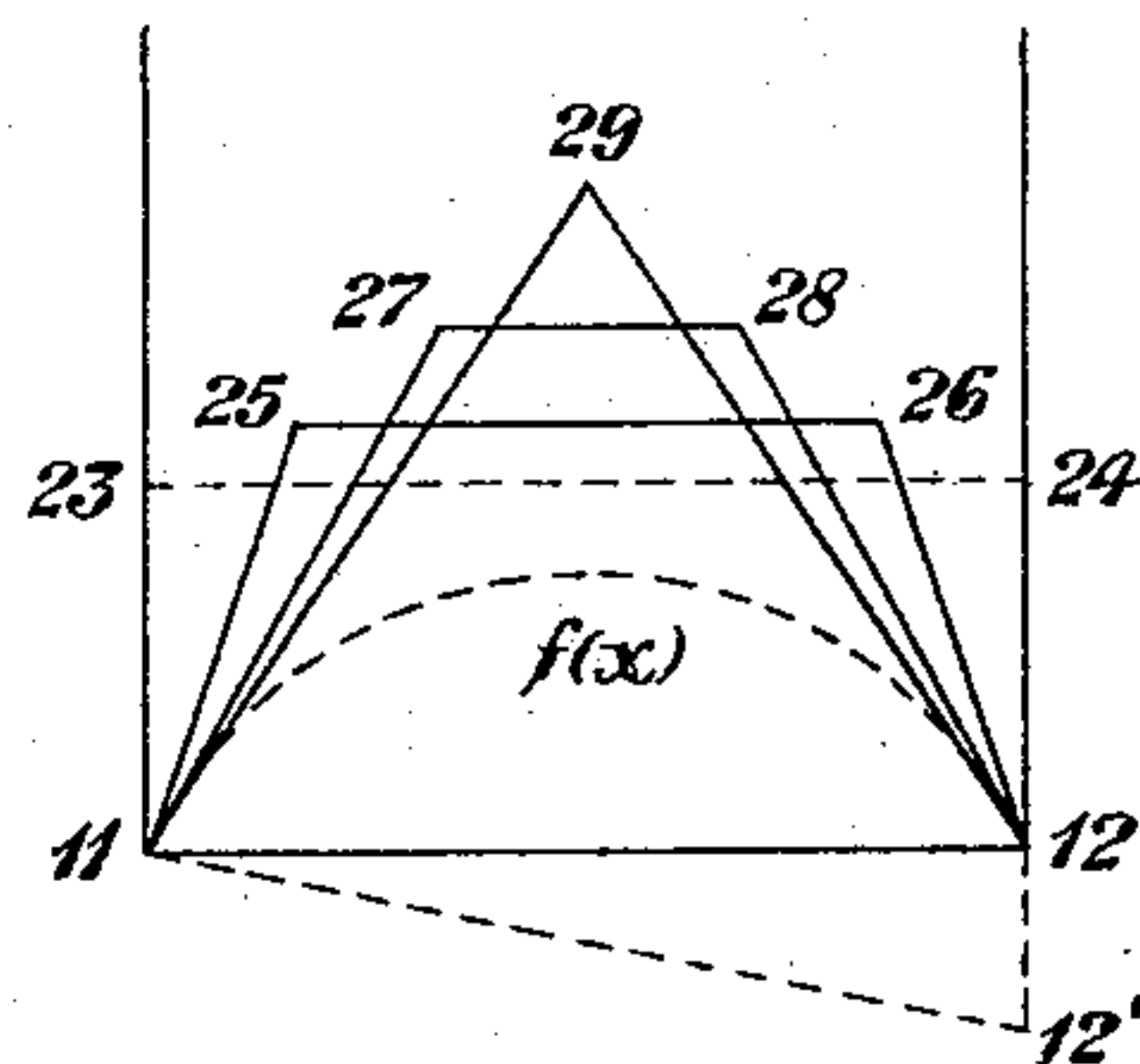


Fig. 5

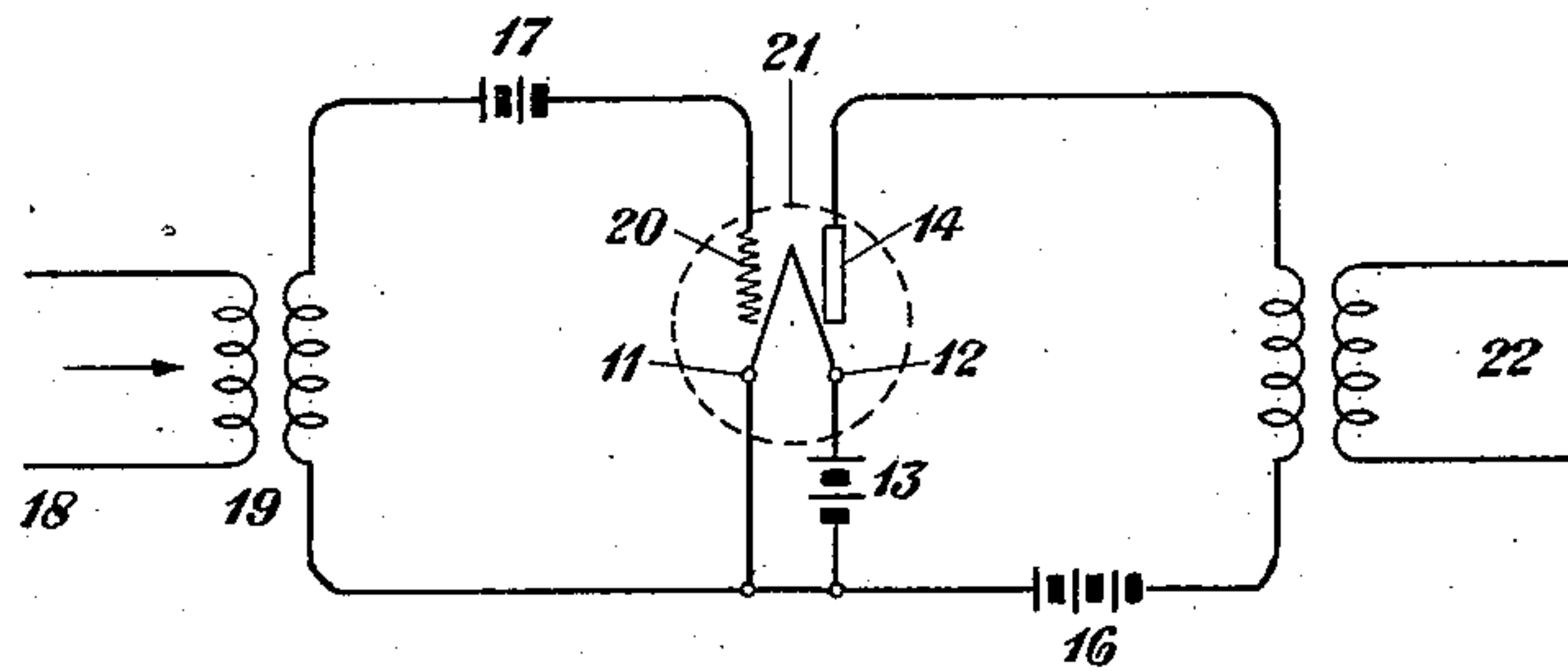


Fig. 2

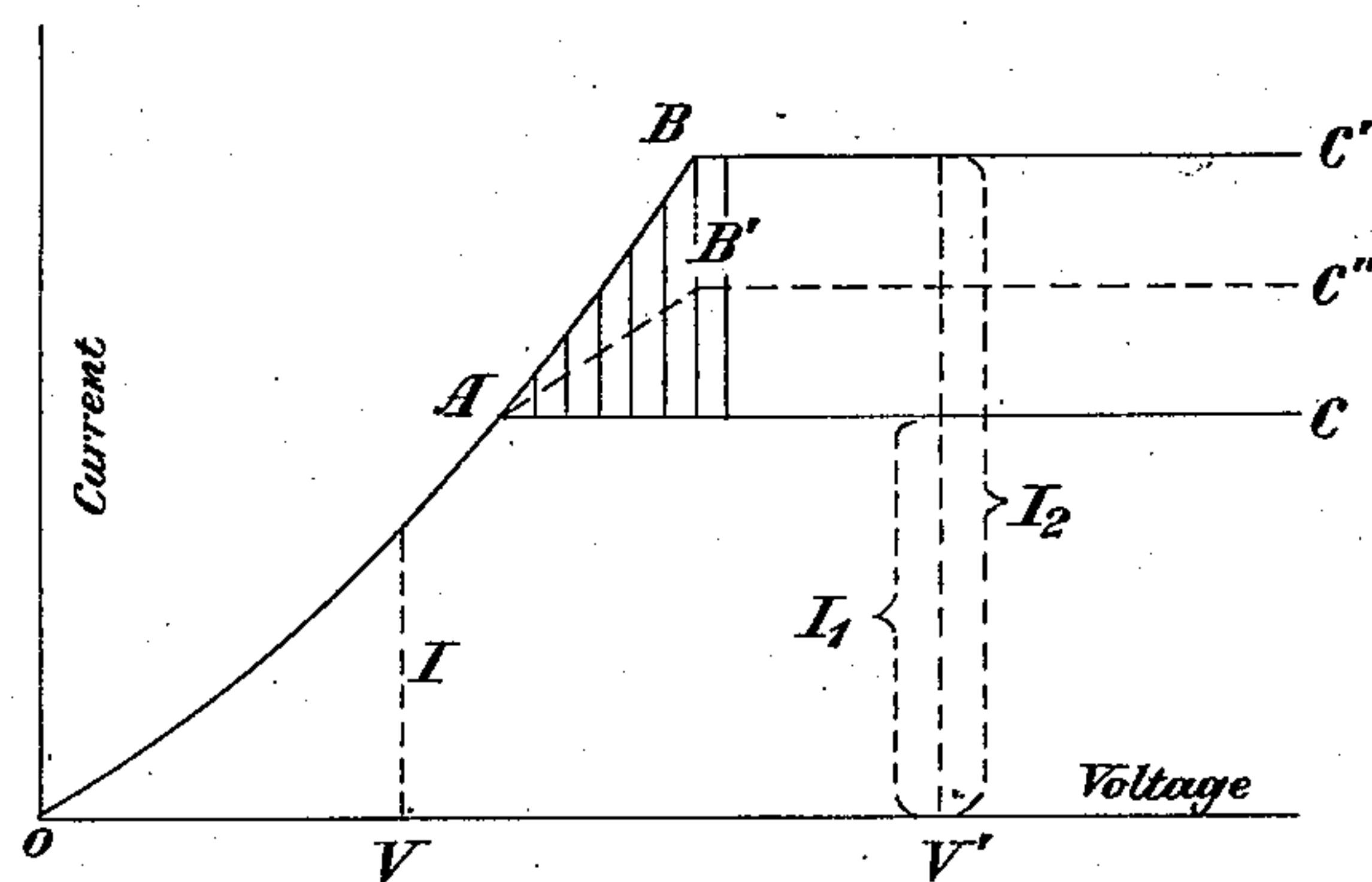


Fig. 3

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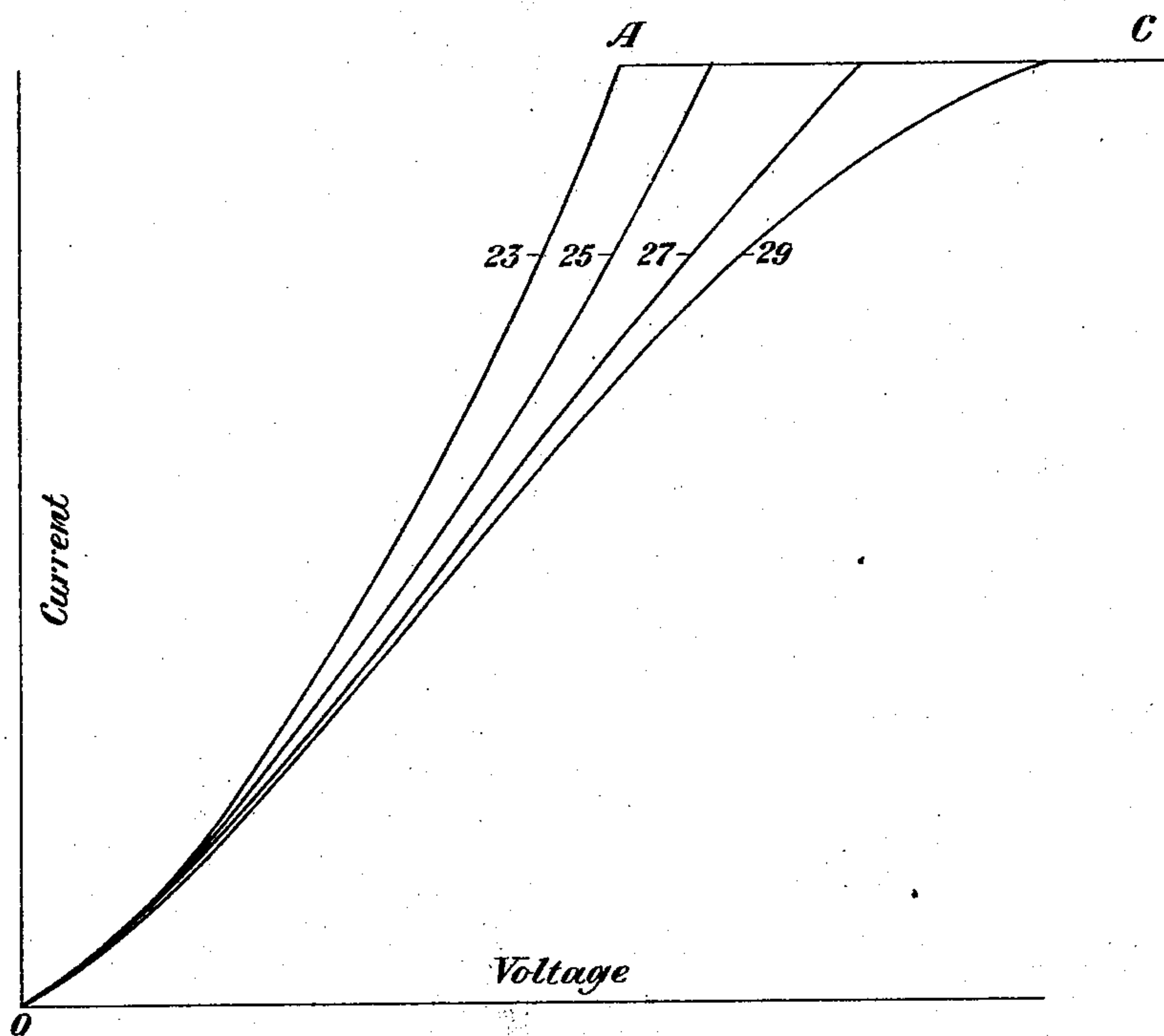


Fig. 4

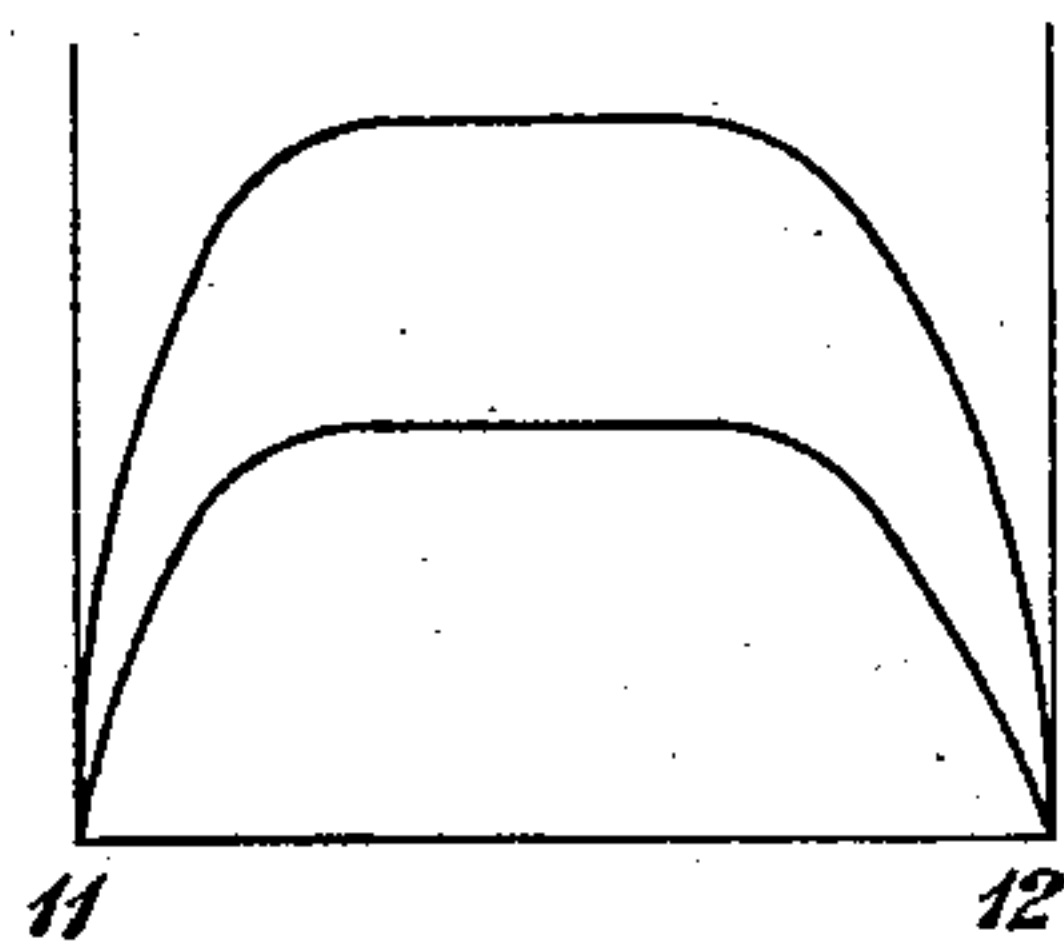


Fig. 6

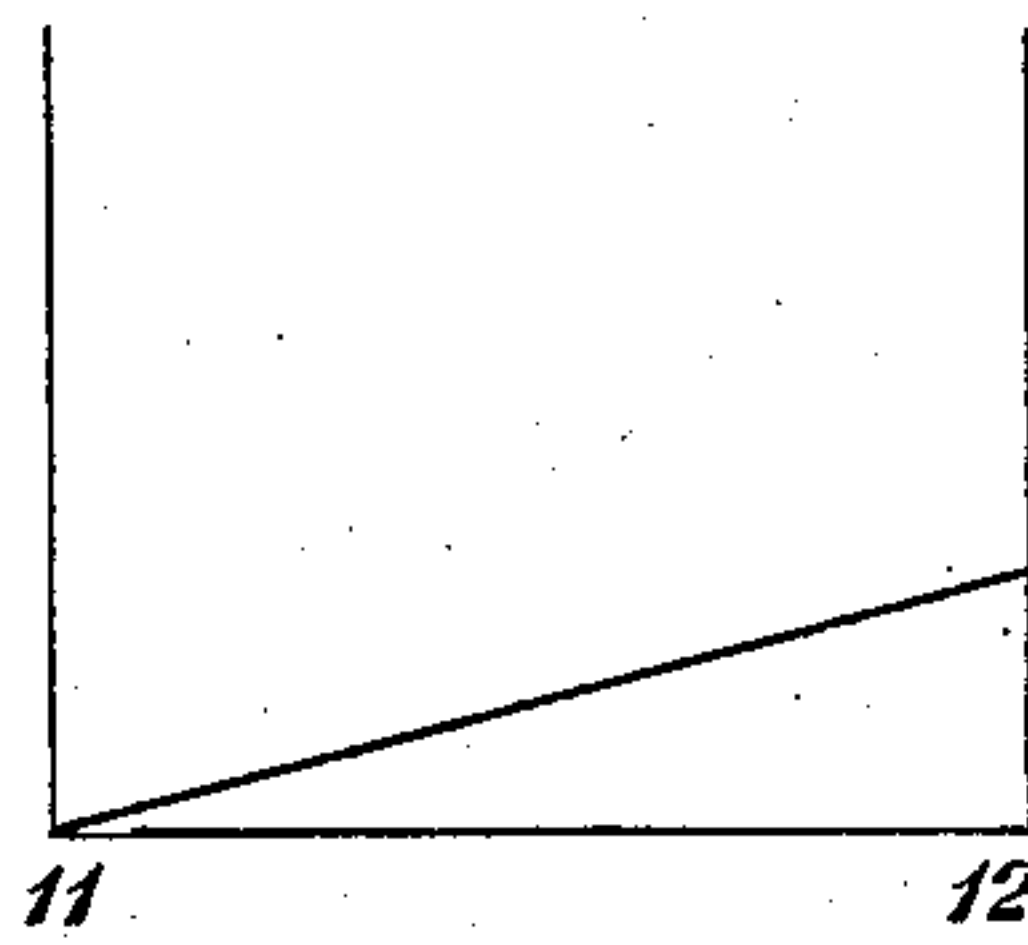


Fig. 7

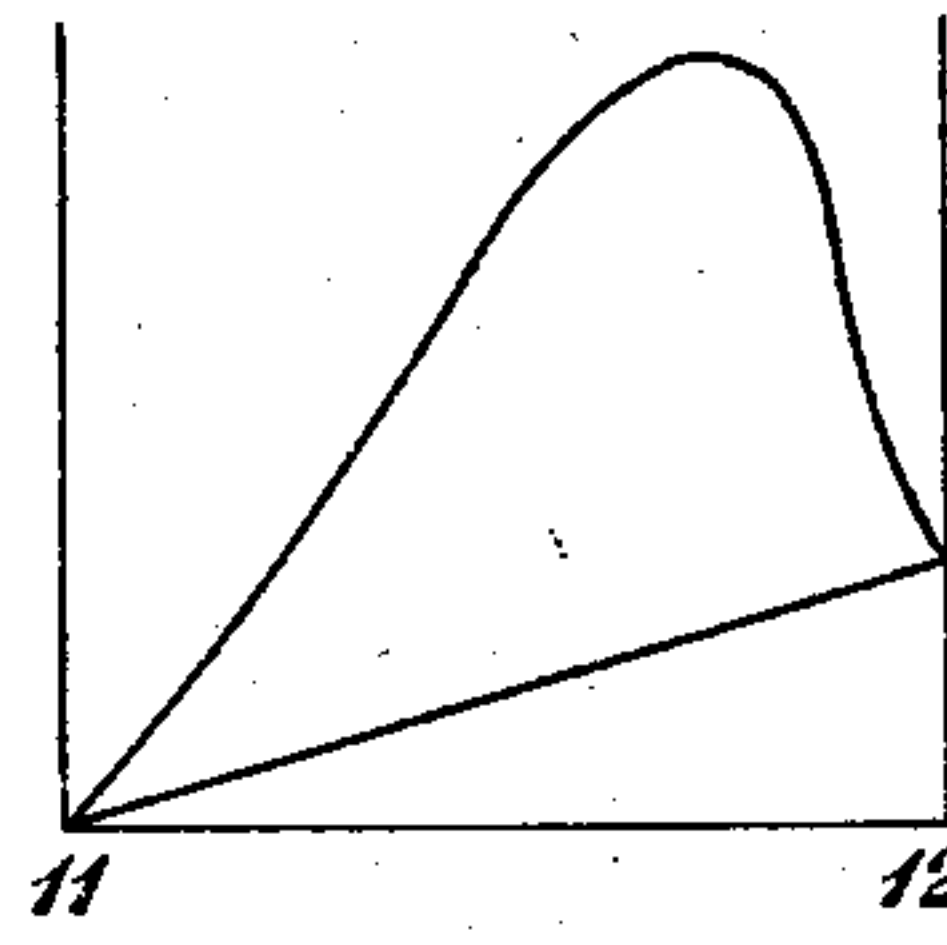


Fig. 8

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THERMIONIC VACUUM TUBE

Application filed December 20, 1924. Serial No. 757,268.

An object of my invention is to provide a new and improved method and apparatus for securing a desired functional relation between the current and voltage in a thermionic vacuum tube. Another object of my invention is to provide for getting the proper shape of the current-voltage characteristic of such a tube. Still another object of my invention is to provide for modifying the shape of such a characteristic to suit special circumstances, as for example, to increase its curvature for a rectifier or to decrease its curvature for an amplifier. These and various other objects of my invention will become apparent on consideration of a limited number of examples of practice in accordance with the invention, which I have chosen to disclose in this specification. It will be understood that the invention is defined in the appended claims and that the following description relates more particularly to the examples of the invention here set forth to illustrate its character.

Referring to the drawings, Figure 1 is a diagram of a two-electrode thermionic vacuum tube and its accompanying circuits; Fig. 2 is a diagram of a three-electrode vacuum tube and its associated circuits; Figs. 3 and 4 are current voltage diagrams, and Figs. 5, 6, 7 and 8 are plots of minimum saturation potentials along the length of a filament cathode.

A two-electrode thermionic vacuum tube of simple design is shown in Fig. 1. Within the evacuated vessel 21 there is a cathode in the form of a filament 11—12 and a corresponding anode 14 in the form of a cylindrical shell having the cathode in its axis. The cathode 11—12 is heated by the current due to the battery 13, and the battery 16 is connected between the cathode 11—12 and the anode 14 at the point 15 so as to make the cathode negative. Accordingly, as electrons are emitted from the cathode 11—12, they (or part of them) are driven across to the anode 14 and thus a current is caused to flow in the circuit of the battery 16.

Due to the "space-charge effect" the electrons near the cathode 11—12 have a tendency to re-enter it, and the voltage of the battery 16 must be pushed up above a certain critical

voltage to get all the electrons across from the filament-cathode 11—12 to the anode 14. When this critical voltage, called herein the minimum saturation potential, is attained, the current remains constant with further increase of voltage. The current-voltage relation will be of the character shown by the curve OAC in Fig. 4.

This curve is based on the assumption that the filament 11—12 is of uniform potential, whereas in fact there will obviously be a drop in potential along its length due to the heating voltage, also other simplifying assumptions are involved, as that the rate of emission is uniform over the entire filament surface, whereas in fact the rate of emission is nonuniform for two principal reasons: variation of the work function over the surface, due to inhomogeneities, impurities, etc., and variation of temperature along the filament, due to cooling of the ends by conduction of heat into the leads, etc.

The higher the temperature of the cathode the greater is the minimum saturation voltage. Thus, if the characteristic has the form OAC as in Fig. 3, for a certain filament temperature, then an increase of the filament temperature will change the characteristic to the locus OBC'.

On account of the lower temperature of the ends of the filament due to conduction of heat into the leads as already mentioned, and because of impurities, inhomogeneities, etc., the minimum saturation potentials for different parts of the filament will be different. Thus if the horizontal line 11—12 in Fig. 6 represents the filament, then the corresponding ordinates of either curve may be taken as representing the corresponding minimum saturation potentials for the respective points of the filament, the two curves being drawn for two different heating voltages. The potential due to the filament heating battery 13 is shown in Fig. 7, and the combination of the effects of Figs. 6 and 7 gives the curve of Fig. 8.

To obtain an understanding of the effect of the current-voltage characteristic of the tube due to the lower minimum saturation potentials toward the ends of the filament,

assume the simple case of a tube with a filament in two parts of equal length, one part having per unit length the characteristic OAC in Fig. 3 and the other part having per unit length the characteristic OBC' in the same figure. Since the two characteristics coincide from O to A the average characteristic per unit length for the filament as a whole will be the same from O to A, but beyond the point A it will extend as AB' C'', the respective ordinates of the latter range averaging the corresponding ordinates of the other two curves. Thus it will be seen that the composite filament has the upper sloping portion of its characteristic displaced to the right.

Now if the filament is composed of a large number of portions of different saturation potentials the displacement to the right will begin far down on the curve and will increase farther along up the curve so that the upper part of the sloping part of the curve will be pushed more and more to the right and will be correspondingly straightened. This is illustrated by comparing the curves 25, 27 and 29 of Fig. 4 with the curve 23. These curves are constructed for certain ideal cases represented in Fig. 5 where the ordinates represent saturation potentials for the successive points along the filament 11—12. When the saturation potential is uniform along the entire length of the filament we have the line 23—24 in Fig. 5, for which the current voltage curve is 23 in Fig. 4.

Next assume that the minimum saturation potential drops off at the ends as shown by the line 11—25—26—12 in Fig. 5. This gives the curve 25 in Fig. 4. A more pronounced transition at the ends of the filament, as indicated by the line 11—27—28—12 in Fig. 5, gives the curve 27 in Fig. 4, and the extreme case represented by 11—29—12 in Fig. 5 gives the curve 29 in Fig. 4. In practice these characteristics are shifted to the right by an amount equal approximately to half the heating voltage and a continuous transition to saturation is provided by the heating voltage, in addition to the change in curvature caused by the variation of the minimum saturation potential. It is evident, however, that the shape of the characteristics is determined by the variation along the filament of the minimum saturation potential, and that the wider the limits between which the minimum saturation potential varies, the greater will be the departure from the characteristic of the ideal equipotential, isothermal filament.

In many practical tubes with a uniformly constructed filament, such an extreme gradation as that shown in 11—29—12 in Fig. 5 would be impossible simply by cooling the ends by conduction of heat into the leads.

Various materials used as filaments for thermionic vacuum tubes emit electrons at

different rates at the same temperature. Furthermore many thermionic vacuum tubes have their filaments coated with certain oxides, such as calcium oxide, these coatings emitting electrons at various rates at the same temperature. Evidently, other things being equal, a filament with high emissivity will require a higher minimum saturation potential than a filament with low emissivity. The shape of the minimum saturation potential curve, Fig. 8, accordingly may be varied by application of coatings of different emissivities on different parts of the filament. In particular the effect of cooling at the ends may be accentuated by application of a coating of high emissivity to the hottest part of the filament coatings, of less emissivity to cooler parts, and least emissivity to the coolest parts of the filament. The resulting variation of minimum saturation potentials is consequently greater, enhancing the straightness of the characteristic. Conversely, by applying coatings of high emissivity to the coolest portions and low emissivity to the hottest portions of the filament, the effect of cooling at the ends may be compensated, giving an approach to a constant minimum saturation potential for the whole filament, and consequently enhancing the curvature of the characteristic.

Thus far the discussion has related to a two-electrode vacuum tube as in Fig. 1. In the three-electrode tube, as in Fig. 2, there is a third electrode or grid 20 usually placed between the filament 11—12 and the anode 14, and the potentials on the grid and anode are in general different. Moreover, although the potential on the grid varies, it is usually kept negative all the time by means of the battery 17 so that no current flows to the grid. Under these circumstances the three-electrode tube can be treated as a two-electrode tube with a hypothetical anode voltage V given by the equation

$$V = \frac{V_p}{\mu} + V_g + \epsilon$$

where V_p is the anode voltage, V_g is the grid voltage, and μ and ϵ are constants for any particular tube.

In case the three-electrode tube is used as an amplifier, it will generally be desirable that the relation shall be linear between the output current in circuit 22 and the input voltage in circuit 18. Referring to Fig. 4, the upper sloping part of the characteristic 25 is nearly a straight line and the intermediate sloping part of the characteristic 27 is very nearly straight, and a portion a little lower down for the characteristic 29 is substantially straight. If the tube is adjusted so that it works as an amplifier on the straight sloping portion of its characteristic, it will amplify without distortion, and by coating the filament-cathode so as to accentuate the

lower emissivity at the cooler parts of the filament, the more advantageous characteristics 25, 27 or 29 can be obtained instead of the ideal characteristic 23.

5 In case a vacuum tube of two electrodes or three electrodes is to be used as a rectifier or detector or modulator, a curved characteristic becomes desirable, and in such a case if the cooling at the ends of the filament gives a characteristic more like 25 or 27 or 29 in Fig. 10 4, the effect may be compensated by coating the cooler parts of the filament with material of higher emissivity so as to bring the characteristic back to or toward the form shown at 23 in Fig. 4, with substantial curvature 15 along its length.

Besides modifying the shape of the characteristic by varying the character of the filament coating along its length, somewhat the 20 same effect may be produced to a degree by varying the cross section of the filament. If the end portions of the filament are of greater cross section than the intermediate portion they will be at lower temperature on that account and the same effect will be secured as if 25 a filament of uniform cross section were coated with material of less emissivity toward its ends. Reciprocally, if the cross section of the filament is greater near its middle part, then on that account the filament will be 30 hotter near its ends and the effect will be somewhat the same as if a uniform filament were coated with material of greater emissivity toward its ends.

35 I claim:

A thermionic high vacuum electron-discharge tube having its cathode in the form of an elongated filament coated with materials of emissivity value varying from zone to zone 40 along its length whereby the current-voltage characteristic is given a desired shape.

In testimony whereof, I have signed my name to this specification this 19th day of December 1924.

45 CHARLES W. CARTER, JR.

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