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OF THE
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KIYOSHI TAKATSU, DIRECTOR.

NO. 237

CALCULATIONS ON VACUUM TUBES AND THE DESIGN OF TRIODES

By

Yuziro Kusunose

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ELECTROTECHNICAL LABORATORY,
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SYNOPSIS

The primary object of the paper is to present in simple form a method of designing triode vacuum tubes.

The working conditions of a triode can be predicted from its static characteristics which are determinable from the electrode configurations. The first two chapters of the paper are devoted to these investigations.

As formulas now available for calculations of the characteristics and the amplification constant have been derived from tubes with electrodes of the simplest structures, special considerations have to be taken for applying them to the present tubes of more complicated structures. Such measures being taken, approximation of calculation to experiment, which may be regarded sufficient for the purpose of designing, has been reached.

For the derivation of various working conditions of a triode from its static characteristics, the writer has worked out a graphical representation of the alter-

nating and direct components of the anode working currents for various anode and grid voltages, approximating the static characteristics as a linear relation. The resulting dynamic characteristic diagram where currents are expressed in the unit of saturation current, and voltages in that of saturating voltage, is applicable to any triode in evaluating the working voltages, currents and powers for a given circuit arrangement as well as given anode and grid voltages, whether the tube be used as an amplifier, an oscillator, or a modulator.

In the last chapter, an essential case of the designing process is shown, in which the use of the triode is indicated and its power output given. The working points are first determined on the dynamic characteristic diagram so as to conform to the use of the triode. All the quantities in the working condition are thus known, being expressed in the units as given above. The power output is known as a quantity $\frac{\text{Power Output}}{\text{Saturation Current} \times \text{Saturating Voltage}}$ where the product in the denominator may accordingly be determined, and this product is next to be split into its component parts. An alternative problem arises here which type of a tube is to be selected, high anode voltage and low emission, or low anode voltage and high emission, and the solution will need both the economical and technical considerations. The amplification constant is then determined so as to comply with the saturating voltage, grid loss being considered.

After this, generally speaking, configurations of the anode and grid are determined from the power and the saturating voltage, grid mesh construction from the amplification constant, and dimensions of the cathode from the saturation current and the estimated life.

All the descriptions throughout the paper are illustrated by numerical examples on various types of tubes tested at the Laboratory.

CONTENTS

LIST OF TUBES GIVEN IN EXAMPLES

LIST OF SYMBOLS

A anode effective area (cm^2.)
a ratio of grid conductor area to grid surface area
c conversion factor of k for plane-electrode tubes
d_f filament diameter (cm.)
d_g grid wire diameter (cm.)
e_a anode voltage (volt)
e_f filament terminal voltage (volt)
e_f' effective filament voltage (volt)
e_g grid voltage (volt)
e_g' equivalent grid voltage (volt)
e_s saturating voltage (volt)
E_a steady anode voltage (volt)
E_g steady grid voltage or grid bias voltage (volt)
$\mathcal{E}_a$ alternating anode voltage, max. value (volt)
$\mathcal{E}_g$ alternating grid voltage, max. value(volt)
g mutual conductance (mho)
G perveance
i electron current (amp.)
i_a anode current, instantaneous value(amp.)
i_g grid current (amp.)
i_f filament current (amp.)
I_a anode mean or direct current (amp.)
I_g grid mean or direct current (amp.)
I_s saturation current (amp.)
$\mathcal{I}_a$ anode alternating current, fundamental component max. value (amp.)
k amplification constant
l total length of filament (cm.)
L life of cathode (hour)
L_g ratio of total length of effective grid wires to axial length of grid.
m number of points of support of filament
n number of grid wires parallel to filament
p pitch of adjacent grid wires (cm.)
P power output of a tube (watt)
q portion of filament power radiated through anode
r anode impedance or internal resistance (ohm)
$\bar{r}$ mean anode impedance (ohm)
R alternating current resistance of a closed resonance circuit (ohm)
$\mathcal{R}$ anode circuit impedance (resistive) (ohm)
r_f filament radius (cm.)
r_g grid wire radius (cm.)
s number of supports of grid wires which lie in the stream of electrons
t thickness of grid support (cm.)
w permissible anode loss per unit area ($watt/cm^2$)
W_a anode loss (watt)
W_f filament heating power (watt)
W_g grid loss (watt)
W_l grid leak loss (watt)
x_a distance of anode to cathode axis (cm.)
x_g distance of grid to cathode axis (cm.)
z_a mean shortest distance of anode to filament (cm.)
z_g mean shortest distance of grid to filament (cm.)
α specific power output
η anode power conversion efficiency

CALCULATIONS ON VACUUM TUBES AND THE DESIGN OF TRIODES

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INTRODUCTION

The rapid growth of radio communication has its origin in the introduction of vacuum tubes, which at the present time form indispensable parts of radio apparatuses, and accordingly a large variety of tubes has come out on the market throughout the world.

In the course of this progress, the designing of vacum tubes has been developed through the experiences of the leading manufacturers, but it does not seem to have been carried to a point where it had been well standardized as in other electrical apparatuses.

The writer has devoted himself to the study on the design problems for several years, and arrived at a definite procedure as is described in this paper, which he believes to be of some use to valve manufacturers, although it is not at all considered to be perfect as is desirable.

The writer's thanks are due to E. Yokoyama, Chief of Radio Section, under whose direction the present work has been carried out and also to N. Kato, I. Miura, S. Maeda and others of the Section for their assistances to the investigations.

CHAPTER I.

COMPUTATION OF CHARACTERISTICS FROM THE ELECTRODE CONFIGURATIONS

(1) Diode Characteristics.

If a diode has a cathode of uniform potential all over the surface, such as an indirectly-heated cathode, or if the anode voltage is very high compared with the filament terminal voltage, the well-known space-charge equation applies to the determination of anode current i_a at a given anode voltage e_a:[1]

$$i_a = G e_a^{\frac{3}{2}} \quad \cdots\cdots\cdots\cdots\cdots (1)$$

When the cathode consists of a filament heated by a direct current at a terminal voltage e_f, the above equation must be corrected for the non-uniformity of anode-to-cathode potential difference along the length of the filament, and the modification may be expressed by the following equations, anode voltage being measured from the negative leg of the filament:[2]

$$\text{for} \quad e_a < e_f: \quad i_a = \frac{2}{5} G \frac{1}{e_f} e_a^{\frac{5}{2}} = \frac{2}{5} G e_f^{\frac{3}{2}} \left(\frac{e_a}{e_f}\right)^{\frac{5}{2}} \quad \cdots\cdots (2)$$

$$\text{for} \quad e_a > e_f: \quad i_a = \frac{2}{5} G \frac{1}{e_f} \left[e_a^{\frac{5}{2}} - (e_a - e_f)^{\frac{5}{2}} \right]$$

$$= \frac{2}{5} G e^{\frac{3}{2}} \left[\left(\frac{e_a}{e_f}\right)^{\frac{5}{2}} - \left(\frac{e_a}{e_f} - 1\right)^{\frac{5}{2}} \right] \quad \cdots\cdots (3)$$

The two equations may be reduced to a single one, as

$$i_a = \frac{2}{5} G e_f^{\frac{3}{2}} f\left(\frac{e_a}{e}\right) \quad \cdots\cdots\cdots (4)$$

(1) I. Langmuir: Phys. Rev. 21, p. 419, 1923 and 22, p. 347, 1923.
(2) Van der Bijl: "Thermionic Vacuum Tube," p. 64.

The values of $f\left(\frac{e_a}{e_f}\right)$ computed for a series of values of $\frac{e_a}{e_f}$ are shown in TABLE I on page 160.

If the filament voltage is not known, it may be calculated from dimensions of the filament by means of CHART II, working temperature or saturation current being assumed. For the use of the chart, the description on page 136 is to be referred.

The constant G which is called "perveance" may be determined from the electrode configurations, and in ordinary cases (Fig. 1),

$$G = 2.33 \times 10^{-6} \frac{A}{x_a^2} \quad \cdots\cdots\cdots (5)$$

in which A = effective anode area.

x_a = distance of the anode surface from the axis of the filament.

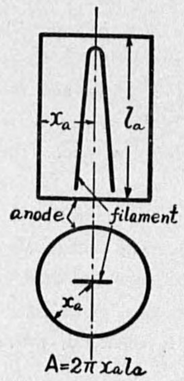


Fig. 1.

All quantities relating to dimensions are expressed in centimeter units, and those relating to electricity in volts, amperes, ohms, watts, etc., unless otherwise specified.

The original equation given by Langmuir[1] for a diode with parallel plane anode and cathode, distance between them being x_a, is

$$i_a = 2.33 \times 10^{-6} \frac{A}{x_a^2} e_a^{\frac{3}{2}}$$

and for a diode with cylindrical anode of radius x_a, and coaxial cathode of radius r_c, length of the system being l_a, it is

$$i_a = 14.65 \times 10^{-6} \frac{l_a}{\beta^2 x_a} e_a^{\frac{3}{2}} = 2.33 \times 10^{-6} \frac{A}{\beta^2 x_a^2} e_a^{\frac{3}{2}}$$

The value of β^2 depends on $\frac{x_a}{r_c}$, but for most practical cases at which this ratio is greater than 10 or so, β^2 tends to unity, and moreover in the complicated structures of filament usually met in practice the meaning of this ratio becomes vague, so we intend to consider β^2 as unity. This being done, the two equations become identical either for plane or cylindrical forms of electrodes.

The above relation for G is equally applicable to anodes of either plane or cylindrical forms. For plane anode tubes the effective anode area is however not the actual whole area of the anode metal, but that area on which electrons are considered to bombard, and the writer has empirically found that this area may be taken as that comprised in the breadth $2x_a$ along the filament length projected on the anode, as illustrated in Fig. 2.

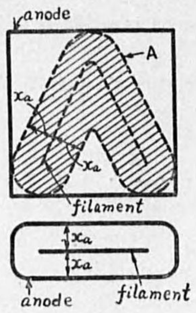


Fig. 2.

The above diode equations are sufficiently accurate for designing, although there are neglected the various minor effects, such as those due to initial velocities of electrons, contact potential difference, magnetic field around the cathode, nonuniformity of cathode temperature causing partial saturation, superposition of anode current on the filament current, and so forth.

When the filament is supported by such a structure as shown in Fig. 3, which is often the case with high-power rectifier tubes, the supporting structure must be considered as grid of a triode and the characteristic must be computed by the eaquation for the triode assuming the grid voltage as zero. (See example 5, page 10)

Fig. 3.

When the anode return is not connected to the negative end of the filament, the anode voltage must be corrected to the value measured from the negative end by adding a voltage which is equal to the potential of the point, where return is connected, above the negative end.

When the filament is lighted by alternating current, and the anode return is at one end of the filament, anode voltage measured above the negative end fluctuates per complete cycle between e_a and $e_a+\sqrt{2}e_f$, e_f being the effective value, and the anode current at an anode voltage e_a shall be taken as the average value of the currents computed for e_a and $e_a+\sqrt{2}e_f$. For rough estimations, equation (1) may however be applied to this case.

If the anode voltage is referred to the neutral point of the filament voltage, filament being lighted by d. c., equation (1) may be applied even at such a low anode voltage as twice that of the filament within an error of 1%. When the anode return is at one leg of the filament, the error will be 10% at $\frac{e_a}{e_f}=7.5$, and 1% at $\frac{e_a}{e_f}=71$.

If residual gases are existent by appreciable amount, the characteristic may be affected in various manners. The anode current usually increases steeper than the $\frac{3}{2}$ power of the voltage due to ionization, in a vacuum lower than, say, 10^{-4} mm. Hg. Such tubes are of no practical value.

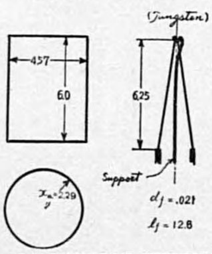
Examples 1 to 9 on the following pages are intended for the illustration of the computing methods as well as for showing their validity in comparison with the observed data.

Example 1.

DIODE TYPE: KN-155 Manufacturer: Tokyo Denki K. K.

Observations

Anode Cathode



Calculations

$x_a = 2.29$

$A = \pi \times 4.57 \times 6.0$

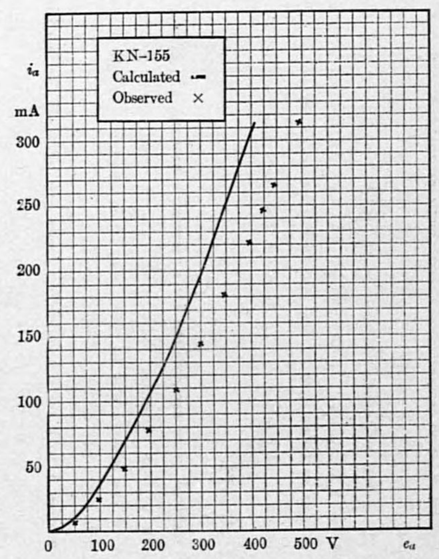
$= 86$

$\frac{A}{x_a^2} = 16.4$

$G = .0381 \times 10^{-3}$

Equation (1)

	e_a	i_a	e_a	$e_a^{\frac{3}{2}}$	i_a
	0	0	0	0	0
e_f=12	100	.026	100	1.0×10^3	.038
i_f=6.1	200	.077	200	2.8	.107
(A. C.)	300	.145	300	5.2	.198
	400	.220	400	8.0	.305
	500	.310	500	11.2	.427

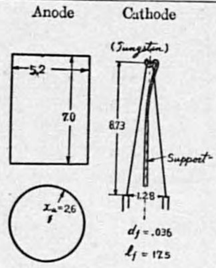


Example 2.

DIODE TYPE: KN-156 Manufacturer: Tokyo Denki K. K.

Observations

Anode Cathode



Calculations

$x_a = 2.6$

$A = \pi \times 5.2 \times 7$

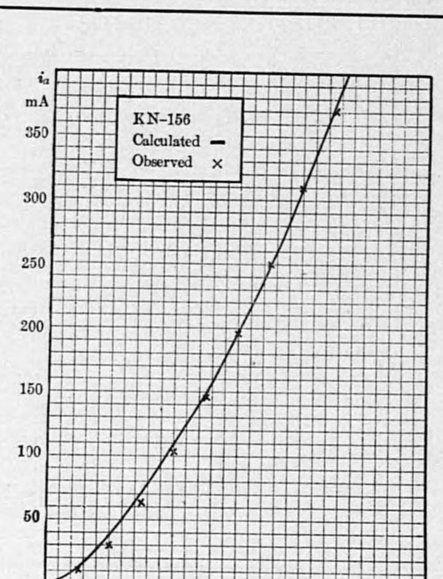
$= 114$

$\frac{A}{x_a^2} = 16.8$

$G = .0392 \times 10^{-3}$

Equation (1)

	e_a	i_a	e_a	$e_a^{\frac{3}{2}}$	i_a
	0	0	0	0	0
e_f=15	100	.030	100	1.0×10^3	.039
i_f=10.35	200	.103	200	2.8	.110
	300	.197	300	5.2	.196
	400	.310	400	8.0	.314
	500	.435	500	11.2	.440

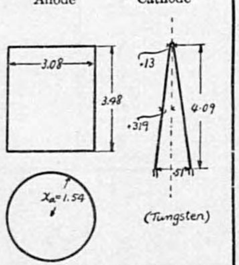


Example 3.

DIODE TYPE: MR-1 Manufacturer: Marconi Co.

Obrervations

Anode Cathode



Calculations

$x_a = 1.54$

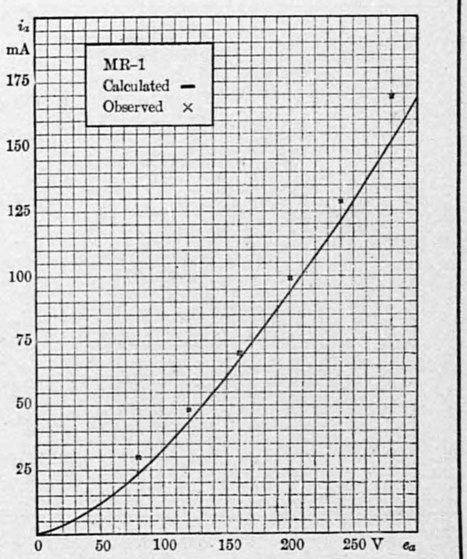
$A = 33.6$

$\frac{A}{x_a^2} = 14.2$

$G = .033 \times 10^{-3}$

Equation (1)

	e_a	i_a	e_a	$e_a^{\frac{3}{2}}$	i_a
	0	0	0	0	0
e_f=9.0	80	.030	80	715	.024
i_f=5.7	120	.048	120	1,330	.044
(D. C.)	160	.070	160	2,034	.072
	200	.099	200	2,825	.093
	240	.128	240	3,715	.122
	280	.168	280	4,620	.152
	320	.228	320	5,720	.189

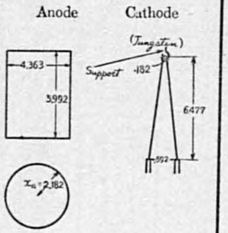


Example 4.

DIODE TYPE: MR-4 Manufacturer: Marconi Co.

Observations

Anode Cathode



Calculations

$x_a = 2.18$

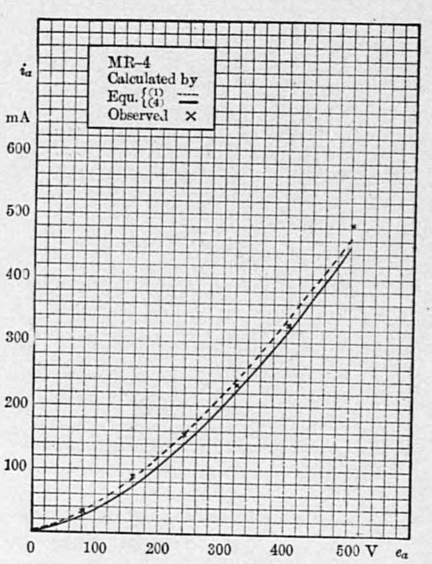
$A = 32.2$

$\frac{A}{x_a^2} = 17.3$

$G = .0402 \times 10^{-3}$

$\frac{2}{5} G e_f^{\frac{3}{2}} = .000707$

	e_a	i_a	Equation (1) e_a	Equation (1) i_a	Equation (4) e_a	Equation (4) i_a
	0	0	0	0	0	0
e_f=12.5	80	.030	120	.053	50	.0117
i_f=6.3	160	.085	160	.082	125	.052
(D. C.)	240	.150	240	.150	250	.149
	320	.225	320	.230	500	.440
	400	.320	400	.321		
	500	.475	500	.450		

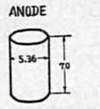


Example 5.

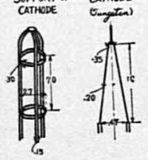
DIODE TYPE: MR-6 Manufacturer: Marconi Co.

Observations

ANODE



SUPPORT OF CATHODE CATHODE (Tungsten)



$e_f = 15.5$ $i_f = 9.8$

e_a	i_a
0	0
100	.010
200	.038
300	.075
400	.120
500	.185

Calculations

Filament support being considered

$x_a = 2.68$ $x_g = 1.35$

$\log \frac{x_a}{x_g} = .298$ $A = 118$

$L_g = n + \frac{2\pi x_g}{l} = 4.2$

$n_a = \frac{nd_gl + 2\pi x_g l}{2x_g l} = .30$

(one of the rings taken into account)

$k = \frac{4.2 \times .298}{.542} = 2.3$

$z_a = 2.48$ $z_g = 1.15$

$G = .096 \times 10^{-3}$

$\frac{2}{5} G e_f^{\frac{3}{2}} = .00234$

Support not considered

$x_a = 2.68$

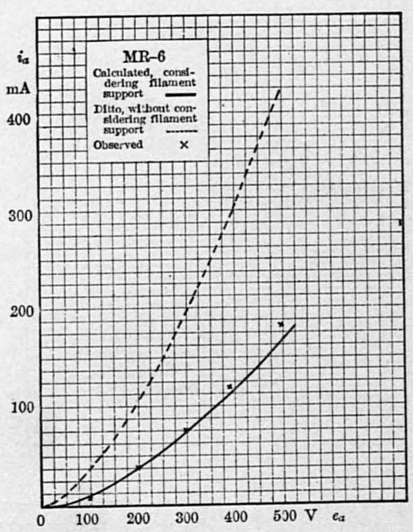
$A = 118$

$\frac{A}{x_a^2} = 14.6$

$G = .038 \times 10^{-3}$

$i_a = G e_a^{\frac{3}{2}}$

e_g'/e_f	e_g'	i	$(e_g=0)$ $e_a = (1+k)e_g'$	e_a	i_a
0	0	0	0	0	0
2	31	.911	102	100	.038
4	62	.039	205	200	.106
6	93	.076	307	300	.198
8	124	.123	410	400	.300
10	155	.173	510	500	.425

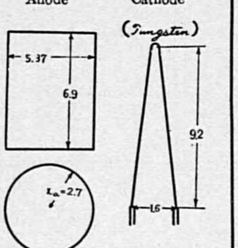


Example 6.

DIODE TYPE: MR-7 A Manufacturer: Marconi Co.

Observations

Anode Cathode (Tungsten)



Calculations

$x_a = 2.7$

$A = \pi \times 5.37 \times 6.9$

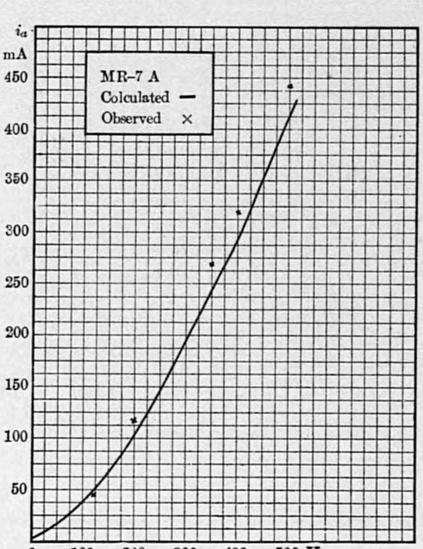
$= 117$

$\frac{A}{x_a^2} = 1.60$

$G = .037 \times 10^{-3}$

Equation (1)

	e_a	i_a	e_a	$e_a^{\frac{3}{2}}$	i_a
	0	0	0	0	0
$e_f = 12.5$	120	.047	120	1,310	.048
$i_f = 25.2$	200	.119	200	2,820	.104
(A. C.)	350	.263	350	6,550	.242
	400	.319	400	8,000	.296
	500	.439	500	11,200	.415

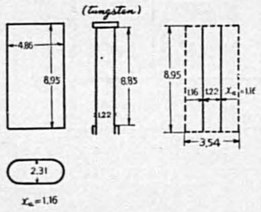


Example 7.

DIODE TYPE: RG-46 Manufacturer: Telefunken G.

Observations

Anode Cathode (tungsten) A



Calculations

$x_a = 1.16$

$A = 2 \times 3.54 \times 8.95$

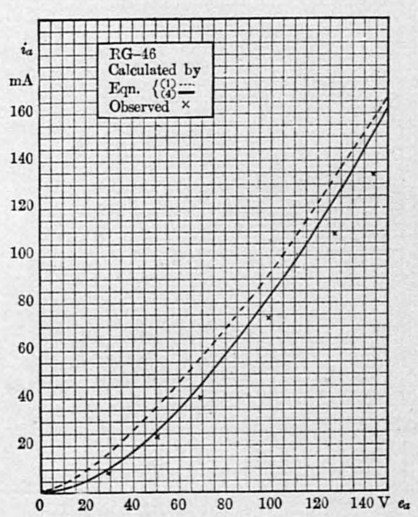
$= 63.4$

$\frac{A}{x_a^2} = 41$

$G = .095 \times 10^{-3}$

$\frac{2}{5} G e_f^{\frac{3}{2}} = .0022$

	e_a	i_a	Eqn (1) e_a	Eqn (1) i_a	Equation (4) e_a/e_f	Equation (4) i
e_f=15.5	0	0	0	0	0	0
	30	.010	31	.016	2	.010
i_f=8.0	51	.025	62	.047	4	.038
(D. C.)	70	.041	93	.085	6	.075
	100	.074	124	.131	8	.122
	128	.110	155	.182	10	.170
	145	.135				

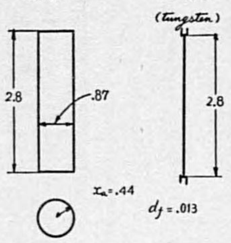


Example 8.

DIODE TYPE: UV-212 Manufacturer: R. C. A.

Observations

Anode Cathode (tungsten)



Calculations

$x_a = .44$

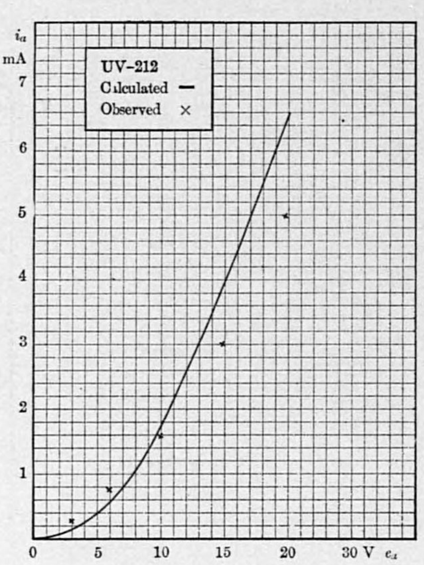
$A = 7.66$

$\frac{A}{x_a^2} = 39.5$

$G = .092 \times 10^{-3}$

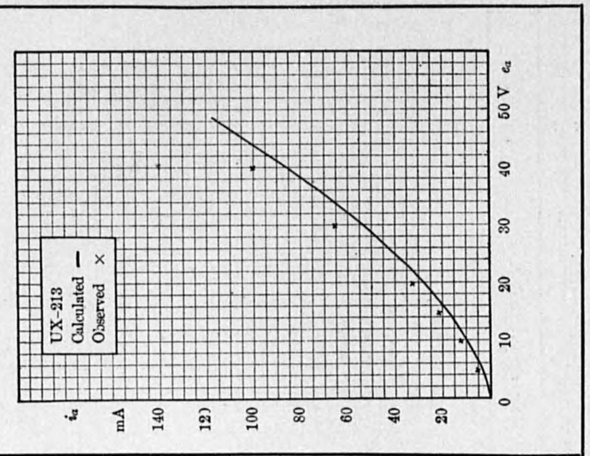
$\frac{2}{5} G e_f^{\frac{3}{2}} = .00424$

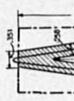
	e_a	i_a	Equation (4) e_a	Equation (4) i_a
e_f=5.1	0	0	0	0
	3	.00030	2.55	.00007
i_f=2.3	6	.00075	5.1	.0004
(D. C.)	10	.0016	10.2	.0018
	15	.0030	15.3	.0039
	20	.0050	20.4	.0066



Example 9.

DIODE TYPE: UX-213 Manufacturer: R. C. A.



Observations			Calculations							
Anode	Cathode	A	$\pi_a=0.129$							
			$A=2.6$							
			$\frac{A}{x_a^2}=156$							
			$G=.364\times10^{-3}$							
			$\frac{2}{5}(Ge_f)^{\frac{3}{2}}=1.63\times10^{-3}$							
			e_f	i_a	$\frac{e_a}{e_f}$	$f\left(\frac{e_a}{e_f}\right)$	e_a	i_a		
			5	.005	0	0	0	0		
			10	.012	0.5	.177	2.5	.0003		
			15	.021	1.0	1.00	5.0	.0016		
			20	.033	1.5	2.57	7.5	.0042		
			30	.066	2.0	4.65	10.0	.0076		
			40	.100	3.0	9.94	15	.016		
					4.0	16.51	20	.027		
					6.0	32.5	30	.053		
					8.0	53.0	40	.087		

$e_f=5.0$ $i_f=2.0$ (D. C.)

(2) Triode Characteristics.

In a triode, an anode voltage e_a and a grid voltage e_g produce as their combined effect a certain strength of electric field around the cathode, and the same electric field can be produced if the grid exists as an only anode and is at the voltage[3]

$$e_g' = \frac{e_a + ke_g}{1+k} \quad \cdots\cdots\cdots\cdots\cdots (6)$$

where k is the amplification constant.

The space current is mainly governed by the electrostatic action of the system of electrodes, and if it be assumed that the two conditions above cited give equal space current, the characteristic of the triode will be expressed by the following equations which are obtained by replacing e_a in the equations (1) and (4) by e_g':

$$i = Ge_g'^{\frac{3}{2}} \quad \cdots\cdots\cdots\cdots\cdots (7)$$

$$i = \frac{2}{5} G e_f^{\frac{3}{2}} f\left(\frac{e_g'}{e_f}\right), \quad \cdots\cdots\cdots\cdots (8)$$

in which $f\left(\frac{e_g'}{e_f}\right)$ may be obtained from TABLE I on page 160,

and $$G = 2.33\times10^{-6}\frac{\text{gride area}}{x_g^2}.$$

For cylindrical electrodes, effective grid area $=2\pi x_g l$

and effective anode area $=2\pi x_a l = A$

hence $$G = 2.33\times10^{-6}\frac{A}{x_a x_g},$$

in which x_a, x_g are the distances of the anode and grid surfaces respectively from the cathode axis. But the writer found by experiments that in the case of triodes having cylindrical anode and grid, and a cathode of other than a single axially-spanned filament, such as V-shaped, the values of x_a and x_g in the expression of

(3) W. H. Eccles: "Continuous Wave Wireless Telegraphy," p. 338.

G should be replaced by the mean shortest distances from the respective electrodes to the filament z_a and z_g, which should be taken in such a way as illustrated in Fig. 4.

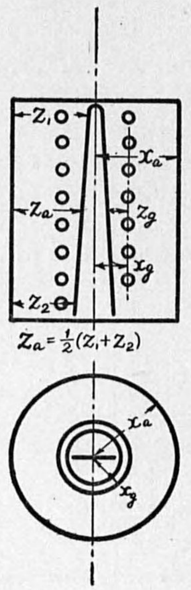


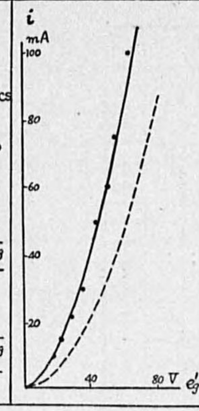
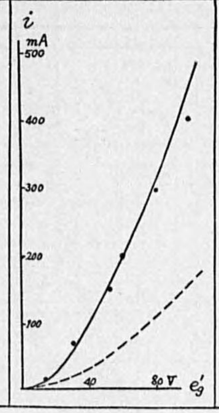
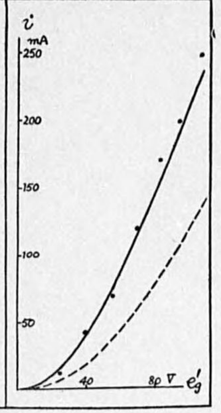
FIG. 4.

Then generally

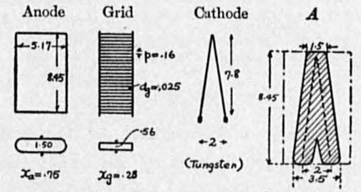
$$G = 2.33 \times 10^{-6} \frac{A}{z_a z_g} \quad \cdots\cdots\cdots\cdots (9)$$

This expression may also be applied to tubes with plane electrodes and in this case evaluation of the anode effective area A should be in accordance with that described for the diode. (Fig. 2)

Example 10. Characteristics of triodes with cylindrical anode and grid, and V-shaped filament.

Tube	UV-206 (R.C.A)	228-A (Western El., Water-cooled)	S-53 (Nihon Musen K.)
Dimensions	$x_a = 2.0$ $z_a = 1.71$ $A = 10.3$ $x_g = 0.98$ $z_g = 0.69$ $e_g = 11$	$x_a = 1.73$ $z_a = 1.20$ $A = 14.8$ $x_g = 1.05$ $z_g = 0.50$ $e_g = 21.5$	$x_a = 2.77$ $z_a = 2.46$ $A = 14.6$ $x_g = 0.98$ $z_g = 0.67$ $e_g = 15$
Charcteristics Observed • Calculated with $G = 2.33 \times 10^{-6} \frac{A}{z_a z_g}$ Ditto with $G = 2.33 \times 10^{-6} \frac{A}{x_a x_g}$			

Example 11. Evaluation of the effective area of a plane anode.
Triode type Cymotron **UV-204** (Tokyo Denki K. K.).
Dimensions are shown in Fig. 5.



(UV-204. T. E. C.)

FIG. 5.

The effective anode area

$$A = 2 \times 2.5 \times 8.45 = 42.3$$

and $G = 0.446 \times 10^{-3}$

If the actual area is taken

$$A'=2\times5.17\times8.45=87.3$$

and $$G'=0.965\times10^{-3}$$

The calculated curves are shown in Fig. 6, which shows the validity of taking $A=42.3$.

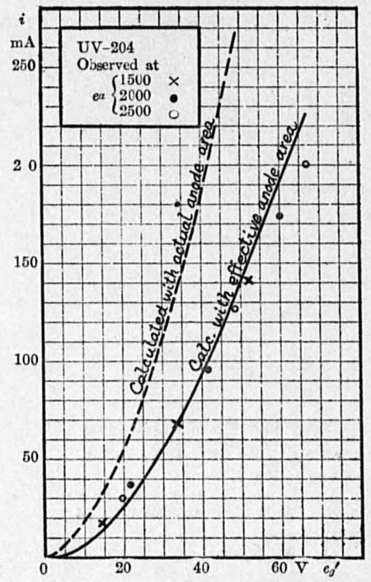


FIG. 6.

If e_a and e_g are given and k is computed by the method described in the following section, the equivalent grid voltage e_g' can be calculated by equation (6), and space current i at the given anode and grid voltages is obtained by equation (7) or (8).

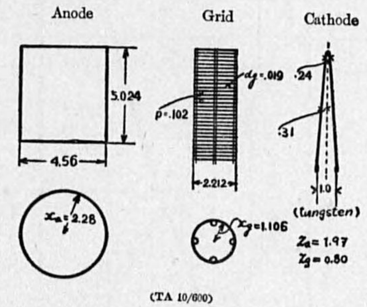
The depiction of the anode current-grid voltage characteristic curves may be simplified in the following manner.

First obtain the numerical relation between i and $\frac{e_g'}{e_f}$ and from it the relation

of i to e_g' for a given value of e_f. Then assume that $e_a=0$, or $e_g'=\frac{k}{1+k}e_g$, and i versus e_g curve can be drawn and this corresponds to the characteristic for the anode voltage zero. In order to obtain a characteristic for any anode voltage e_a, this curve for $e_a=0$ should be shifted horizontally to the negative grid voltage direction by an amount of $\frac{e_a}{k}$ in the grid voltage scale, because i is solely determined by e_a+ke_g and an increase of anode voltage by e_a' can be compensated by the reduction of grid voltage by $\frac{e_a'}{k}$ to keep e_a+ke_g unvaried and hence to give equal space current.

It should be remembered that a slightest error in the calculated value of k causes a considerable amount of error on the resulting values of i especially at high anode voltages.

Example 12. Computation of static characteristics.
Triode type **TA10/600** (Philips' Lamp Works)
Dimensions are shown in Fig. 7.



(TA 10/600)

FIG. 7.

Calculation:

$$A=2\pi\times2.28\times5.02=72.0$$

$$z_a=1.97 \qquad z_g=0.80$$

From equation (9)

$$G=0.110\times10^{-3} \qquad e_f=12.5 \text{ (rating)}$$

$$\frac{2}{5}Ge_f^{\frac{3}{2}}=0.00208$$

i calculated by equation (8) is as follows and is plotted in Fig. 8, together with the observed data.

$\frac{e_g'}{e_f}$	e_g'	i
0	0	0
1	12.5	.0021
3	37.5	.0206
5	62.5	.050
8	100	.110

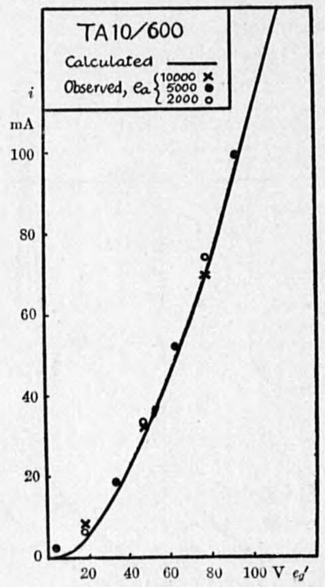


Fig. 8.

Amplification constant calculated by equation (12) given later is $k=112$, while the observed value is 114.

To draw i versus e_g characteristics, assume $e_a=0$, then

$$e_g'=\frac{k}{1+k}e_g$$

or $$e_g=1.01e_g'$$

i to e_g relations are then obtained as in the following table.

Draw i versus e_g curve for $e_a=0$ as shown in Fig. 9. To obtain characteristic curve for an anode voltage e_a, shift this curve to the left by $\frac{e_a}{k}$ in grid voltage scale. The resulting curves are shown in Fig. 9, in which the observed data are also plotted.

i	e_g'	e_g
0	0	0
.0021	12.5	12.6
.0206	37.5	37.9
.050	62.5	63.2
.110	100	101

e_a	e_a/k
2,000	17.8
6,000	53.7
10,000	89.4

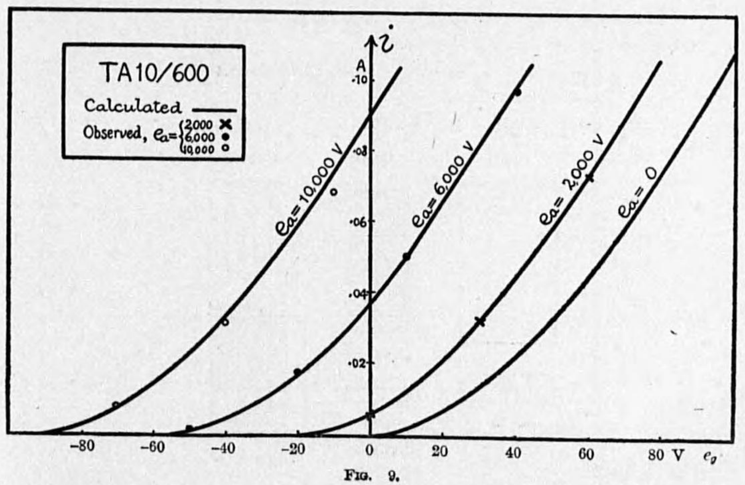


Fig. 9.

Observed data of the tube:

$e_f=12.5$ $i_f=6.58$ $k=114$

e_a	e_g	$e_g'=\frac{e_a+ke_g}{1+k}$	i_a	i_g	$i=i_a+i_g$
10,000	−70	17.56	.008	0	.008
	−40	47.2	.032	0	.032
	−10	77.0	.069	0	.069
6,000	−50	2.63	.002	0	.002
	−20	32.7	.018	0	.018
	10	62.0	.050	.0010	.051
	40	91.8	.094	.0035	.098
2,000	0	17.4	.006	0	.006
	30	47.1	.030	.0025	.033
	60	76.8	.070	.0035	.074

Example 13. Computation of static characteristics.

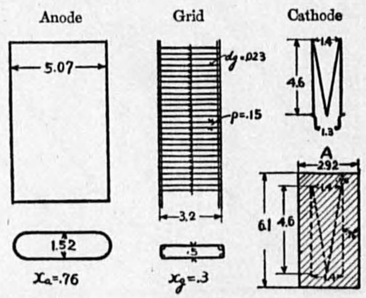
Triode type **UV-204A** (R. C. A.)

Calculations; refer to Fig. 10 for the dimensions,

$x_a=x_a=0.76$ $x_g=x_g=0.30$ $A=2\times6.1\times2.92=35.4$

$G=0.361\times10^{-3}$

$e_f=11$ (rating) $\frac{3}{8}Ge_f^{\frac{3}{2}}=0.0052$



(UV-204 A)

FIG. 10.

$\frac{e_g'}{e_f}$	e_g'	$f\left(\frac{e_g'}{e_f}\right)$	i
0	0	0	0
2	22	4.65	.024
4	44	16.51	.086
6	66	32.5	.169
8	88	53.0	.276
10	110	74.0	.385

i versus e_g' curve is drawn as shown in Fig. 11, in which observed values are also plotted to show the validity of the calculation.

By the calculation explained later,

$L_g=12.6$ $c=1.6$ $\pi a=0.50$ $k=\frac{1.7\times12.6\times.404}{.335}=25.8$ (k observed $=23$)

To draw i versus e_g characteristics, first assume $e_a=0$,

then $e_g'=\frac{k}{1+k}e_g$ or $e_g=1.04e_g'$

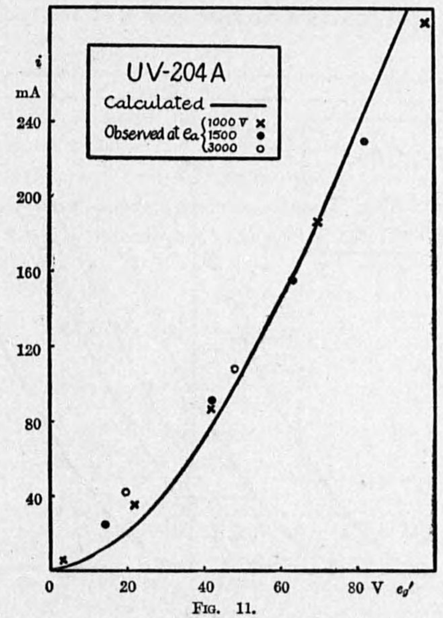


FIG. 11.

i	e_g'	e_g
0	0	0
.024	22	23
.086	44	46
.169	66	69
.276	88	92
.385	110	114

e_a	$\frac{e_a}{k}$
1,000	39
1,500	58
2,000	77
3,000	116

Draw i versus e_g curve for $e_a=0$ as shown in Fig. 12.

For any anode voltage e_a this curve should be shifted by $\frac{e_a}{k}$ given in the table.

The resulting characteritic curves are shown in Fig. 12. There is a considerable error in the curve for $e_a=3{,}000\,V$. This is caused by the discrepancy of the calculated value of k from the actual one. If the observed value of k is taken in the above calculations the resulting curves are of course consistent with the calculated ones.

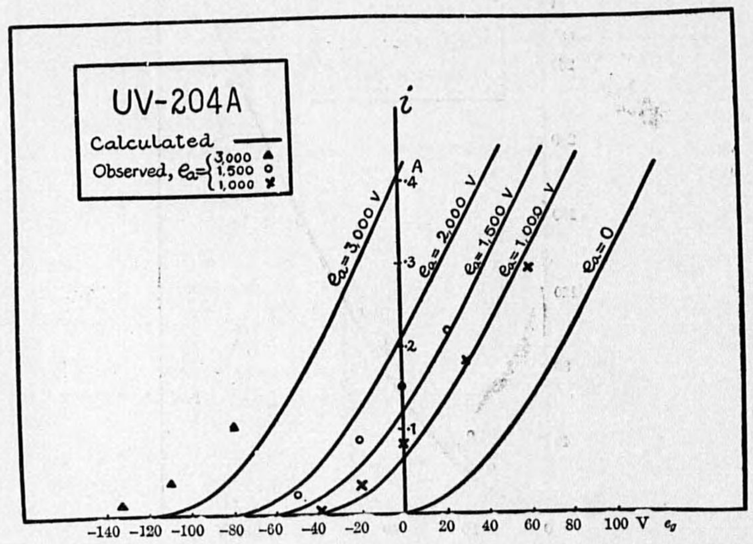


Fig. 12.

Observed data of the tubes:

e_f=11 i_f=3.9 k=23

e_a	e_g	$e_g'=\frac{e_a+ke_g}{1+k}$	i_a	i_g	$i=i_a+i_g$
1,000	− 40	3.3	.005	0	.005
	− 21	22	.035	0	.035
	0	42	.086	0	.086
	30	70	.172	.011	.183
	60	98	.274	.019	.293
1,500	− 51	14	.024	0	.024
	− 21	42	.090	0	.090
	0	63	.154	.001	.155
	21	82	.220	.009	.229
3,000	−131	0	.013	0	.013
	−110	19.6	.041	0	.041
	− 80	48	.107	0	.107

The space current i is the sum of anode and grid currents,

$$i=i_a+i_g \qquad \cdots\cdots\cdots\cdots\cdots (10)$$

As long as the grid is negative, $i_g=0$ and $i_a=i$, but when grid becomes positive, grid current begins to flow. In the ordinary tubes, the grid is so constructed that it does not greatly absorb the space current, and as long as the positive grid voltage is low, grid current is not appreciable compared with anode current, and in this region the following formulas are applicable for the rough estimation of the grid current:[4]

$$i_g=\gamma a\sqrt{\frac{e_g}{e_a}}\,.\,i_a=\frac{\gamma a\sqrt{\frac{e_g}{e_a}}}{1+\gamma a\sqrt{\frac{e_g}{e_a}}}\,i.$$

and hence

$$i_a=\frac{i}{1+\gamma a\sqrt{\frac{e_g}{e_a}}} \qquad \cdots\cdots\cdots (11)$$

in which $\gamma=\sqrt{\frac{\log\frac{x_a}{r_c}}{\log\frac{x_g}{r_c}}}$ are usually of the order: $\gamma=1-2\fallingdotseq 1.5$.

(4) H. Lange: Z f. hochfrequ. Techn., p. 105, April 1928.

The writer's empirical formula $i_g=0.2\sqrt{a\frac{ke_g}{e_a+ke_g}}.\ i$ is also applicable in some cases. Error in i_g does not much affect the value of i_a at low grid voltages.

When the grid voltage becomes so high as to approach the anode voltage, the characteristics are severely affected by secondary emissions from the electrodes, and grid current usually increases very rapidly while anode current falls off in equal rate.

At $e_a=0$, the electron current is totally absorbed in the grid if the grid voltage is positive.

Example 14. Calculation of grid current.

Tube	Observed data					Calculated grid current	
	e_a	e_g	i_a	i_g	i	$i_g=1.5\,a\sqrt{e_g/e_a}\,i_a$	$i_g=0.2\sqrt{a\frac{ke_g}{e_a+ke_g}}.\,i$
102-D (a=.156) (k=30)	100	5.2	.0046	.0003	.0049	.00025	.00030
	100	8.3	.0074	.0004	.0078	.00050	.00051
	148	5.2	.0065	.0003	.0068	.00029	.00039
	148	8.3	.0100	.0004	.0104	.00055	.00065
UV-199 (a=.108) (k=6.6)	20	6	.0023	.0002	.0025	.00020	.00014
	20	16	.0040	.0005	.0045	.00058	.00027
	60	10	.0038	.0003	.0041	.00025	.00020
	100	16	.0042	.0003	.0045	.00027	.00022
MT-4 (a=.274) (k=140)	1000	100	.072	.011	.083	.0093	.0084
	1000	140	.120	.012	.132	.018	.0135
	2000	80	.057	.009	.066	.0047	.0064
	2000	120	.112	.010	.122	.0112	.0120
	3000	20	.014	.002	.016	.0015	.0012
	3000	140	.153	.008	.161	.043	.0160
MT-7 A (a=.153) (k=80)	1000	80	.100	.016	.116	.0064	.0085
	1000	139	.230	.028	.258	.0195	.019
	5000	20	.106	.005	.111	.0016	.0042
	5000	70	.208	.015	.223	.0037	.0127
MT-9 (a=.245) (k=90)	1000	80	.305	.027	.332	.031	.031
	3000	40	.223	.012	.235	.0094	.017
	5000	20	.230	.003	.233	.0033	.012

Tube	Observed data					Calculated grid current	
	e_a	e_g	i_a	i_g	i	$i_g=1.5\,a\sqrt{e_g/e_a}\,i_a$	$i_g=0.2\sqrt{a\frac{ke_g}{e_a+ke_g}}.\,i$
UV-204A (a=.16) (k=25)	1000	30	.172	.011	.183	.006	.010
	1000	60	.274	.019	.293	.009	.018
	5000	21	.220	.009	.229	.006	.009
UV-201A (a=.105) (k=7)	20	5	.0025	.0001	.0026	.0002	.00013
	20	15	.0095	.0013	.0108	.0013	.00064
	60	5	.0065	.0001	.0066	.0003	.00026
	60	10	.0113	.0004	.0117	.0007	.00056

Example 15. Characteristics at highly positive grid voltage (Fig. 13). A tube, with a grid of remarkable secondary emission (Fig. 14), and another with less appreciable secondary emission (Fig. 15).

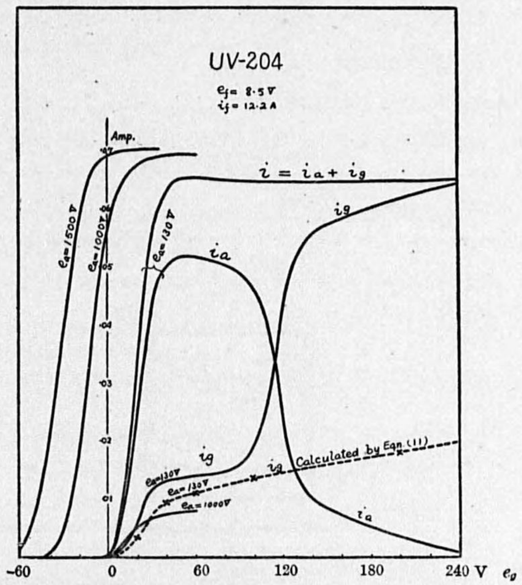


FIG. 13.

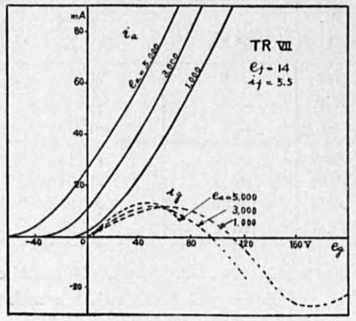


FIG. 14.

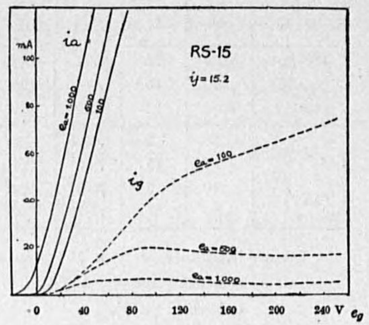


FIG. 15.

(3) Parameters of a Triode.

(i) Amplification Constant.

By the amplification constant k is meant that the electrostatic influence of the grid upon the cathode is k times that of the anode, and theoretical formulas are available for its computation.

Notations regarding the electrode dimensions are illustrated in Fig. 16,

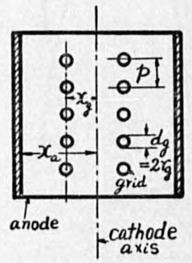


FIG. 16.

For $r_g \ll p \ll x_g$,

and for plane-electrode tubes[5],

$$k=\frac{2\pi x_g}{p}\cdot\frac{\frac{x_a}{x_g}-1}{\log_e\frac{p}{2\pi r_g}} \quad \cdots\cdots\cdots\cdots (k1)$$

and for cylindrical-electrode tubes[6],

$$k=\frac{2\pi x_g}{p}\cdot\frac{\log\frac{x_a}{x_g}}{\log\frac{p}{2\pi r_g}} \quad \cdots\cdots\cdots\cdots (k2)$$

if the condition $r_g \ll p \ll x_g$ is not fulfilled, the more general formula for cylindrical-electrode tubes is to be applied,[7]

$$k=\frac{\frac{2\pi x_g}{p}\cdot\log\frac{x_a}{x_g}-\log\cosh\frac{2\pi r_g}{p}}{\log\cosh\frac{2\pi r_g}{p}-\log\sinh\frac{2\pi r_g}{p}} \quad \cdots\cdots\cdots (k3)$$

The formulas for cylindrical electrodes were originally derived for grid wires parallel to the filament, but they are equally applicable to grids of a spiral or a system of parallel wires spanned crossways to the length of the filament.

Example 16. Amplification constant of tubes with simple structure.

(a) Triode type R (S. F. R.)

A receiving tube with cylindrical anode and spiral grid. Dimensions are shown in Ex. 46 on page 69.

$x_a=0.44$ $x_g=0.18$ $p=0.16$ $d_g=0.028$ $r_g=0.014$

$\frac{2\pi x_g}{p}=7.1$ $\frac{2\pi r_g}{p}=0.55$ $\log\frac{x_a}{x_g}=0.39$

(5) W. Schottkey: Archiv f. Elektrotechnik., 8, p. 21, 1919.

(6) M. Abraham: Archiv f. Elektrotechnik., 8, p. 42, 1919.
R. W. King: Phys. Rev., 15, p. 256, 1920.

(7) F. B. Vogdes: Phys. Rev., 24, p. 683, 1924 and 25, p. 255, 1925.

$$(k3)\quad k=\frac{7.1\times0.39-0.06}{0.064+0.237}=9.2$$

$$(k2)\quad k=7.1\times\frac{0.39}{0.26}=10.6$$

Observed value of $k=9.8$

By equation (12)

$$k=9.2$$

(b) Triode type **A B T** (made at the Laboratory)

Electrode configurations are similar to the above.

$$x_a=0.20\quad x_g=0.14\quad p=0.12\quad r_g=0.0085$$

$$\frac{2\pi x_g}{p}=7.3\quad \frac{2\pi r_g}{p}=0.44\quad \log\frac{x_a}{x_g}=0.155$$

$$(k3)\quad k=\frac{7.3\times0.155-0.04}{0.04+0.345}=2.8$$

$$(k2)\quad k=7.3\times\frac{0.155}{0.357}=3.2$$

Observed value of $k=2.9$

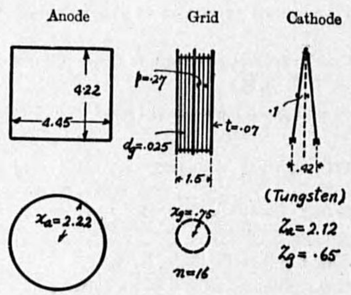
By equation (12),

$$L_g=7.3\quad c=1\quad \pi a=0.44,\quad k=\frac{7.3\times0.155}{0.385}=2.9$$

Example 17. Triodes with grid wires arranged in parallel to the filament.

(a) Type **P A V** (the Laboratory)

Dimensions are shown in Fig. 17.



(PAV)

FIG. 17.

Of 16 grid wires, 4 wires forming the support have the radius $r_g'=0.035$ and the other 12 wires $r_g''=0.0125$ average radius being $r_g=0.018$

$$x_a=2.22\quad x_g=0.75\quad n=16$$

$$p=\frac{2\pi x_g}{n}=0.27\quad \log\frac{x_a}{x_g}=0.472$$

$$(k3)\quad k=\frac{16\times0.472-0.029}{0.029+0.433}=16.3$$

k observed $=16.7$ (at $e_a=1500$, $e_g=-30$)

By equation (12),

$$L_g=16\quad c=1\quad \pi a=0.38$$

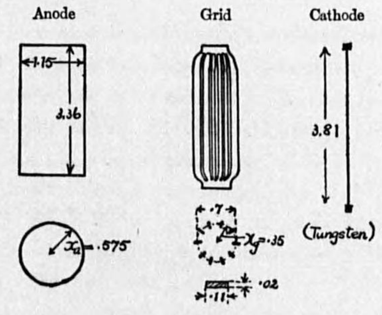
$$k=\frac{16\times0.472}{0.444}=17.0$$

(b) Type **B N** (Siemens Halske A. G.)

The grid is formed of wires of rectangular cross-section (Fig. 18). Consider an equivalent circular wire of equal perimeter, as the electrostatic capacity is mainly governed by the surface area.

Thus

$$r_g=\frac{2\times(0.11+0.02)}{2\pi}=0.041$$



(BN)

FIG. 18.

$n=10 \quad x_a=0.58 \quad x_g=0.35$

$p=\frac{2\pi x_g}{n}=0.22 \quad \log\frac{x_a}{x_g}=0.219 \quad \frac{2\pi r_g}{p}=1.17$

$(k3) \quad k=\frac{10\times 0.219-0.248}{0.248-0.164}=23.1$

k observed=26

In an actual triode in which anode and grid are plane, the cathode is not actually plane but is a filament arranged on a plane surface and, accordingly, does not strictly conform to the condition from which the formula has been derived. But by trying the formulas on these cases, the writer has found that the formula for plane (k 1) is applicable for a tube with W-shaped filament, while it gives a somewhat larger value for a tube with V-shaped filament. The formula for cylinder (k 2), if applied to these tubes, gives lower values than observed ones. Comparing the two formulas, we find that they are different only in terms of $\frac{x_a}{x_g}$ and

$$\frac{k \text{ plane}}{k \text{ cylinder}}=\frac{\frac{x_a}{x_g}-1}{\log_e\frac{x_a}{x_g}}.$$

This ratio is shown in a curve in Fig. 19.

The writer applied the formula for cylindrical electrodes to various types of plane electrode tubes and the ratio of the observed to the calculated values for each tube was computed and plotted into Fig. 19. From this we know that for approximate calculations of k for plane-electrode tubes, the formula for cylindrical electrodes may be applied if some factor is multiplied. The two straight lines in Fig. 19 give these factors for either W-shaped or V-shaped filament, and these factors, being designated by c, are tabulated in TABLE II on page 160. For plane-electrode tubes in which the grid consists of a mesh, the value of k computed by the formula for cylinder agrees well with the observed one, and c is to be taken as unity.

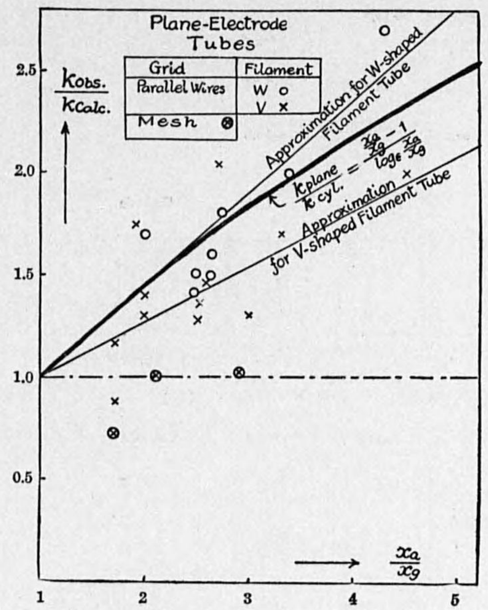


FIG. 19.

Example 18. A plane-electrode tube with a cathode of W-shaped filament.

Type **UV-203** (Tokyo Denki K. K.)

Dimensions, (Fig. 20)

$x_a=0.49 \quad x_g=0.19 \quad p=0.12 \quad r_g=0.0085$

$\frac{2\pi x_g}{p}=9.95 \quad \frac{2\pi r_g}{p}=0.445 \quad \frac{p}{2\pi r_g}=2.25 \quad \frac{x_a}{x_g}=2.60 \quad \log\frac{x_a}{x_g}=0.412$

By the equation for plane,

$(k1) \quad k=9.95\times\frac{1.60}{2.34\times 0.353}=19.6$

by the equation for cylinder,

$(k2) \quad k=9.95\times\frac{0.412}{0.353}=11.6$

The observed value of $k=15.9$

By equation (12),

$$L_g=9.95 \quad \pi a=0.445 \quad c=1.74$$

$$k=\frac{9.95\times0.412\times1.74}{0.467}=15.3$$

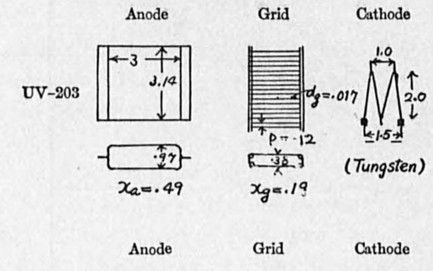


Fig. 20.

Example 19. A plane electrode tube with a cathode of V-shaped filament.

Type **UV-201A** (R. C. A)

Dimensions (Fig. 20.):

$$x_a=0.34 \quad x_g=0.17 \quad p=0.102 \quad r_g=0.0053$$

$$\frac{2\pi x_g}{p}=10.5 \quad \frac{2\pi r_g}{p}=0.33 \quad \frac{p}{2\pi r_g}=3.03 \quad \frac{x_a}{x_g}=2.0 \quad \log\frac{x_a}{x_g}=0.301$$

By the equation for plane,

$$k=10.5\times\frac{1.0}{2.30\times0.482}=9.4$$

By the equation for cylinder,

$$k=10.5\times\frac{0.301}{1.022}=3.1$$

k observed $=8.2$

By equation (12),

$$L_g=10.5 \quad \pi a=0.33 \quad c=1.30$$

$$k=\frac{10.5\times0.301\times1.30}{0.505}=8.1$$

The formula ($k3$) is a more general form of ($k2$), and this is to be taken as a standard formula. In this formula $\log\cosh\frac{2\pi r_g}{p}$ is of the order of 0.1 and is small compared with $\frac{2\pi x_g}{p}\log\frac{x_a}{x_g}$ which is usually of the order of 10 to 100, and so the formula may be reduced to a simpler form:

$$k=\frac{c\frac{2\pi x_g}{p}\cdot\log\frac{x_a}{x_g}}{\log\coth\frac{2\pi r_g}{p}}.$$

In the above formula grid is considered to be formed of parallel wires only. But in actual cases supports are usually added and in some cases grid is constructed of wires weaved into a mesh.

The writer has brought out the following deductions in order to make the formula equally applicable to these cases.

The quantity $\frac{2\pi x_g}{p}$ means the "total active length of grid wires per unit axial length of the grid," because $2\pi x_g$ is the length of one turn of grid wire in circular form and $\frac{1}{p}$ is the number of turns per unit length. This quantity is denoted by L_g thus

$$L_g=\frac{2\pi x_g}{p}$$

Example 20. A cylindrical electrode tube, with a spiral wire of wide pitch of winding.

Type RE-84 (Telefunken G.)

Dimensions are shown in Ex. 48 on page 71.

$$x_a=0.263 \quad x_g=0.125 \quad p=0.25 \quad r^2=0.025$$

$$\frac{2\pi x_g}{p}=3.14 \quad \frac{2\pi r_g}{p}=0.628 \quad \log\frac{x_a}{x_g}=0.323$$

$$k=\frac{3.14\times 0.323}{0.25}=3.96$$

k observed $=4.5$

If actual length of the spiral grid wire per unit axial length of the grid is taken instead of $\frac{2\pi x_g}{p}$

$$L_g=\sqrt{1+\left(\frac{2\pi x_g}{p}\right)^2}=3.30$$

and

$$k=\frac{3.30\times 0.323}{0.25}=4.4$$

which is more coincident with the observed value.

For a grid consisting of a square mesh of very thin wires

$$L_g=\frac{4\pi x_g}{p},$$

but when grid wire is not of small diameter, effect of overlapping of the wires should be considered. At each crossing point of two wires, active length of one wire is reduced by an amount equal to the diameter of the wire, and as the number of the crossing per unit axial length of grid is $\frac{2\pi x_g}{p^2}$ (Fig. 21),

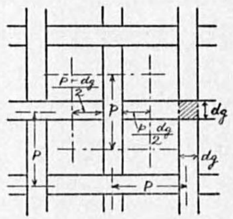


Fig. 21.

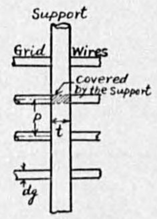


Fig. 22.

$$L_g=\frac{4\pi x_g}{p}-\frac{2\pi x_g}{p^2}d_g=\frac{4\pi x_g}{p}\left(1-\frac{r_g}{p}\right)$$

Effect of grid support should be considered in the same way and for a grid of parallel wires,

$$L_g=\frac{2\pi x_g}{p}+s-\frac{st}{p}.$$

in which s is the number of grid supporting wires which is active in influencing on the space charge or is in the path of the electron current. $\frac{st}{p}$ is the amount of reduction of effective length of the grid wires due to the grid support covering a portion of each grid wire. (Fig. 22)

For a grid made of a mesh, the effect of supports may not be considered, as the total length of the wires is very large, and moreover the increase of L_g due to supports is usually canceled by the reduction of it due to the support covering a portion of the mesh.

The quantity $\frac{2\pi r_g}{p}$ in the formula of k on page 35 signifies π-times $\frac{d_g}{p}$ or "π-times the ratio of the grid conductor projected area to the grid surface area," and this ratio of areas being denoted by a,

$$\pi a=\pi\frac{\text{(grid wire projected area per unit length of the grid)}}{2\pi x_g}$$

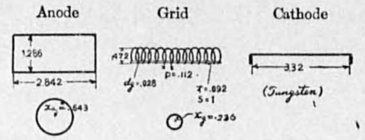
For a grid of a mesh or of a system of parallel wires,

$$\pi a=\frac{L_g d_g}{2x_g}=\frac{L_g r_g}{x_g}.$$

If the parallel wire grid has supports,

$$\pi a=\frac{(L_g-s)\,d_g+st}{2x_g}$$

Example 21. A triode with grid supported by a thick wire.
Type **TA 08/10** (Philips' Lamp Works)



(TA 08/10)

FIG. 23.

$x_a=0.643$ $x_g=0.236$ $p=0.112$ $r_g=0.014$

$\log\frac{x_a}{x_g}=0.436$

Without considering the support;

$\frac{2\pi x_g}{p}=13.2$ $\frac{2\pi r_g}{p}=0.79$ $k=31.6$

Considering the support, $s=1$ $t=0.092$

$L_g=\frac{2\pi x_g}{p}+s\left(1-\frac{t}{p}\right)=13.4$ $\pi a=\frac{(L_g-s)d_g+st}{2x_g}=0.93$

$k=43$

Observed value of $k=46$

Example 22. A triode with grid formed of a mesh.
Type **MT-4** (Marconi Co.)
Dimensions (See example 38, page 61)

$x_a=2.17$ $x_g=0.93$ $p=0.13$ $r_g=0.011$ $\log\frac{x_a}{x_g}=0.368$

Without consideration of the overlapping of grid wires,

$L_g=\frac{4\pi x_g}{p}=90$ $\pi a=\frac{L_g r_g}{x_g}=1.06$

$k=\frac{90\times0.368}{0.105}=315$

Considering the overlapping;

$L_g=\frac{4\pi x_g}{p}\left(1-\frac{r_g}{p}\right)=90\times0.91=81$ $\pi a=\frac{L_g r_g}{x_g}=0.96$

$k=\frac{81\times0.368}{0.129}=230$

Observed value of $k=210$.

The formula for the amplification constant finally attains the form:

$$k=\frac{c\,L_g\log\frac{x_a}{x_g}}{\log\coth\pi a} \quad \cdots\cdots\cdots\cdots\cdots (12)$$

The TABLES II, III and IV on pages 160 and 161 will facilitate calculations.

The amplification constant is mainly governed by grid construction and depends little on anode area and filament configuration. Main factors determining k are $\frac{x_a}{x_g}$, $\frac{p}{x_g}$, and $\frac{r_g}{p}$, and similar tubes of equal relative dimensions give equal values of k whatever the size may be.

(ii) Mutual Conductance and Anode Impedance.

The mutual conductance for given anode and grid voltages (e_a, e_g) can be obtained by differentiation of the characteristic equation, thus

$$g=\frac{\partial i_a}{\partial e_g}=\frac{2}{5}G\frac{1}{e_f}\cdot\frac{\partial}{\partial e_g}\left[e_g'^{\frac{5}{2}}-(e_g'-e_f)^{\frac{5}{2}}\right]$$

$$\fallingdotseq1.5\,G\frac{k}{1+k}\left(\sqrt{e_g'}-\frac{1}{4}\frac{e_f}{\sqrt{e_g'}}\right) \quad \cdots\cdots (13)$$

in which $e_g'=\frac{e_a+ke_g}{1+k}$

This is strictly applicable when grid current is not appreciable.

The mutual conductance is principally governed by the perveance G which is proportional to the anode effective area and is inversely proportional to the electrode distances.

The anode impedance r may also be obtainded as

$$r=\frac{\partial e_a}{\partial i_a} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (14)$$

but it is more convenient to calculate it from the known values of k and g by the relation

$$r=\frac{k}{g} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (15)$$

Example 23. Calculation of mutual conductance and anode impedance.

Triode type **T-100** (Marconi Co.)

Dimensions (Fig. 24),

$x_a=1.15$ $x_g=0.44$ $p=0.095$ $r_g=0.0075$ $A=23.9$

k calc.$=52.7$ $z_a=1.15-0.08=1.07$ $z_g=0.44-0.08=0.36$

$e_f=10\ V$ (rating)

$G=0.127\times10^{-3}$ $1.5\,G\dfrac{k}{1+k}=0.187\times10^{-3}$.

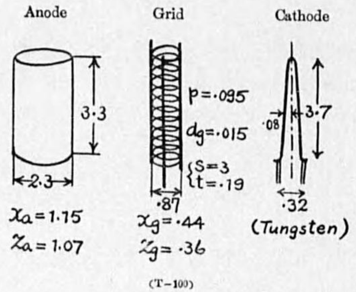


FIG. 24.

1) To obtain g and r for $e_a=1{,}500$ and $e_g=0$.

$e_g'=\dfrac{1{,}500}{52.7+1}=27.9$ $\sqrt{e_g'}=5.28$

$g=0.187\times10^{-3}\times4.81=.00090$ $r=\dfrac{52.7}{0.00090}=585{,}000$

Observed values:

$k=48$ $g=.00089$ $r=540{,}000$

2) For $e_a=2{,}000$, and $e_g=-20$.

$e_g'=\dfrac{2000-20\times52.7}{52.7+1}=17.7$ $\sqrt{e_g'}=4.20$

$g=.000675$ $r=78{,}100$

Observed values:

$k=48$ $g=.000675$ $r=71{,}000$

(4) Saturating Part of the Characteristic.

The saturation current I_s depends upon the material of which the cathode is made, and for a given material it depends upon the dimensions and working temperature of the cathode. General features of three kinds of materials widely used for cathodes are described in the following.

(i) Tungsten.

Its working temperature is generally 2300° to 2500°K, and is widely used for high-power tubes.

The emission can be calculated by means of CHART II annexed to this paper and explained on page 136.

Examples of the application of the chart: dimensions of filament and its heating current being given, to find the terminal voltage and emission.

a) $r_f=0.006$ $l=9.9$

i_f	e_f		I_s	
	Calculated	Observed	Calculated	Observed
1.7	10.8	9.4	0.0083	0.009
1.9	12.8	11.5	0.033	0.026
2.1	14.8	14.0	0.21	0.22
2.3	16.8	17.0	0.60	0.46

b) $r_f=0.0125$ $l=9.6$

i_f	e_f		I_s	
	Calculated	Observed	Calculated	Observed
5.4	7.9	7.4	0.0465	0.044
5.8	8.7	8.4	0.15	0.14
6.2	9.7	9.4	0.32	0.38
6.8	11.1	10.5	0.82	0.90

The saturation current is quite a variable quantity, and they are much affected by the existence of residual gas and thorium.

(ii) Thoriated Tungsten.

A small quantity of thoria is contained in tungsten and is reduced to thorium in the process of activation and forms an atomic layer on the tunsgsten surface and thus facilitates the electron emission, the working temperature being of the order of 1900°K. This kind of filament requires less heating power than pure tungsten for equal emission and is widely used for receiving and medium power tubes. The emission depends among other things on the degree of activation, that is the area on the cathode covered by thorium, and moreover thorium is very sensitive to residual gases.

The relation between the working temperature and the heating current or voltage can be calculated by the same chart as that for tungsten, but the emission is quite variable. The curves in Fig. 72 on page 139 may be applied for a rough estimation of emission obtainable on the most favourable conditions.

(iii) Oxide-coated Cathode.

This type of cathode works at still lower temperature of the order of 1100°K, and is used for receiving and low power amplifying or transmitting tubes.

The material on which the oxides of barium, strontium, calcuim or other similar metals are coated is different according to the process of manufacture, and platinum, nickel, tungsten, or alloys of these metals are generally used. Thus the calculation of cathode characteristics are different for materials used.

The following table shows general characteristics for the three types of filament.

Filament	Working temperature	Emission per unit heating power	Commonly used heating power
Tungsten	2300–2500°K	2–5 mA/watt	75–80 watt/cm.²
Thoriated tungsten	1900–2100°K	20–100 〃	30 〃
Oxide-coated	900–1100°K	50–150 〃	5 〃

The point at which the anode current commences to saturate occurs at an anode voltage such as

$$e_s=\left(\frac{I_s}{G}\right)^{\frac{2}{3}}$$

If the cathode consists of a uniformly emissive surface of equal potential all over it, the characteristic would sharply bend to saturate as soon as the anode voltage reached saturating voltage e_s. But in actual cases slow bending of the characteristic curve is invariably observed, which is caused by the non-uniformity of filament temperature as well as the voltage drop along the filament. The expression of anode current considering the latter cause only is as follows[8]; in a range of the anode voltage for saturation: $e_s<e_a<e_s+e_f$

$$i=\frac{1}{5}G\frac{1}{e_f}\left\{e_s^{\frac{3}{2}}(5e_a-3e_s)-2(e_a-e_f)^{\frac{5}{2}}\right\}$$

in which e_a should be replaced by e_g' in case of a triode. This equation represents a curve which is continuous to that shown by equation (3) at anode voltage $e_a=e_s$.

This expression does however, not sufficiently conform with the observed values as shown in Ex. 24, and this fact shows that the non-uniformity of emissive power on the cathode is the more important factor.

Accurate calculation of this part of characteristic is very complicated, as the

(8) Van der Bijl, loc. cit. on p. 2.

temperature distribution along the filament must be known, but the writer finds no need of it for the designing purpose as this part of characteristic is of little practical importance.

In dull-emitter tubes such as thoriated tungsten or oxide-coated filament tubes, the saturation does not appear so sharply as in bright-emitter tubes with tungsten filament. This is because that the temperature difference along the filament is more marked in the former, as the working temperature is low and, besides radiation considerable portion of heat is lost at the ends of the filament due to conduction of leads. In oxide-coated filament tubes rough surface of the filament augments the above phenomenon of partial saturation.

Example 24. Calculation of the saturating part of characteristics.

(a) Triode **type BN** (Siemens Halske A. G.)

Dimensions are given in Ex. 17b on page 31.

$I_s=0.022$ (observed value is taken) $e_f=4.7$ (tungsten filament.)

$z_a=0.58$ $z_g=0.35$ $A=12.1$ $\frac{A}{z_a z_g}=60$

$G=0.14\times10^{-3}$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=.00057$ $\frac{1}{5}G\frac{1}{e_f}=0.00595\times10^{-3}$

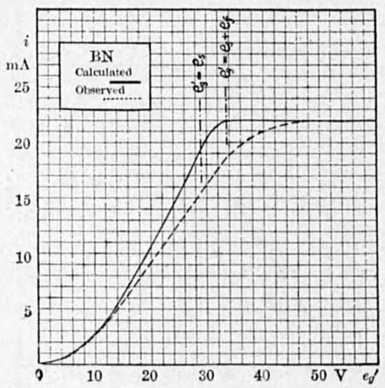


FIG 25.

$e_s=\left(\frac{0.022}{0.14\times10^{-3}}\right)^{\frac{2}{3}}=29.1$

Below saturation $e_g'<e_s$			Saturating part $e_s<e_g'<e_s+e_f$			
$\frac{e_g'}{e_f}$	e_g'	i	e_g'	$(5e_g'-3e_s)e_s^{\frac{3}{2}}$	$2(e_g'-e_f)^{\frac{5}{2}}$	i
0	0	0	30	9,870	6,480	0.0196
2	9.4	0.0026	31	10,620	7,100	0.0209
4	19	0.0097	32	11,330	7,780	0.0211
6	28	0.0185	33	12,190	8,520	0.0218

(b) Diode type **UX-213** (R. C. A.)

Dimensions and characteristics are given in Ex. 9 on page 14.

Thoriated-tungsten filament, $e_f=3.4$ $i_f=1.5$

$z_a=1.29$ $A=2.6$ $G=0.364\times10^{-3}$

$I_s=0.058$ (observed value being taken), $e_s=29.3$

The results of calculation are shown in Fig. 26.

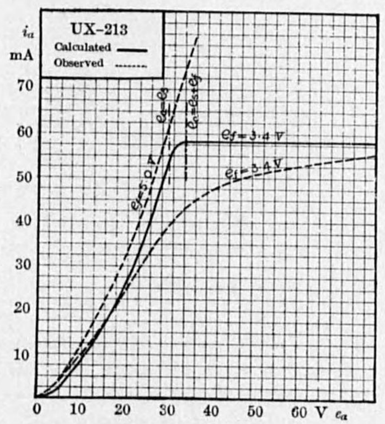
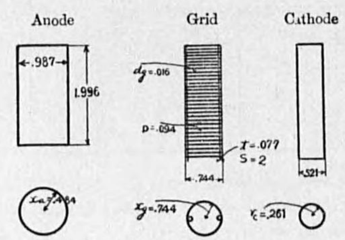


FIG. 26.

(c) Triode type **KL-1** (Marconi Co.)

This tube, being of indirectly-heated type, has no potential difference on the cathode surface.

$$\mu_a=0.223 \qquad \mu_g=0.111 \qquad A=5.97 \qquad \frac{A}{\mu_a\mu_g}=241$$



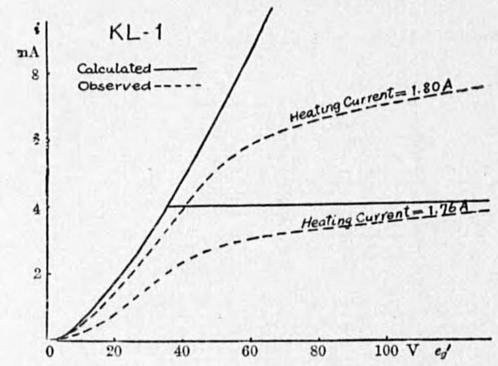


Fig. 27.

If the cathode has uniform emissive power all over the surface and if the electron current is to saturate at 4.0 mA for instance, the characteristic should have a sharp bending at this current as shown in Fig. 27. But the observed curves show very slow bending for saturation, which is attributed to the non-uniformity of temperature or emissive power on the cathode surface.

(5) Examples for the Computation of Characteristics.

Examples given on the following pages show the method of computation applied to various types of tubes. The dimensions of the electrodes were directly obtained in some cases by breaking up the tubes, but in most cases this could not be done and the microscopic cathetometer was used for this purpose, and error of observations were, therefore, unavoidable in measuring small dimensions such as diameter of wire.

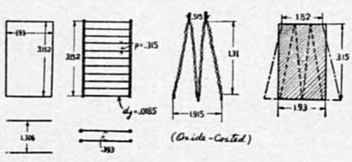
Filaments were lighted with d. c. unless otherwise noted, and anode and grid voltages were referred to the negative leg of the filament. Rated values of filament voltage were taken in most cases for both observations and calculations. The three parameters were observed at particular anode and grid voltages given in the tables, and the mutual conductance and the anode impedance were calculated for the same condition, with the calculated value of the amplification constant. Characteristics were shown as the relation of electron current to the equivalent grid voltage, as this is the simplest expression of characteristics and is determined by the least number of factors.

Example 25.

TRIODE TYPE: **205-B** Manufacturer: Western Electric Co.

Observations

Anode Grid Cathode *A*



$e_f=6.5$, $i_f=1.36$ A. C.

$e_a=400$ $k=6.4$

$e_g=-35$ $g=.00135$

$r=4{,}700$

e_a	e_g	e_g'	i_a	i_g	i
200	−20	9.7	.0097		.0097
	0	27.1	.035		.035
	10	35.7	.049	.0005	.050
	20	44.4	.063	.0009	.064
300	−30	14.6	.015		.015
	−20	23.4	.028		.028
400	−60	2.2	.0055		.0055
	−50	10.8	.0125		.0125
	−40	19.5	.022		.022
	−30	28.1	.037		.037

Calculations

$L_g=3.92$ $A=12.3$

$\frac{x_a}{x_g}=3.32$ $\frac{A}{z_a z_g}=95.4$

$\log\frac{x_a}{x_g}=.52$ $G=.221\times10^{-3}$

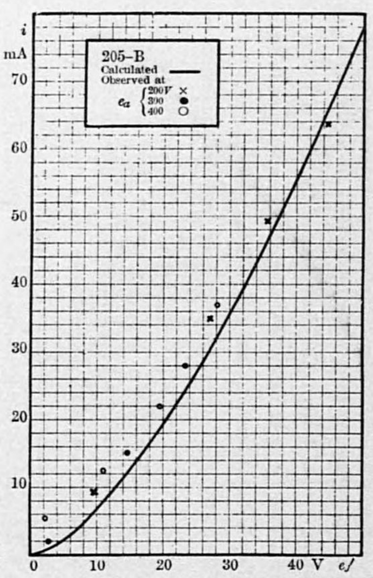
$c=2.1$ $i=Ge_g^{\frac{3}{2}}$

$\pi a=.19$

$k=\frac{2.1\times3.92\times.52}{.74}=5.8$

$e_g'=29$ $g=.0014$, $r=4{,}100$

e_g'	$e_g'^{\frac{3}{2}}$	i
0	0	0
10	31.6	.007
20	89.5	.020
30	164	.036
40	253	.056
50	354	.078

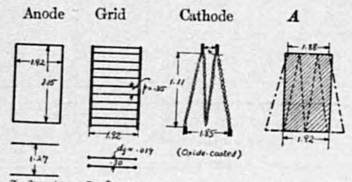


Example 26.

TRIODE TYPE: **205-D** Manufacturer: Western Electric Co.

Observations

Anode Grid Cathode *A*



$e_f=4.6$, $i_f=1.6$

$e_a=300$ $k=7$

$e_g=-8$ $g=.0021$

$r=3{,}400$

e_a	e_g	e_g'	i_a	i_g	i
250	−16	16.7	.017		.017
	− 4	27	.035		.025
	8	38	.060	.0005	.061
300	−20	19	.022		.022
	− 8	30	.042		.042
	0	37	.058		.058
350	−20	25	.032		.032
	−12	32	.047		.047
	0	43	.075		.075

Calculations

$L_g=3.5$ $A=12$

$\frac{x_a}{x_g}=4.3$ $\frac{A}{z_a z_g}=120$

$\log\frac{x_a}{x_g}=.630$ $G=.277\times10^{-3}$

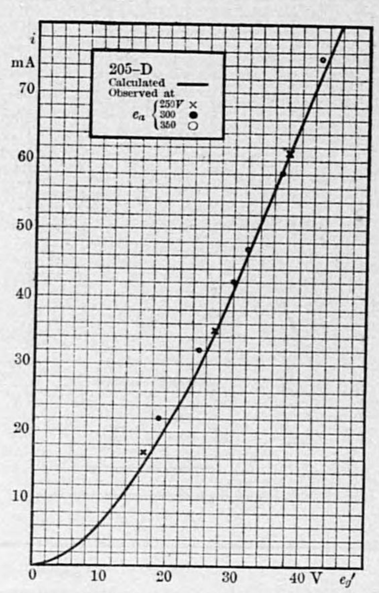
$c=2.5$ $e_f=4.6$

$\pi a=.123$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=.00109$

$k=\frac{2.5\times3.5\times.63}{0.94}=5.9$

$e_g'=30.5$ $g=.0019$, $r=3{,}100$

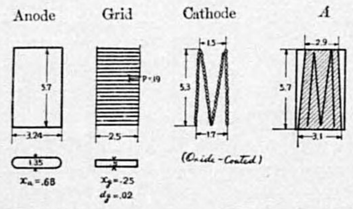
e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	9.2	.005
4	16.51	18.4	.013
6	32.5	27.6	.035
8	53	36.8	.058
10	74	46	.081



Example 27.

TRIODE TYPE: 211-A Manufacturer: Western Electric Co.

Observations



Calculations

L_a=8.3 A=34.2

$\frac{x_a}{x_g}$=2.7 $\frac{A}{z_a z_g}$=200

$\log\frac{x_a}{x_g}$=.435 G=0.47×10⁻³

c=1.8 e_f=9.0

πa=0.33 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=0.0051

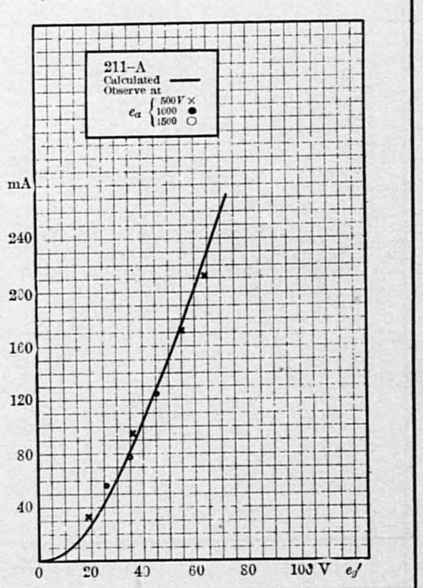
e_f=9.0 i_f=3.3 $\begin{cases} e_a=1{,}000 & k=12.8 \\ e_g=-45 & g=.00304 \\ & r=4{,}200 \end{cases}$

$k=\frac{1.8\times8.3\times.435}{0.51}$=12.7

e_g'=31 $\begin{cases} g=.0034 \\ r=3{,}750 \end{cases}$

e_a	e_g	e_g'	i_a	i_g	i
500	−20	18	.032		.032
	0	36	.095		.095
	20	55	.171	—	.171
	30	64	.211	—	.211
1000	−90	—	.002		.002
	−50	26	.057		.057
	−30	45	.125		.125
1500	−80	35	.078		.078

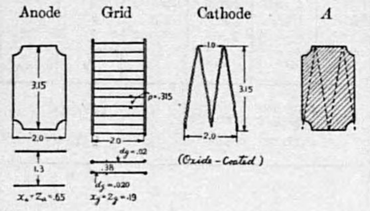
e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	18	.024
4	16.51	36	.084
6	32.5	54	.166
8	53	72	.270



Example 28.

TRIODE TYPE: 216-A Manufacturer: Western Electric Co.

Observations



Calculations

L_g=3.79 A=12

$\frac{x_a}{x_g}$=3.42 $\frac{A}{z_a z_g}$=90

$\log\frac{x_a}{x_g}$=0.535 G=0.21×10⁻³

c=2.1 e_f=5.0

πa=0.20 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=0.00094

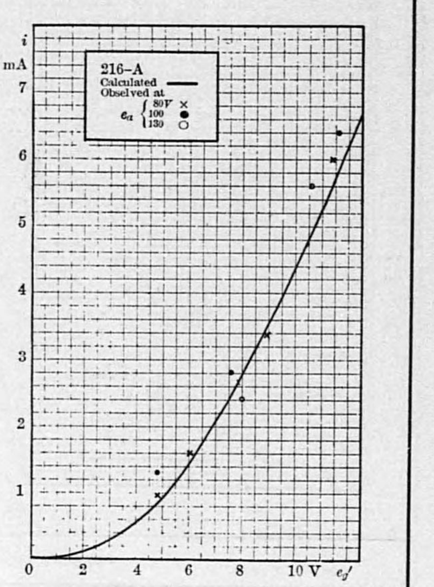
e_f=5.0 i_f=1.0 $\begin{cases} e_a=100 & k=6 \\ e_g=0 & g=0.0011 \\ & r=5{,}500 \end{cases}$

$k=\frac{2.1\times3.79\times0.535}{0.714}$=6.05

e_g'=14.3 $\begin{cases} g=0.00095 \\ r=6{,}400 \end{cases}$

e_a	e_g	e_g'	i_a	i_g	i
80	−7.65	4.9	.00095	0	$=i_a$
	−6.15	6.1	.0016		
	−3	8.9	.0034		
	0	11.4	.0060		
100	−11.0	4.9	.0013	〃	〃
	− 7.65	7.7	.0028		
	− 3.05	11.7	.0064		
130	−12.3	8.0	.0024	〃	〃
	− 9.19	10.7	.0056		

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
0.5	0.177	2.5	.00016
1.0	1.00	5.0	.00094
2.0	4.65	10	.00435
3.0	9.94	15	.0093

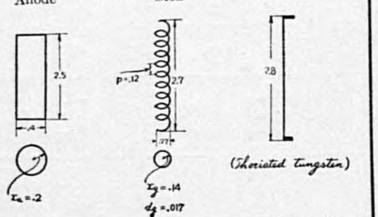


Example 29.

TRIODE TYPE: **ABT** Manufacturer: The Laboratory

Observations

Anode / Grid / Cathode



e_f=3.25
i_f=0.075

$\begin{cases} e_a=29 \\ e_g=0 \end{cases}$ k=2.9, g=0.00093, r=3,100

e_a	e_g	e_g'	i_a	i_g	i
15	0	3.8	.0006		.0006
	4	6.8	.0024	.0001	.0025
	8	9.8	.0044	.0007	.0051
29	−7	2.2	.0003		.0003
	−4	4.5	.0009		.0009
	0	7.4	.0030		.0030
	6	11.9	.0070	.0004	.0074
43	−8	5.2	.0010		.0010
	−6	6.6	.0018		.0018
	0	11.0	.0057		.0057

Calculations

L_g=7.3 A=3.14

$\frac{r_a}{r_g}$=1.43 $\frac{A}{z_a z_g}$=112

$\log\frac{r_a}{r_g}$=.155 G=.000216

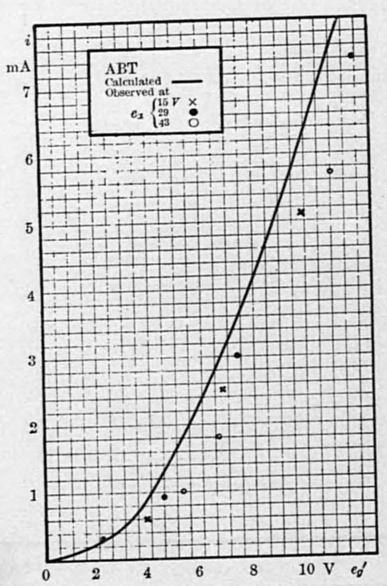
c=1 e_f=3.25

πa=.44 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=.000605

$k=\frac{7.3\times.155}{.385}$=2.94

e_g'=7.4 $\begin{cases} g=.00071 \\ r=4,100 \end{cases}$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
1	1.0	3.25	.00061
2	4.65	6.5	.0028
3	9.94	9.75	.0060
4	16.51	13.00	.010

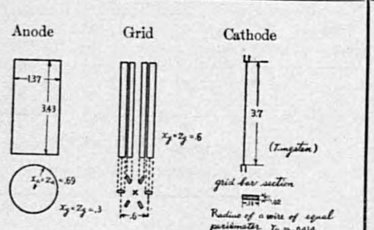


Example 30.

TRIODE TYPE: **BE** Manufacturer: Siemens Halske A. G.

Observations

Anode / Grid / Cathode



e_f=4.8
i_f=2.1

$\begin{cases} e_a=400 \\ e_g=-10 \end{cases}$ k=10.2, g=.00384, r=12,100

e_a	e_g	e_g'	i_a	i_g	i
300	−20	8.6	.0030		.0030
	−10	17.7	.0090		.0090
	0	27	.0175		.0175
400	−30	8.4	.0035		.0035
	−15	23	.0134		.0134
	− 5	34	.0217		.0217
500	−35	12.8	.0060		.0060
	−25	22	.0133		.0133
	−10	36	.0251		.0251

Calculations

L_g=6 A=14.8

$\frac{r_a}{r_g}$=2.30 $\frac{A}{z_a z_g}$=71.5

$\log\frac{r_a}{r_g}$=.362 $G=.167\times10^{-3}$

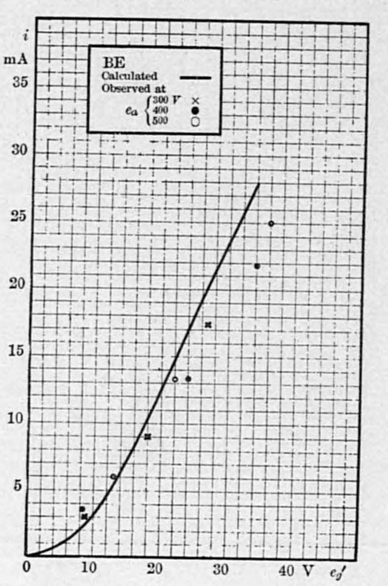
c=1 e_f=4.8

πa=.83 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=.00070

$k=\frac{6\times.362}{.169}$=12.8

e_g'=26.6 $\begin{cases} g=.0011 \\ r=11,600 \end{cases}$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	9.6	.0033
4	16.51	19.2	.0116
6	32.5	28.8	.0228
8	53.0	38.4	.037
10	74.0	48	.052

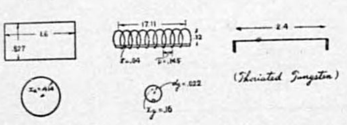


Example 31.

TRIODE TYPE: **DER** Manufacturer: Marconi Co.

Observations

Anode Grid Cathode



Calculations

$L_{ig}=7.66$ $A=4.17$

$\frac{x_1}{x_g}=2.58$ $\frac{A}{z_a z_g}=63.5$

$\log\frac{x_1}{x_g}=.413$ $G=.148\times10^{-3}$

$c=1$ $e_f=1.9$

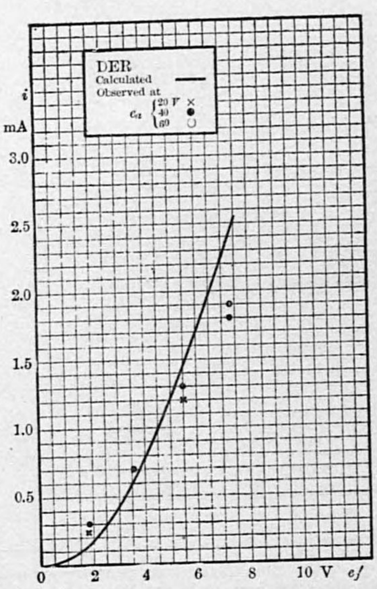
$\pi a=.58$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=.154\times10^{-3}$

$e_f=1.9$ $i_f=0.4$ $\begin{cases}e_a=60\\e_g=0\end{cases}$ $k=10$ $g=.00037$ $r=28{,}000$

$k=\frac{7.66\times.413}{0.29}=10.9$ $e_g=5.04$ $\begin{cases}g=.00043\\r=25{,}400\end{cases}$

e_a	e_g	e_g'	i_a	i_g	i
20	0	1.8	.00025		.00025
	4	5.5	.0012		.0012
40	−2	1.8	.0003		.0003
	0	3.6	.0007		.0007
	4	7.3	.0018		.0018
60	0	5.5	.0013		.0013
	2	7.3	.0019		.0019

e_g'/e_f	$f(e_g'/e_f)$	e_g	i
0	0	0	0
1	1.00	1.9	.00015
2	4.65	3.8	.00072
3	9.94	5.7	.00153
4	16.51	7.6	.00255

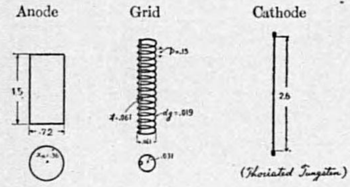


Example 32.

TRIODE TYPE: **DEV** Manufacturer: Marconi Co.

Observations

Anode Grid Cathode



Calculations

$L_{ig}=7.54$ $A=3.39$

$\frac{x_1}{x_g}=2.0$ $\frac{A}{z_a z_g}=52.3$

$\log\frac{x_1}{x_g}=.301$ $G=.123\times10^{-3}$

$c=1$ $e_f=3.0$

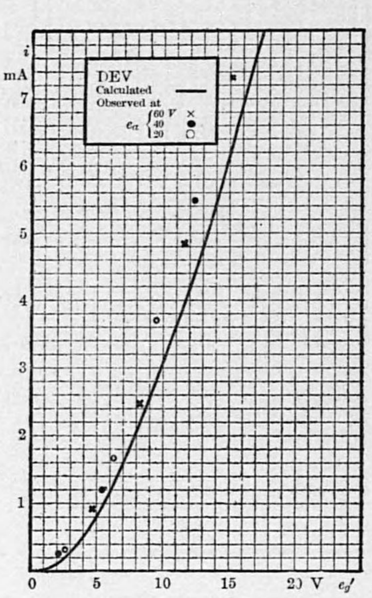
$\pi a=.515$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=.256\times10^{-3}$

$e_f=3.0$ $i_f=.285$ $\begin{cases}e_a=60\\e_g=0\end{cases}$ $k=6.3$ $g=.00045$ $r=14{,}000$

$k=\frac{7.54\times.301}{.325}=6.9$ $e_g'=7.6$ $\begin{cases}g=.00038\\r=18{,}000\end{cases}$

e_a	e_g	e_g'	i_a	i_g	i
60	−4	4.77	.00092		.00092
	0	8.21	.00215		.00215
	4	11.66	.00453	.00028	.00481
	8	15.11	.00678	.00055	.00733
40	−4	2.12	.00022		.00022
	0	5.45	.00120		.00120
	8	12.38	.00490	.00060	.00550
20	0	2.74	.00030		.00030
	4	6.2	.00145	.00017	.00162
	8	9.65	.00310	.00061	.00371

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
.5	.177	1.5	.00005
1.0	1.00	3.0	.00026
1.5	2.57	4.5	.00066
2.0	4.65	6.0	.00119
2.5	7.13	7.5	.00183
3.0	9.94	9.0	.00254
4.0	16.51	12.0	.00423
5.0	24.1	15.0	.00617

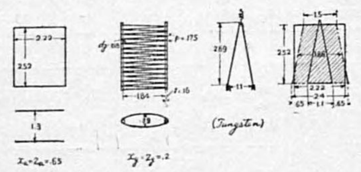


Example 33.

TRIODE TYPE: H Manufacturer: De Forest Co.

Observations

Anode Grid Cathode A



$e_f = 9.75$ $i_f = 2.35$

$e_a = 2{,}000$, $e_g = -80$ $k = 12.2$, $g = .00166$, $r = 7{,}350$

e_a	e_g	e_g'	i_a	i_g	i
1000	− 39	40	.033		.033
	0	76	.098		.098
	30	103	.154	.003	.157
	49	121	.185	.003	.188
1500	−119	3.8	.007		.007
	− 98	23	.013		.013
	− 59	59	.061		.061
	− 30	93	.114		.114
2500	−148	53	.044		.044
	−138	62	.059		.059
	−119	86	.090		.090

Calculations

$L_g = 7.18$ $A = 9.5$

$\frac{x_a}{x_g} = 3.25$ $\frac{A}{z_a z_g} = 73$

$\log \frac{x_a}{x_g} = .512$ $G = .170 \times 10^{-3}$

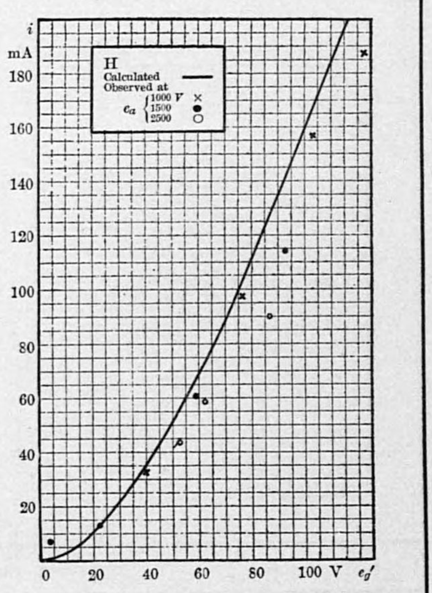
$c = 1.7$ $e_f = 9.75$

$\pi a = .32$ $\frac{2}{5} G e_f^{\frac{3}{2}} = .00206$

$k = \frac{1.7 \times 7.18 \times .512}{.518} = 12.1$

$e_g' = 80$ $g = .0020$, $r = 6{,}000$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	19.5	.0094
4	16.51	39	.034
6	32.5	59	.067
8	53	78	.109
10	74	98	.153

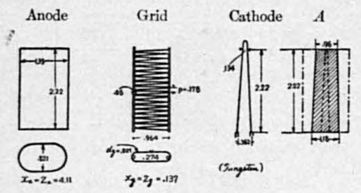


Example 34.

TRIODE TYPE: LS-5 Manufacturer: Marconi Co.

Observations

Anode Grid Cathode A



$e_f = 5.25$ $i_f = 0.85$

$e_a = 240$, $e_g = 0$ $k = 5.0$, $g = .00104$, $r = 4{,}800$

e_a	e_g	e_g'	i_a	i_g	i
80	− 8	6.6	.0024		.0024
	0	13.3	.0078		.0078
	12	23.3	.0184	.0008	.0192
160	−24	6.6	.0025		.0025
	−16	13.3	.0075		.0075
	− 8	20	.0148		.0148
240	−44	3.3	.0011		.0011
	−36	10.0	.0044		.0044
	−28	16.7	.0100		.0100
	−20	23.3	.0176		.0176
	−12	30.2	.0262		.0262
	− 4	36.7	.0348		.0318

Calculations

$L_g = 4.84$ $A = 4.74$

$\frac{x_a}{x_g} = 3.00$ $\frac{A}{z_a z_g} = 84.2$

$\log \frac{x_a}{x_g} = .477$ $G = .96 \times 10^{-3}$

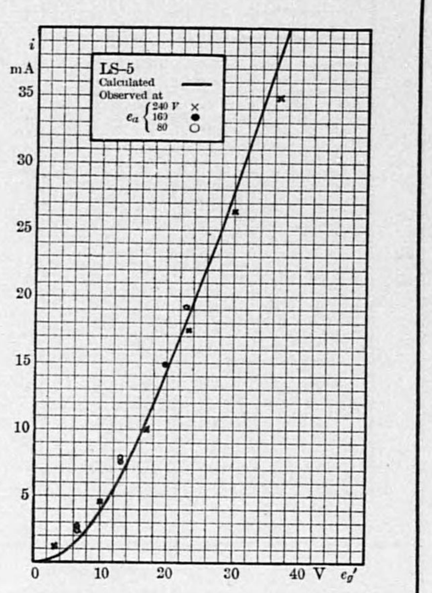
$c = 1.6$ $e_f = 5.25$

$\pi a = .37$ $\frac{2}{5} G e_f^{\frac{3}{2}} = .944 \times 10^{-3}$

$k = \frac{1.6 \times 4.84 \times .477}{.456} = 8.1$

$e_g' = 37.5$ $g = .00146$, $r = 5{,}530$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
1	1.00	5.25	.00094
2	4.65	10.5	.0044
3	9.94	15.8	.0094
4	16.51	21.0	.0156
5	24.1	26.3	.0228
6	32.5	31.5	.0307
8	53.0	42.0	.050

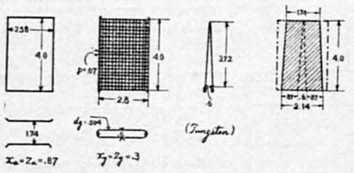


Example 35.

TRIODE TYPE: MS-III Manufacturer: C. H. F. Müller

Observations

Anode / Grid / Cathode / A



$e_f=7.4$, $i_f=4.2$, $\begin{cases} e_a=1{,}000 \\ e_g=+20 \end{cases}$ $k=50$, $g=.0014$, $r=39000$

e_a	e_g	e_g'	i_a	i_g	i
400	21	28	.0274	.004	.0314
	52	59	.0695	.004	.0735
800	10.5	26	.025	.0005	.026
	41	56	.0675	.003	.071
	51	66	.082	.004	.086
1400	0	27	.026		.026
	30	57	.069	.0035	.0725
	41	68	.085	.004	.089

Calculations

$L_g=52.3$ $A=15.5$

$\frac{x_a}{x_g}=2.90$ $\frac{A}{z_a z_g}=59.4$

$\log\frac{x_a}{x_g}=.464$ $G=.138\times10^{-3}$

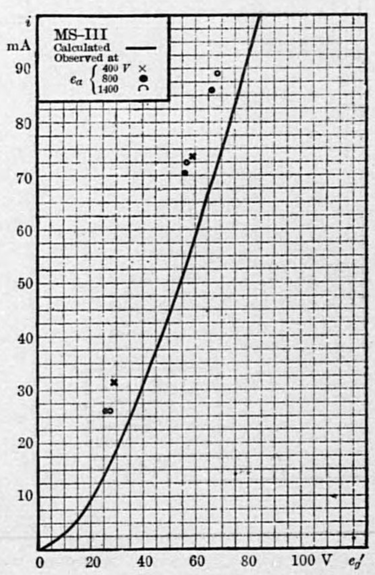
$c=1$ $e_f=7.4$

$\pi a=.35$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=.00110$

$k=\frac{52.3\times.464}{.481}=50.4$

$e_g'=40$ $\begin{cases} g=.0012 \\ r=42{,}000 \end{cases}$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	14.8	.0051
4	16.51	29.6	.0182
6	32.5	44.4	.036
8	53	59.2	.058
10	74	74.0	.081

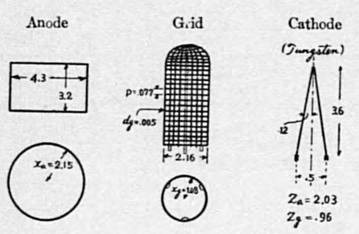


Example 36.

TRIODE TYPE: MT-1 Manufacturers: Marconi Co.

Observations

Anode / Grid / Cathode



$e_f=9.0$, $i_f=6.0$, $\begin{cases} e_a=8000 \\ e_g=30 \end{cases}$ $k=160$, $g=.000526$, $r=304{,}000$

e_a	e_g	e_g'	i_a	i_g	i
4000	−10	24.8	.0058	0	.008
	39	63.6	.020	.002	.022
	98	122	.056	.002	.058
6000	0	37.3	.0105	0	.011
	39	76	.027	.002	.029
8000	0	49.7	.0155	0	.0155
	39	88	.0335	.0025	.036
10000	−20	42.2	.012	0	.012
	20	82.0	.030	.002	.032

Calculations

$L_g=172$ $A=43$

$\frac{x_a}{x_g}=1.99$ $\frac{A}{z_a z_g}=22.4$

$\log\frac{x_a}{x_g}=.299$ $G=.0523\times10^{-3}$

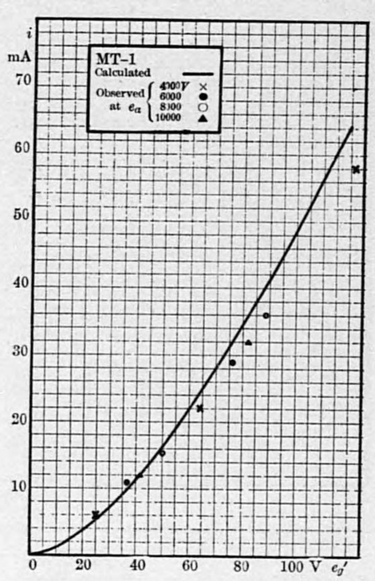
$c=1$ $e_f=9.0$

$\pi a=.40$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=.557\times10^{-3}$

$k=\frac{172\times.299}{.420}=123$

$e_g'=97$ $\begin{cases} g=.00075 \\ r=164{,}000 \end{cases}$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	18	.0026
4	16.51	36	.0092
6	32.5	54	.0181
8	53	72	.0297
10	74	90	.0412

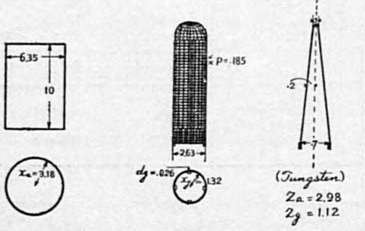


Example 37.

TRIODE TYPE: **MT-2** Manufacturer: Marconi Co.

Observations

Anode / Grid / Cathode



$e_f = 17$, $i_f = 15$ A. C. $\begin{cases} e_a = 3{,}000 \\ e_g = +60 \end{cases}$ $k = 200$, $g = .00185$, $r = 108{,}000$

e_a	e_g	e_g'	i_a	i_g	i
1000	20	25	.014	.005	.019
	50	55	.050	.015	.065
	80	85	.108	.025	.133
3000	20	35	.026	.005	.031
	50	65	.068	.015	.083
	80	95	.127	.025	.152
5000	20	45	.039	.005	.044
	50	75	.085	.015	.100
	80	105	.146	.025	.171

Calculations

$L_g = 83$ $A = 2{\cdot}0$

$\frac{x_a}{x_g} = 2.41$ $\frac{A}{z_a z_g} = 57$

$\log \frac{x_a}{x_g} = .382$ $G = .135 \times 10^{-3}$

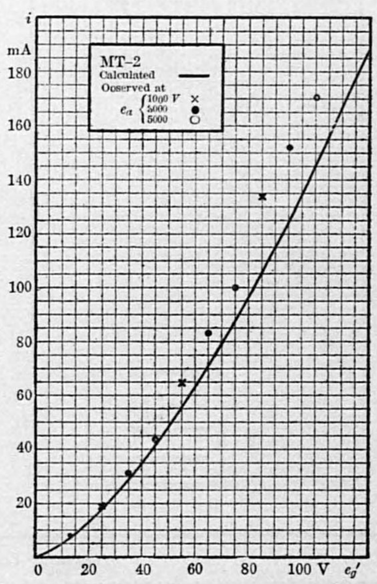
$c = 1$ $i = G e_g'^{\frac{3}{2}}$

$\pi a = .82$

$k = \frac{83 \times .382}{.171} = 185$

$e_g' = 60$ $\begin{cases} g = .00160 \\ r = 115{,}000 \end{cases}$

e_g'	$e_g'^{\frac{3}{2}}$	i
0	0	0
40	250	.034
70	585	.079
100	1000	.135

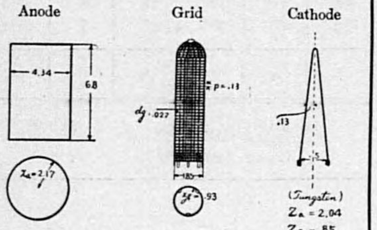


Example 38.

TRIODE TYPE: **MT-4** Manufacturer: Marconi Co.

Observations

Anode / Grid / Cathode



$e_f = 12.5$, $i_f = 6.3$ $\begin{cases} e_a = 1000 \\ e_g = 70 \end{cases}$ $k = 210$, $g = .0012$, $r = 175{,}000$

e_a	e_g	e_g'	i_a	i_g	i
1000	10.5	15	.004	.001	.005
	41	46	.022	.008	.030
	100	104	.090	.026	.116
	116	120	.114	.030	.144
3000	21	35	.015	.003	.018
	60	74	.050	.013	.063
	81	94	.080	.017	.097
5000	0	24	.0075		.0075
	21	45	.0215	.004	.0255
	41	64	.040	.008	.048

Calculations

$L_g = 82$ $A = 93$

$\frac{x_a}{x_g} = 2.33$ $\frac{A}{z_a z_g} = 58$

$\log \frac{x_a}{x_g} = .368$ $G = .135 \times 10^{-3}$

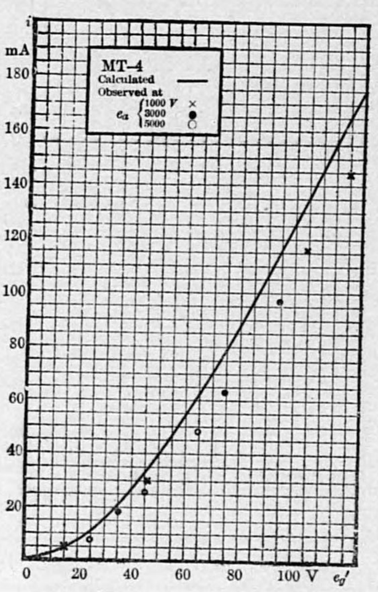
$c = 1$ $e_f = 12.5$

$\pi a = .97$ $\frac{2}{5} G e_f^{\frac{3}{2}} = .00238$

$k = \frac{82 \times .368}{.127} = 237$

$e_g' = 72$ $\begin{cases} g = .0016 \\ r = 148{,}000 \end{cases}$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	25	.011
4	16.51	50	.039
6	32.5	75	.077
8	53.0	100	.126
10	74.0	125	.176

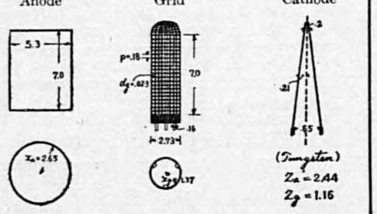


Example 39.

TRIODE TYPE: **MT-6** Manufacturer: Marconi Co.

Observations

Anode / Grid / Cathode



e_f=15.5 i_f=9.5

e_a=3000, e_g=+50

k=154, g=.00120, r=128,000

e_a	e_g	e_g'	i_a	i_g	i
1000	20	26	.009	.0024	.0114
	60	64	.049	.012	.061
	100	106	.114	.021	.135
3000	20	39	.020	.003	.023
	60	79	.063	.012	.080
	100	119	.173	.023	.196

Calculations

I_g=92 A=116

$\frac{z_a}{z_g}$=1.93 $\frac{A}{z_a z_g}$=41

$\log\frac{z_a}{z_g}$=.286 G=.096×10⁻³

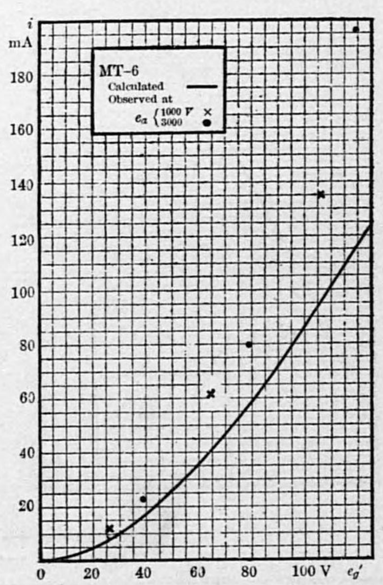
c=1 e_f=15.5

πa=.80 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=.00234

$k=\frac{92\times.286}{.178}=148$

e_g'=70 g=.00115, r=129,000

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	31	.0109
4	16.51	62	.0387
6	32.5	93	.076
8	53	124	.124
10	74	155	.173

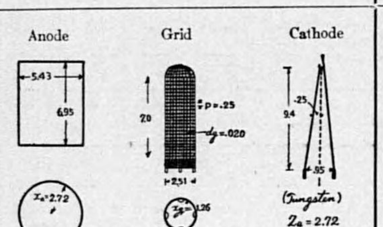


Example 40.

TRIODE TYPE: **MT-7A** Manufacturer: Marconi Co.

Observations

Anode / Grid / Cathode



e_f=12.5 i_f=21.5

e_a=5,000, e_g=0

k=61, g=.00149, r=41,000

e_a	e_g	e_g'	i_a	i_g	i
1000	0	16	.0045	.0002	.005
	40	55	. 41	.007	.048
	80	95	.100	.016	.116
3000	−20	29	.013		.013
	0	49	.032	.001	.033
	59	107	.114	.011	.125
5000	−59	24	.010		.010
	10	71	.059		.059
	20	100	. 06	.005	.111

Calculations

I_g=61 A=119

$\frac{z_a}{z_g}$=2.16 $\frac{A}{z_a z_g}$=48

$\log\frac{z_a}{z_g}$=.325 G=.112×10⁻³

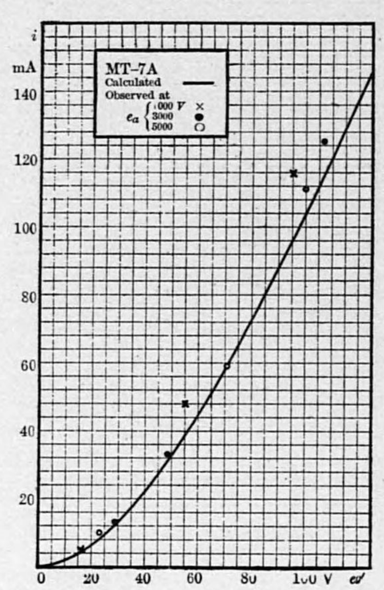
c=1 e_f=12.5

πa=.48 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=1.98×10⁻³

$k=\frac{61\times.335}{.352}=58$

e_g'=85 g=.00139, r=41,700

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.56	25	.0092
4	16.51	50	.0326
6	32.5	75	.064
8	53	100	.104
10	74	125	.146

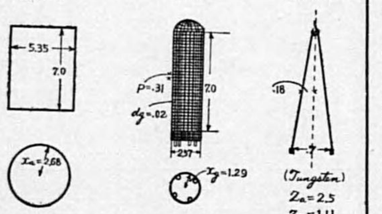


Example 41.

TRIODE TYPE: **MT-7 B** Manufacturer: Marconi Co.

Observations

Anode Grid Cathode



Calculations

L_g=52 A=118

$\frac{x_a}{x_g}$=2.08 $\frac{A}{z_a z_g}$=42.5

$\log \frac{x_a}{x_g}$=.318 G=.099×10⁻²

c=1 e_f=15

πa=.40 $\frac{2}{5} G e_f^{\frac{3}{2}}$=.00230

e_f=15 i_f=10

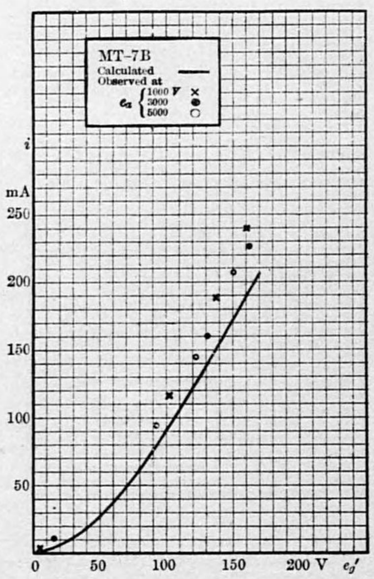
e_a=5,000 e_g=0 k=40 g=.00196 r=20,400

$k=\frac{52\times.318}{.420}=39.4$

e_g'=124 g=.0016 r=24,600

e_a	e_g	e_g'	i_a	i_g	i
1000	− 20	4.9	.003		.003
	80	102	.105	.012	.117
	117	138	.170	.018	.188
	139	160	.219	.021	.240
3000	−59	15.6	.012		.012
	59	131	.151	.009	.160
	90	161	.215	.013	.228
5000	−30	93	.093		.093
	0	122	.144	.001	.145
	30	151	.200	.007	.207

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	30	.0107
4	16.51	60	.039
6	32.5	90	.075
8	53.0	120	.123
10	74.0	150	.172

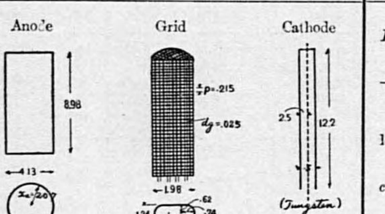


Example 42.

TRIODE TYPE: **MT-9** Manufacturer: Marconi Co.

Observations

Anode Grid Cathode



Calculations

L_g=38 A=117

$\frac{x_a}{x_g}$=3.34 $\frac{A}{z_a z_g}$=104

$\log \frac{x_a}{x_g}$=.524 G=.242×10⁻²

c=1 e_f=15.5

πa=.77 $\frac{2}{5} G e_f^{\frac{3}{2}}$=.0120

e_f=15.5 i_f=24.0

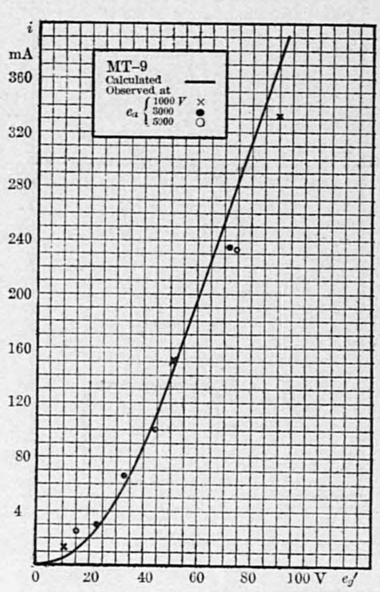
e_a=4000 e_g=0 k=91 g=.0032 r=28,500

$k=\frac{38\times.524}{.190}=104$

e_g'=38 g=.0020 r=52,000

e_a	e_g	e_g'	i_a	i_g	i
1000	0	10.9	.013		.013
	40	51	.137	.014	.151
	80	90	.305	.027	.332
3000	−10	23	.030		.030
	0	33	.066		.066
	40	72	.223	.012	.235
5000	−40	15	.025		.025
	−10	44	.100		.100
	20	74	.230	.003	.233

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
1	1.00	15.5	.012
2	4.65	31.0	.056
4	16.51	62.0	.198
6	32.5	93.0	.390

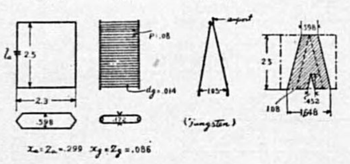


Example 43.

TRIODE TYPE: MU-20 Manufacturer: Daven Radio Co.

Observations

Anode Grid Cathode A



$x_a+z_a=.299$ $x_g+z_g=.086$

Calculations

$L_g=6.76$ $A=5.172$

$\frac{x_a}{x_g}=3.48$ $\frac{A}{z_a z_g}=201$

$\log\frac{x_a}{x_g}=0.541$ $G=.469\times10^{-3}$

$c=1.6$ $e_f=6.94$

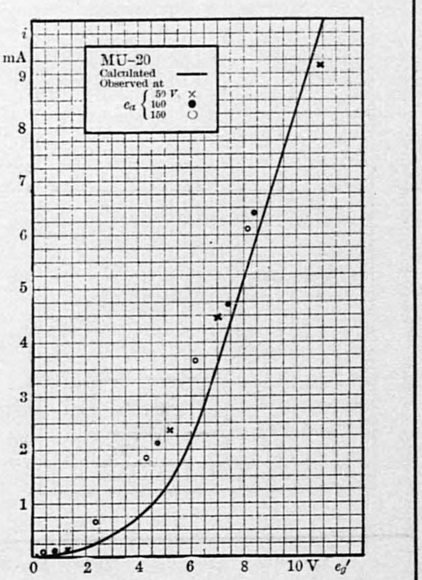
$\pi a=.551$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=3.17\times10^{-2}$

$e_f=6.94$ $i_f=0.25$ $\begin{cases}e_a=150\\e_g=-.4\end{cases}$ $k=20.4$ $g=.00134$ $r=15{,}200$

$k=\frac{1.6\times6.76\times.541}{.3}=19.5$ $e_g'=6.6$ $\begin{cases}g=.00127\\r=15{,}300\end{cases}$

e_a	e_g	e_g'	i_a	i_g	i
150	−6	1.29	.0002		.0002
	−2	5.11	.00235		.00235
	0	7.01	.00445	.000012	.00446
	4	10.8	.00912	.00017	.00914
100	−4	.84	.00016		.00016
	0	4.67	.0021	.00001	.00211
	4	8.46	.00637	.000017	.00639
50	−2	.43	.0001		.0001
	0	2.34	.00065	.00001	.00066
	2	4.24	.00177	.00006	.00183
	4	6.15	.00347	.00017	.00364
	6	8.04	.00568	.00036	.00604

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
.25	.031	1.74	.000106
.5	.177	3.47	.000607
.75	.415	5.21	.00144
1.00	1.00	6.94	.00343
1.5	2.57	10.41	.00882

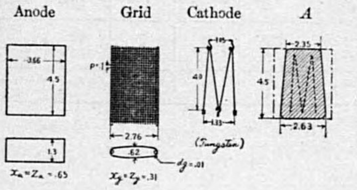


Example 44.

TRIODE TYPE: PAX Manufacturer: The Laboratory

Observations

Anode Grid Cathode A



$x_a+z_a=.63$ $x_g+z_g=.31$

Calculations

$L_g=37$ $A=22.4$

$\frac{x_a}{x_g}=2.1$ $\frac{A}{z_a z_g}=111$

$\log\frac{x_a}{x_g}=.324$ $G=.259\times10^{-3}$

$c=1.0$ $e_f=11$

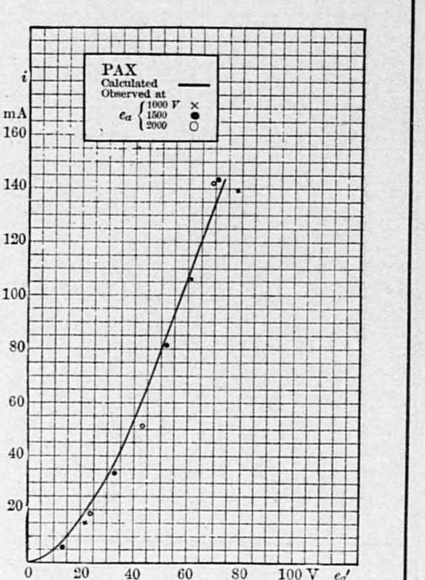
$\pi a=.60$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=.0038$

$e_f=11$ $i_f=5.48$ $\begin{cases}e_a=2{,}000\\e_g=+10\end{cases}$ $k=45$ $g=.0020$ $r=22{,}500$

$k=\frac{37\times.005}{.27}=44.1$ $e_g'=53.3$ $\begin{cases}g=.0027\\r=16{,}400\end{cases}$

e_a	e_g	e_g'	i_a	i_g	i
1000	0	22.2	.015		.015
	39	60.3	.090	.0159	.106
	58	78.5	.120	.0186	.139
1500	−20	13.	.0058		.006
	0	32.6	.0328		.033
	20	52.1	.073	.0082	.081
	39	70.7	.126	.0167	.143
2000	−20	23.9	.0176		.018
	0	43.5	.0512		.051
	20	69.3	.134	.0078	.142

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	22	.018
6	32.5	66	.123
8	53.0	88	.201
10	74.0	110	.281

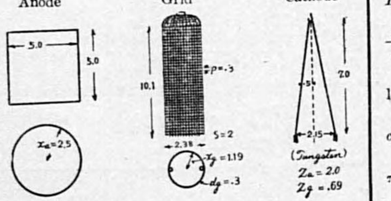


Example 45.

TRIODE TYPE: **PAY** Manufacturer: The Laboratory

Observations

Anode / Grid / Cathode



$e_f=14.5$ $i_f=8.0$

$\begin{cases} e_a=4{,}000 \\ e_g=0 \end{cases}$ $k=57.1$ $g=.0017$ $r=33{,}600$

Calculations

$L_g=50$ $A=75$

$\frac{x_g}{x_g}=2.10$ $\frac{A}{z_a z_g}=54.4$

$\log\frac{x_a}{x_g}=.322$ $G=.126\times10^{-3}$

$c=1$ $e_f=14.5$

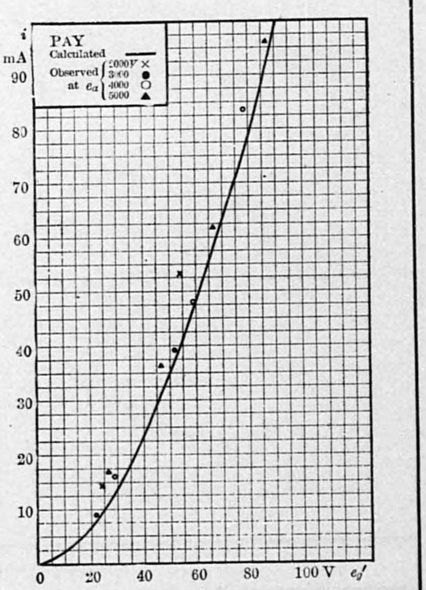
$\pi a=.63$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=.0023$

$k=\frac{50\times.322}{.254}=63.4$

$e_g'=62$ $\begin{cases} g=.0014 \\ r=45{,}000 \end{cases}$

e_a	e_g	e_g'	i_a	i_g	i
2000	−10	24.6	.0145	.003	.0145
	20	54	.050		.053
3000	−30	22.1	.0085		.0085
	0	51.6	.039		.039
4000	−40	29.5	.016		.016
	−10	59.	.048		.048
	10	78.6	.082	.0014	.0834
5000	−60	27.1	.017		.017
	−40	46.7	.036		.036
	−20	66.4	.062		.062
	0	86.	.096		.096

e_g'/f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	29	.013
4	16.51	58	.046
6	32.5	87	.091
8	53.0	116	.148

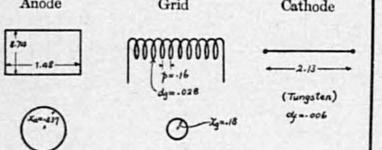


Example 46.

TRIODE TYPE: **R** Manufacturer: S. F. R.

Observations

Anode / Grid / Cathode



$e_f=4.0$ $i_f=1.0$

$\begin{cases} e_a=60 \\ e_g=0 \end{cases}$ $k=9.8$ $g=.00035$ $r=28{,}000$

Calculations

$L_g=7.1$ $A=4.07$

$\frac{x_a}{x_g}=2.43$ $\frac{A}{z_a z_g}=51.6$

$\log\frac{x_a}{x_g}=.385$ $G=.120\times10^{-3}$

$c=1$ $e_f=4.0$

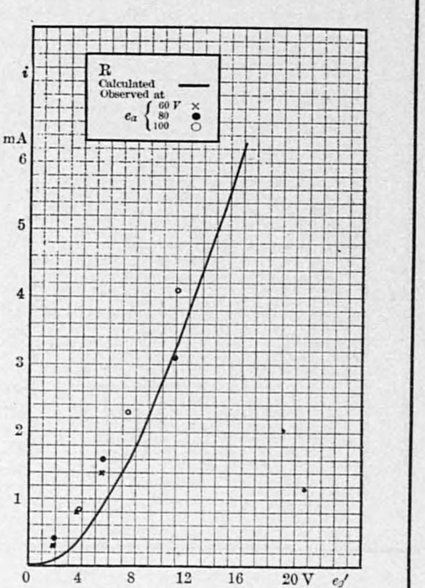
$\pi a=55$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=.384\times10^{-3}$

$k=\frac{7.1\times.385}{.302}=9.1$

$e_g'=5.9$ $\begin{cases} g=.00033 \\ r=28{,}000 \end{cases}$

e_a	e_g	e_g'	i_a	i_g	i
60	−4	1.8	.0003		.0003
	−2	3.7	.0008		.0008
	0	5.6	.0014		.0014
80	−6	1.9	.0004		.0004
	−2	5.6	.0016		.0016
	2	10.8	.0031		.0031
100	−6	3.8	.0008		.0008
	−2	7.4	.0023		.0023
	2	11.1	.0041		.0041

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
1	1.00	4	.00038
2	4.65	8	.00179
3	9.94	12	.00382
4	16.51	16	.00625

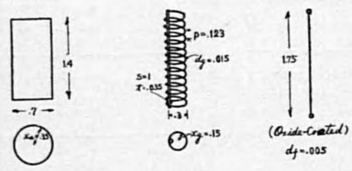


Example 47.

TRIODE TYPE: **RE-11** Manufacturer: Telefunken G.

Observations

Anode / Grid / Cathode



e_f=2.8 i_f=.50 $\begin{cases} e_a=40 \\ e_g=0 \end{cases}$ $k=10$ $g=.00018$ $r=56{,}000$

e_a	e_g	e_g'	i_a	i_g	i
40	−2	1.8	.0002		.0002
	0	3.6	.0005		.0005
60	−4	1.8	.0002		.0002
	−2	3.6	.0006		.0006
80	−5	2.7	.00025		.00025
	−4	3.6	.0005		.0005
	−2	5.5	.0010		.0010

Calculations

L_g=8.4 A=3.08

$\frac{x_a}{x_g}$=2.34 $\frac{A}{z_a z_g}$=58.7

$\log\frac{x_a}{x_g}$=.37 $G=.137\times10^{-3}$

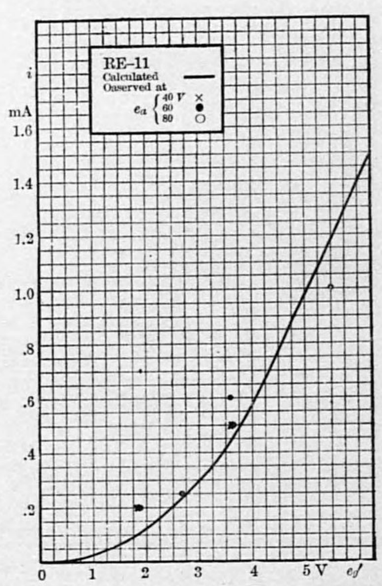
c=1 e_f=2.8

πa= 49 $\frac{2}{5}Ge_f^{\frac{3}{2}}=.26\times10^{-3}$

$k=\frac{8.4\times.37}{.344}=9.1$

e_g'=4.0 $\begin{cases} g=.00030 \\ r=30{,}000 \end{cases}$

e_g/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
1	1.00	2.8	.00026
2	4.65	5.6	.00121
3	9 94	8.4	.00259

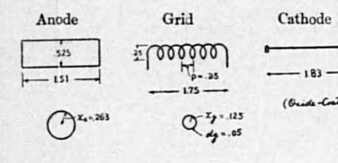


Example 48.

TRIODE TYPE: **RE-84** Manufacturer: Telefunken G.

Observations

Anode / Grid / Cathode



e_f=1.5 i_f=.26 $\begin{cases} e_a=60 \\ e_g=0 \end{cases}$ $k=4.3$ $g=0.00062$ $r=7{,}000$

e_a	e_g	e_g'	i_a	i_g	i
60	− 8	4.9	.0020		.0020
	− 4	8.1	.0036		.0036
	0	11.3	.0053		.0053
80	−10	7.0	.0032		.0032
	− 6	10.2	.0052		.0052
	0	15 1	.0085		.0085
100	−10	10.8	.0060		.0060
	− 3	16.4	.0098		.0098

Calculations

L_g=3.3 A=2.5

$\frac{x_a}{x_g}$=2.1 $\frac{A}{z_a z_g}$=77

$\log\frac{x_a}{x_g}$=.323 $G=.18\times10^{-3}$

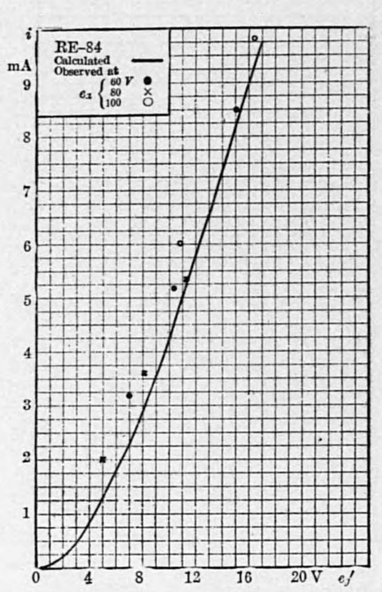
c=1 e_f=1.5

πa=.66 $\frac{2}{5}Ge_f^{\frac{3}{2}}=.11\times10^{-3}$

$k=\frac{3.3\times.323}{.238}=4.5$

e_g'=11 $\begin{cases} g=.00071 \\ r=6{,}300 \end{cases}$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4 65	3.0	.0005
4	16 51	6.0	.0018
6	32 5	9.0	.0035
8	53.0	12.0	.0058
10	74.0	15.0	.0081

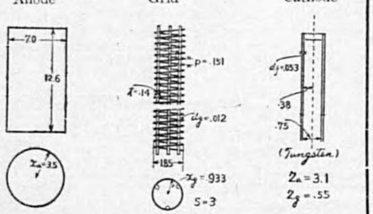


Example 49.

TRIODE TYPE: **RS-15** Manufacturer: Telefunken G.

Observations

Anode / Grid / Cathode



e_f=16 i_f=17.1

$\begin{cases} e_a=2{,}000 \\ e_g=50 \end{cases}$ k=60 g=.0045 r=13,300

e_a	e_g	e_g'	i_a	i_g	i
1000	− 10.5	6.1	.007		.007
	0	16	.022		.022
	21	37	.066	.006	.072
	41	55	.131	.012	.143
	60.5	76	.202	.018	.220
	81	96	.298	.026	.324
3000	− 41	15.4	.009		.009
	− 21	28	.043		.043
	0	49	.103	.002	.105
	+ 41	89	.273	.014	.284
6000	− 81	18.5	.030		.030
	− 60	39	.079		.079
	− 41	57	.147		.147

Calculations

L_g=38.9 A=277

$\frac{x_a}{x_g}$=3.77 $\frac{A}{z_a z_g}$=162

$\log \frac{x_a}{x_g}$=.576 G=.379×10⁻³

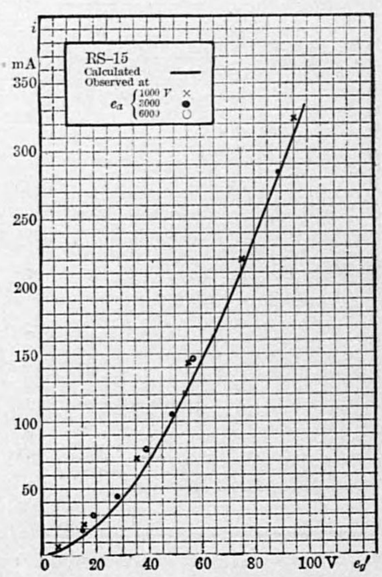
c=1 e_f=16

πa=.46 $\frac{2}{5} G e_f^{\frac{3}{2}}$=.0097

$k=\frac{38.9\times.576}{.369}$=60.5

e_g'=82 $\begin{cases} g=.0047 \\ r=12{,}900 \end{cases}$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	32	.045
4	16.51	64	.160
6	32.5	96	.315
8	53.0	128	.514

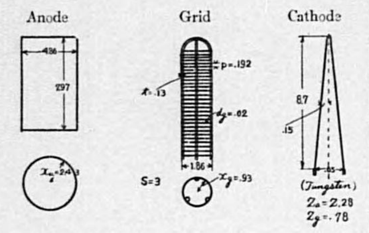


Example 50.

TRIODE TYPE: **T-450 A** Manufacturer: Marconi Co.

Observations

Anode / Grid / Cathode



e_f=18 i_f=5.4

$\begin{cases} e_a=4{,}000 \\ e_g=-40 \end{cases}$ k=33 g=.00194 r=23,600

e_a	e_g	e_g'	i_a	i_g	i
4000	−80	39.6	.020		.020
	−40	78	.070		.070
	0	127	.145		.145
4500	−80	54	.040		.040
	−40	93	.100		.100
	0	132	.180		.180
5000	−80	69	.060		.060
	−40	108	.130		.130
	0	137	.195		.195

Calculations

L_g=31.2 A=117

$\frac{x_a}{x_g}$=2.61 $\frac{A}{z_a z_g}$=66

$\log \frac{x_a}{x_g}$=.417 G=.153×10⁻³

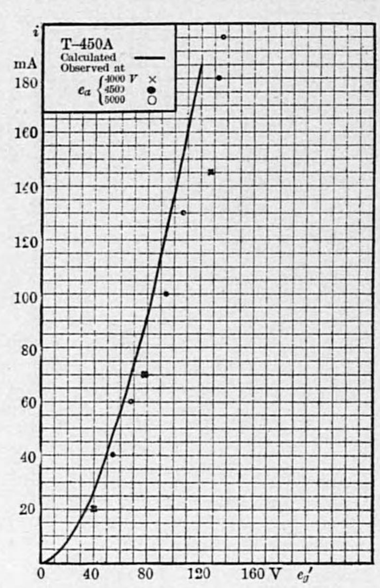
c=1 e_f=18

πa=.51 $\frac{2}{5} G e_f^{\frac{3}{2}}$=.00465

$k=\frac{31.2\times.417}{.329}$=39

e_g'=61 $\begin{cases} g=.00160 \\ r=24{,}400 \end{cases}$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	36	.0216
4	16.51	72	.077
6	32.5	108	.151

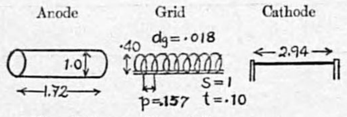


Example 51.

TRIODE TYPE: **TA 04/5** Manufacturer: Philips' Lamp Works

Observations

Anode Grid Cathode



Calculations

L_g=8.3 A=5.44

$\frac{x_a}{x_g}$=2.52 $\frac{A}{z_a z_g}$=54.4

$\log\frac{x_a}{x_g}$=.402 G=.127×10⁻³

c=1 e_f=5.0

πa=.59 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=.57×10⁻³

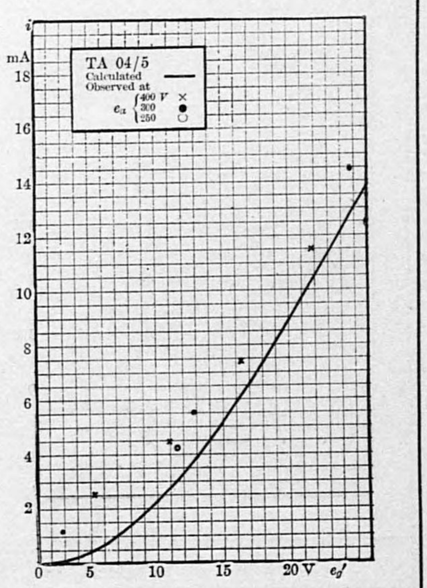
e_f=5.0 i_f=1.67

e_a=400 k=11.6
e_g=−14 g=.00078
r=14,900

$k=\frac{8.3\times.402}{.276}$=12

e_g'=18 g=.00071, r=17,000

e_a	e_g	e_g'	i_a	i_g	i	e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
400	−30	4.12	.0025		.0025	.5	.177	2.5	.000102
	−24	9.7	.00445		.00445	1	1.00	5.0	.00057
	−18	15.15	.00735		.00735	1.5	2.57	7.5	.00147
	−12	20.7	.0115		.0115	2	4.65	10.0	.00266
300	−24	1.75	.0012		.0012	3	9.94	15.0	.00565
	−12	12.8	.0055		.0055	4	16.51	20.0	.00942
	0	23.8	.0144		.0144	5	24.1	25.0	.0137
250	− 6	10.3	.0042		.0042				

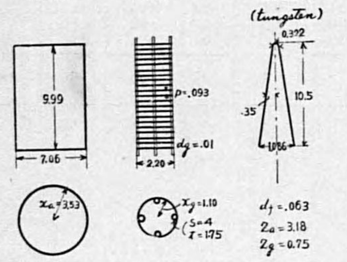


Example 52.

TRIODE TYPE: **TA 10/3000** Manufacturer: Philips' Lamp Works.

Observations

Anode Grid Cathode (tungsten)



Calculations

L_g=70.7 A=221

$\frac{x_a}{x_g}$=3.21 $\frac{A}{z_a z_g}$=93.2

$\log\frac{x_a}{x_g}$=.507 G=.217×10⁻³

c=1 e_f=13

πa=.63 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=4.06×10⁻³

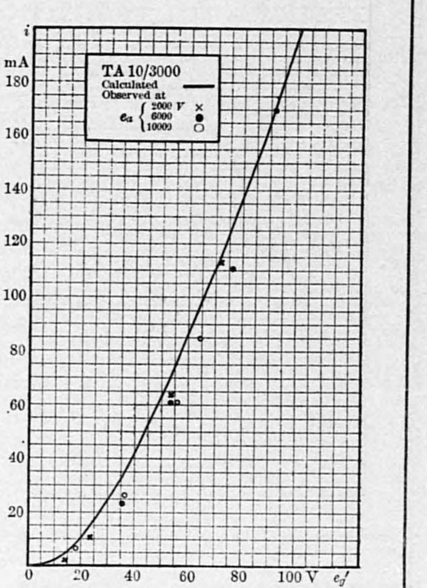
e_f=13 i_f=24.6

e_a=80,00 k=127
e_g=+11 g=0.0027
r=47,000

$k=\frac{70.7\times.507}{.254}$=141

e_g'=73.4 g=.00264, r=53,400

e_a	e_g	e_g'	i_a	i_g	i	e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
2000	0	14.8	.0020		.002	1	1.00	13	.004
	10	24.2	.0100	.0005	.0105	2	4.65	26	.019
	40	52.4	.0570	.0066	.0636	3	9.94	39	.040
	60	71.4	.1040	.0095	.1135	4	16.51	52	.097
6000	−10	35.1	.0235		.0235	5	24.1	65	.098
	10	53.9	.0600	.0006	.0606	6	32.5	78	.132
	30	76.6	.1070	.0040	.1110	8	53.0	104	.215
	50	91.7	.1620	.0080	.1700	10	74.1	130	.330
10000	−60	17.75	.0070		.0070				
	−40	36.6	.0270		.0270				
	−20	55.4	.0610		.0610				
	−10	64.7	.0850		.0850				

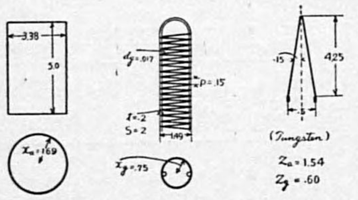


Example 53.

TRIODE TYPE: TR-V Manufacturer: Nihon Musen D. D. K. K.

Observations

Anode / Grid / Cathode



e_f=11.2 i_f=3.4 $\begin{cases} e_a=150 \\ e_g=0 \end{cases}$ k=31 g=.0013 r=23,800

e_a	e_g	e_g'	i_a	i_g	i
500	0	15.6	.005		.005
	40	54	.038	.004	.042
	80	93	.091	.010	.101
1000	0	31	.015		.015
	40	70	.057	.005	.062
1500	−20	27.5	.014		.014
	20	66	.053	.002	.055
	60	105	.111	.008	.119

Calculations

L_g=30.7 A=53

$\frac{x_a}{x_g}$=2.25 $\frac{A}{z_a z_g}$=57.4

$\log\frac{x_a}{x_g}$=.35 G=.134×10⁻³

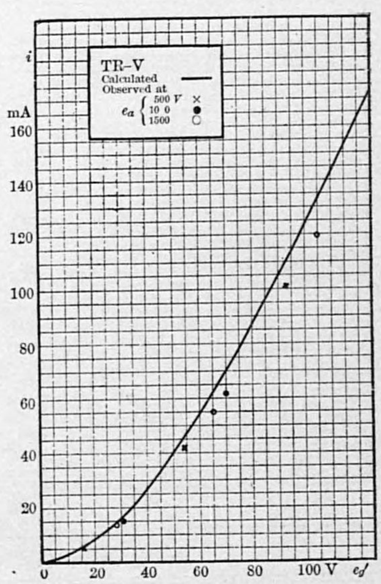
c=1 e_f=11.2

πa=.59 $\frac{2}{5}Ge_f^{\frac{5}{2}}$=.00199

$k=\frac{30.7\times.35}{.276}$=39

e_g'=38 $\begin{cases} g=.0011 \\ r=35{,}000 \end{cases}$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	22.4	.009
4	16.51	44.8	.033
6	32.5	67.2	.065
8	53	89.6	.105
10	74	112	.147

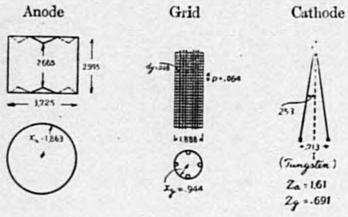


Example 54.

TRIODE TYPE: UN-154 Manufacturer: Tokyo Denki K. K.

Observations

Anode / Grid / Cathode



e_f=10 i_f=6 $\begin{cases} e_a=3{,}000 \\ e_g=+65 \end{cases}$ k=210 g=.00104 r=21,200

e_a	e_g	e_g'	i_a	i_g	i
1000	10	14.7	.0015	.001	.0025
	50	54.5	.020	.0065	.0265
	80	84.4	.047	.0111	.0581
	120	1.242	.091	.0140	.105
2000	30	39.3	.009	.0035	.0125
	60	69.2	.031	.0080	.039
	90	99.1	.061	.0109	.0719
3000	40	54.0	.0168	.005	.0218
	80	93.9	.055	.0093	.0643
	100	113.9	.080	.0106	.0906

Calculations

L_g=174 A=234.3

$\frac{x_a}{x_g}$=1.97 $\frac{A}{z_a z_g}$=30.8

$\log\frac{x_a}{x_g}$=.295 G=.072×10⁻³

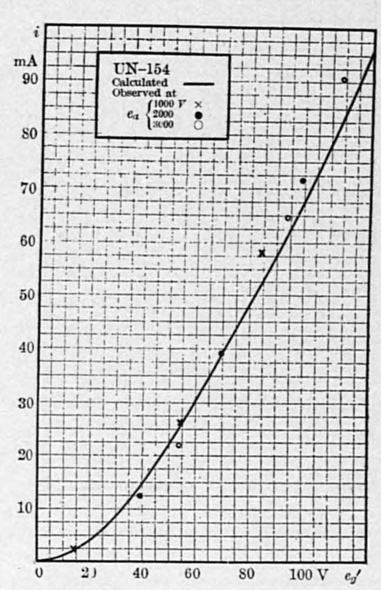
c=1 e_f=10

πa=.74 $\frac{2}{5}Ge_f^{\frac{5}{2}}$=.071×10⁻³

$k=\frac{174\times.295}{.202}$=252

e_g'=74 $\begin{cases} g=.00090 \\ r=28{,}000 \end{cases}$

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
1	1.00	10	.00091
2	4.65	20	.00423
3	9.94	30	.00905
4	16.51	40	.0152
5	24.1	50	.0219
6	32.5	60	.0296
8	53.0	80	.0482
10	74.0	100	.0673

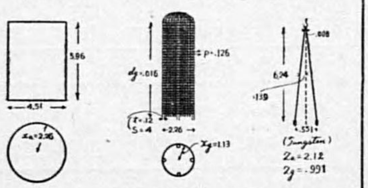


Example 55.

TRIODE TYPE: **UN-155** Manufacturer: Tokyo Denki K. K.

Observations

Anode / Grid / Cathode



e_f=12 i_f=6

e_a=2,000 e_g=+80

k=125 g=.00114 r=110,000

Calculations

I_g=106 A=84.6

$\frac{x_a}{x_g}$=1.99 $\frac{A}{z_a z_g}$=40.5

$\log\frac{x_a}{x_g}$=.299 G=.0944×10⁻³

c=1 e_f=12

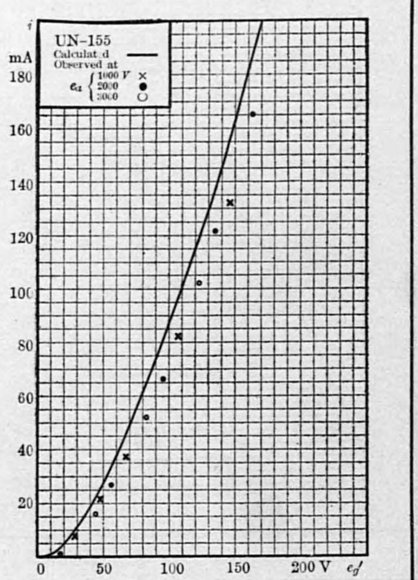
πa=.75 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=.00157

$k=\frac{106\times.299}{.198}$=160

e_g'=93 g=.00131 r=122,000

e_a	e_g	e_g'	i_a	i_g	i
1000	20	27.8	.006	.0019	.008
	40	47.6	.017	.0046	.0216
	60	67.5	.032	.0070	.039
	100	107	.072	.0105	.0825
	140	147	.120	.0120	.132
2000	0	15.9	.001		.001
	40	55.5	.022	.0046	.0266
	80	95.2	.057	.0090	.066
	120	135.	.112	.0096	.1216
3000	20	43.6	.0135	.0019	.0154
	60	83.4	.045	.0070	.052
	100	123	.094	.0082	.1022
	140	163	.153	.0075	.1605

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
1	1.00	12	.00157
2	4.65	24	.0073
3	9.94	36	.0156
4	16.51	48	.0259
5	24.1	60	.0378
6	32.5	72	.051
8	53.0	96	.0832
10	74.0	120	.1161
15	138.0	180	.2163

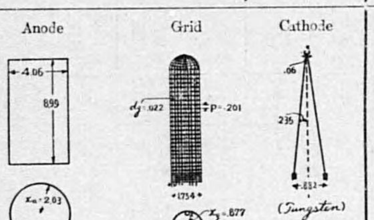


Example 56.

TRIODE TYPE: **UN-159** Manufacturer: Tokyo Denki K. K.

Observations

Anode / Grid / Cathode



e_f=17 i_f=23.5

e_a=9,000 e_g=−30

k=90 g=.00204 r=44,100

Calculations

I_g=56.5 A=115

$\frac{x_a}{x_g}$=2.32 $\frac{A}{z_a z_g}$=99.8

$\log\frac{x_a}{x_g}$=.365 G=.233×10⁻³

c=1 e_f=17

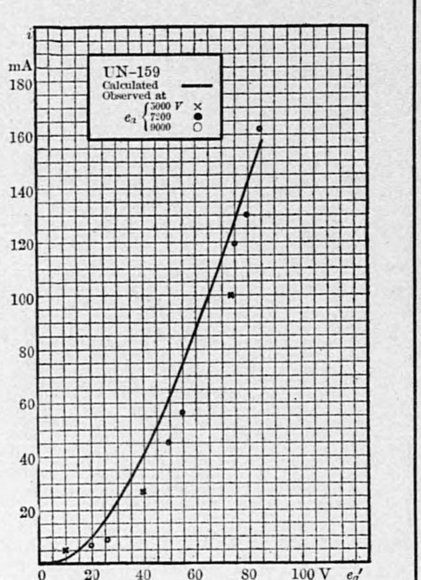
πa=.71 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=.00651

$k=\frac{56.5\times.365}{.212}$=96

e_g'=123 g=.0037 r=26,000

e_a	e_g	e_g'	i_a	i_g	i
9000	−90	9.9	.005		.005
	−60	39.6	.027		.027
	−30	73.6	.100		.100
7200	−60	19.8	.007		.007
	−30	49.5	.045		.045
	0	79.2	.130		.130
5000	−30	25.3	.009		.009
	0	54.9	.056		.056
	20	74.8	.115	.003	.118
	30	84.8	.152	.010	.162

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
.5	.177	8.5	.0011
1.0	1.00	17.	.0065
2.0	4.65	34.	.0304
3.0	9.94	51.	.0647
4.0	16.51	68.	.1075
5.0	24.1	85.	.157

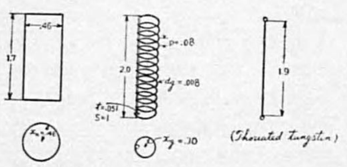


Example 57.

TRIODE TYPE: **UV-199** Manufacturer: Tokyo Denki K. K.

Observations

Anode Grid Cathode



Calculations

$L_g=12.1$ $A=2.46$

$\frac{x_a}{x_g}=1.53$ $\frac{A}{z_a z_g}=71.2$

$\log\frac{x_a}{x_g}=.185$ $G=.166\times10^{-3}$

$c=1$ $e_f=3.35$

$\pi a=.466$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=.41\times10^{-3}$

$e_f=3.35$ $i_f=.06$

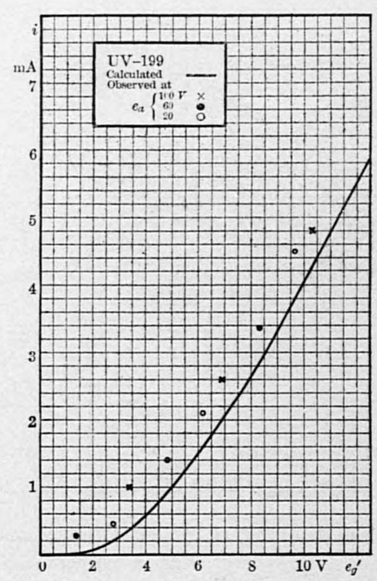
$\begin{cases}e_a=100\\e_g=0\end{cases}$ $k=6.25$ $g=.00060$ $r=10{,}400$

$k=\frac{12.1\times.185}{.360}=6.22$

$e_g'=13.8$ $\begin{cases}g=.00075\\r=8{,}300\end{cases}$

e_a	e_g	e_g'	i_a	i_g	i
100	−12	3.25	.0010		.0010
	− 8	6.90	.0026		.0026
	− 4	10.35	.0048		.0048
60	− 8	1.38	.0003		.0003
	− 4	4.83	.0014		.0014
	0	8.28	.00335		.00335
20	0	2.76	.00045		.00045
	4	6.21	.00195	.00015	.00210
	8	9.66	.004	.0005	.0045

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
.5	.177	1.675	.000073
.75	.414	2.51	.000111
1.0	1.00	3.35	.00041
1.5	2.57	5.025	.00104
2.0	4.65	6.70	.00191
2.5	7.13	8.375	.00292
3.0	9.94	10.05	.00407
4.0	16.51	13.4	.00676

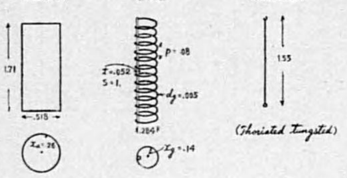


Example 58.

TRIODE TYPE: **UV-199** Manufacturer: R. C. A.

Observations

Anode Grid Cathode



Calculations

$L_g=11.3$ $A=2.78$

$\frac{x_a}{x_g}=1.86$ $\frac{A}{z_a z_g}=76.5$

$\log\frac{x_a}{x_g}=.269$ $G=.178\times10^{-3}$

$c=1$ $e_f=3.0$

$\pi a=.37$ $\frac{2}{5}Ge_f^{\frac{3}{2}}=.37\times10^{-3}$

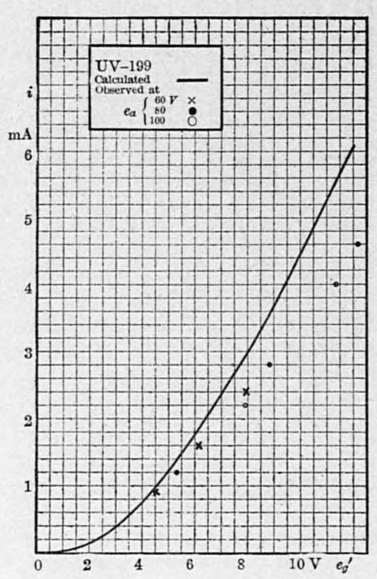
$e_f=3.0$ $i_f=.06$ A. C. $\begin{cases}e_a=60\\e_g=0\end{cases}$ $k=6.6$ $g=.00044$ $r=15{,}000$

$k=\frac{11.3\times.269}{.456}=6.7$

$e_g'=7.8$ $\begin{cases}g=.00053\\r=13{,}000\end{cases}$

e_a	e_g	e_g'	i_a	i_g	i
60	−4	4.5	.0009		.0009
	−2	6.2	.0016		.0016
	0	7.9	.0024		.0024
80	−6	5.3	.0012		.0012
	−2	8.8	.0028		.0028
	2	12.2	.0046		.0046
100	−6	7.9	.0022		.0022
	−2	11.4	.0040		.0040

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
1	1.00	3	.00037
2	4.65	6	.00172
3	9.94	9	.00367
4	16.51	12	.0061

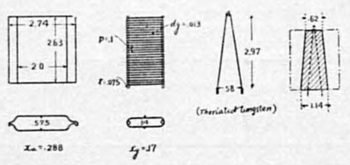


Example 59.

TRIODE TYPE: **UV-201A** Manufacturer: Tokyo Denki K. K.

Observations

Anode Grid Cathode *A*



e_f=5.0 i_f=.244

e_a=80, e_g=0 k=7.0 g=.00062 r=11,200

e_a	e_g	e_g'	i_a	i_g	i
21	0	2.6	.0003		.0003
	6	7.9	.0023	.0002	.0025
	12	13.1	.0052	.0007	.0059
61	−3	5.0	.0010		.0010
	2	9.4	.0035	0	.0035
	8	14.6	.0072	.0003	.0075
	14	19.9	.0117	.0007	.0124
102	−6	7.5	.0023		.0023
	0	12.7	.0060		.0060
	6	18.0	.0106	.0002	.0108
	10	21.5	.0142	.0004	.0146

Calculations

L_g=10.7 A=4.57

$\frac{x_a}{x_g}$=1.7 $\frac{A}{z_a z_g}$=93.5

$\log\frac{x_a}{x_g}$=.229 G=.218×10⁻³

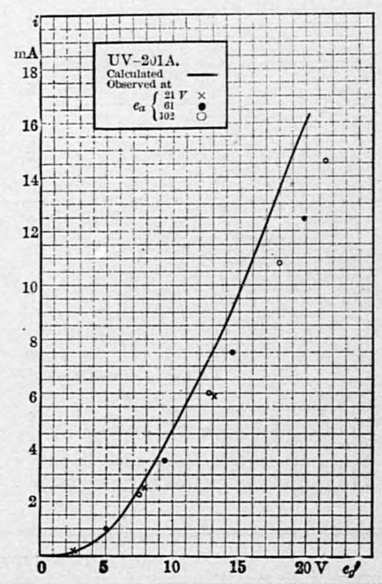
c=1.2 e_f=5.0

πa=.41 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=.98×10⁻³

$k=\frac{1.2\times10.7\times.229}{.411}=7.1$

e_g'=9.9 g=.00077, r=9,200

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
0.5	.177	2.5	.00017
1	1.00	5	.00098
2	2.60	10	.00455
3	9.24	15	.00974
4	16.51	20	.0162

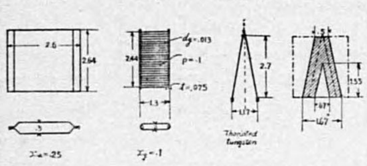


Example 60.

TRIODE TYPE: **UV-201A** Manufacturer: R. C. A.

Observations

Anode Grid Cathode *A*



e_f=5.0 i_f=.253

e_a=80, e_g=0 k=8.5 g=.0010 r=8,500

e_a	e_g	e_g'	i_a	i_g	i
20	0	2.1	.0004		.0004
	3	4.8	.0017	.0001	.0018
	6	7.5	.0033	.0004	.0043
60	−3	3.6	.0008		.0008
	0	6.3	.0028		.0028
	3	9.0	.0055	.0001	.0056
	6	11.7	.0088	.0003	.0091
100	−6	5.2	.0018		.0018
	−3	7.8	.0041		.0043
	0	10.5	.0073		.0073

Calculations

L_g=6.28 A=4.77

$\frac{x_a}{x_g}$=2.5 $\frac{A}{z_a z_g}$=191

$\log\frac{x_a}{x_g}$=.398 G=.445×10⁻³

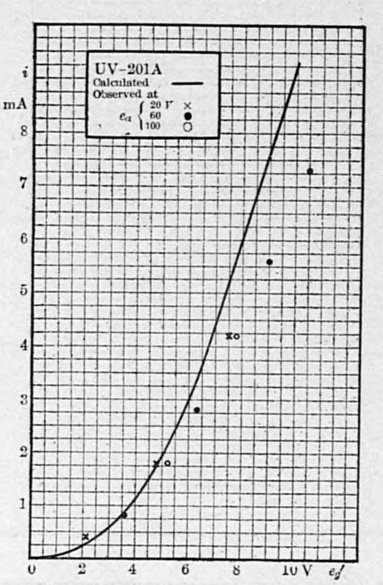
c=1.45 e_f=5.0

πa=.41 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=1.99×10⁻³

$k=\frac{1.45\times6.28\times.398}{.411}=8.8$

e_g'=8.2 g=.0014, r=6,100

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
0.5	.177	2.5	.00035
1	1.00	5	.00199
1.5	2.57	7.5	.00512
2	4.65	10	.00825

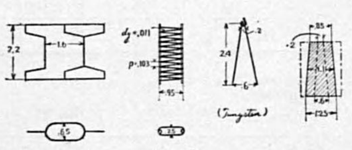


Example 61.

TRIODE TYPE: UV-202 Manufacturer: R. C. A.

Observations

Anode Grid Cathode *A*



$x_a = .325$ $x_g = .125$

$e_f = 7.5$ $i_f = 2.31$

$\begin{cases} e_a = 350 \\ e_g = -10 \end{cases}$ $k = 2.3$ $g = .0016$ $r = 5{,}800$

e_a	e_g	e_g'	i_a	i_g	i
300	−30	1.9	.003		.003
	− 8	22	.024		.024
	8	36	.049	.0009	.050
350	−30	6.8	.005		.005
	− 8	27	.033		.033
	8	41	.057	.0009	.058
400	−20	21	.023		.023
	− 8	31	.041		.041
	8	46	.063	.0009	.064

Calculations

$L = 7.6$ $A = 4.8$

$\frac{x_a}{x_g} = 2.6$ $\frac{A}{z_a z_g} = 118$

$\log \frac{x_a}{x_g} = .415$ $G = .276 \times 10^{-3}$

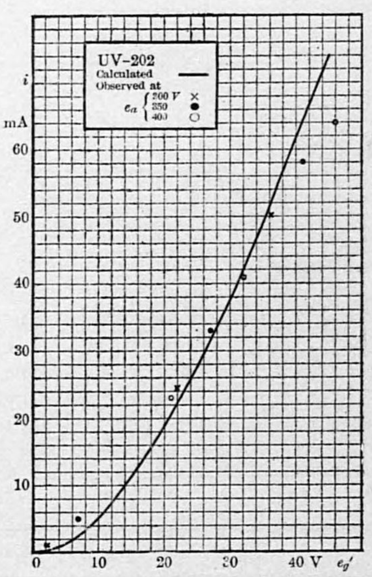
$c = 1.5$ $e_f = 7.5$

$\pi a = .74$ $\frac{2}{5} G e_f^{\frac{3}{2}} = .00227$

$k = \frac{1.5 \times 7.6 \times .415}{.493} = 9.6$

$e_g' = 24$ $\begin{cases} g = .0017 \\ r = 5{,}700 \end{cases}$

e_g'/e_f	$f(e_g/e_f)$	e_g'	i
0	0	0	0
1	1.00	7.5	.0023
2	4.65	15.0	.0105
4	16.51	30.0	.037
6	32.5	45.0	.074

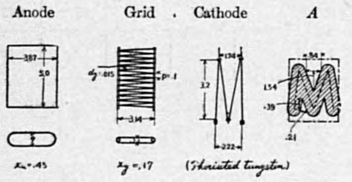


Example 62.

TRIODE TYPE: UV-203A Manufacturer: R. C. A.

Observations

Anode Grid Cathode *A*



$x_a = .45$ $x_g = .17$ (Thoriated tungsten)

$e_f = 9.5$ $i_f = 3.25$ A. C. $\begin{cases} e_a = 500 \\ e_g = +20 \end{cases}$ $k = 25$ $g = .0050$ $r = 5{,}000$

e_a	e_g	e_g'	i_a	i_g	i
500	−10.5	9	.023		.023
	0	19	.056	.001	.057
	21	39	.155	.008	.163
	40	58	.255	.015	.270
1000	−10.5	28.5	.092		.092
	10.5	48	.192	.004	.196
2000	−60	19	.059		.059
	−50.5	28.5	.092		.092

Calculations

$L_g = 10.7$ $A = 25.4$

$\frac{x_a}{x_g} = 2.65$ $\frac{A}{z_a z_g} = 332$

$\log \frac{x_a}{x_g} = .42$ $G = 774 \times 10^{-3}$

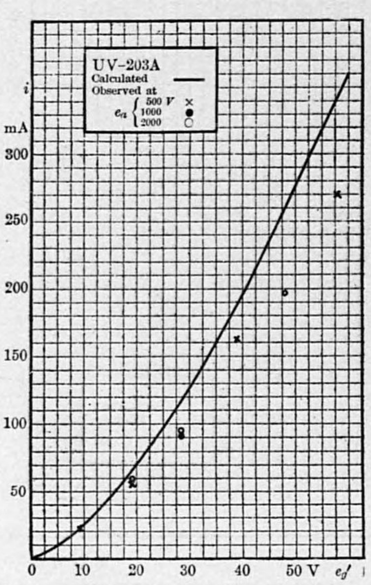
$c = 1.75$ $i = G e_g'^{\frac{3}{2}}$

$\pi a = .57$

$k = \frac{1.75 \times 10.7 \times .42}{.289} = 27$

$e_g' = 37$ $\begin{cases} g = .0068 \\ r = 4{,}000 \end{cases}$

e_g'	$e_g'^{\frac{3}{2}}$	i
0	0	0
10	31.6	.025
20	89	.069
30	164	.127
40	253	.196
50	354	.274
60	465	.360

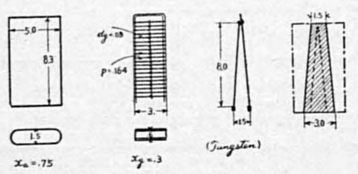


Example 63.

TRIODE TYPE: UV-204 Manufacturer: R. C. A.

Observations

Anode Grid Cathode *A*



e_f=11.4, i_f=14.75, A. C. e_a=2,000, e_g=0, k=26, g=.0048, r=5,400

e_a	e_g	e_g'	i_a	i_g	i
1500	−40	17.5	.018		.018
	−20	37	.058		.058
	0	56	.126		.126
	20	75	.210		.210
2500	−60	35.5	.048		.048
	−40	55	.110		.110
	−20	74	.210		.210

Calculations

L_g=11.5 A=38.1

$\frac{x_a}{x_g}$=2.5 $\frac{A}{z_a z_g}$=169

$\log\frac{x_a}{x_g}$=.398 G=.395×10⁻³

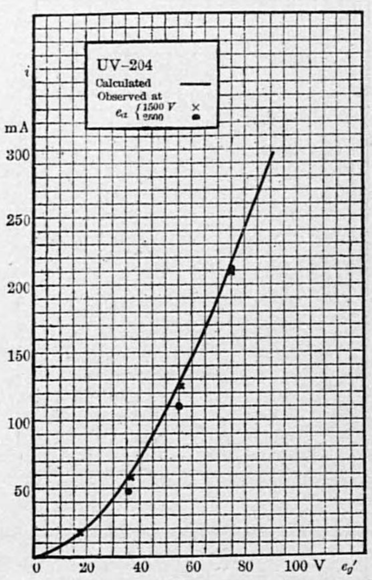
c=1.45 e_f=11.4

πa=.575 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=.00607

$k=\frac{1.45\times11.5\times.398}{.285}$=23.3

e_g'=65 g=.0 46, r=6,400

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	22.8	.026
4	16.51	45.6	.093
6	32.5	68.4	.182
8	53.0	91.2	.298

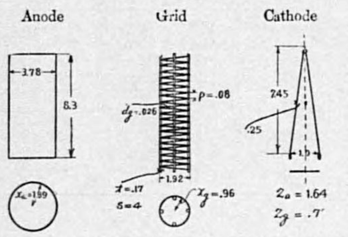


Example 64.

TRIODE TYPE: UV-206 Manufacturer: Tokyo Denki K. K.

Observations

Anode Grid Cathode



e_f=11.0, i_f=14.5, e_a=10,000, e_g=+20, k=316, g=.00206, r=153,000

e_a	e_g	e_g'	i_a	i_g	i
6,000	−20	− 1	.001		.001
	0	19	.013		.013
	20	39	.037	.004	.041
	29	48	.052	.006	.058
	48	67	.102	.010	.112
8,000	−20	5.3	.003		.003
	0	25.4	.0195	.001	.021
	29	54	.0655	.006	.072
10,000	−20	11.7	.0065		.0065
	0	32	.028	.001	.029
	29	61	.079	.007	.086

Calculations

L_g=67 A=98.6

$\frac{x_a}{x_g}$=1.97 $\frac{A}{z_a z_g}$=85

$\log\frac{x_a}{x_g}$=.294 G=.198×10⁻³

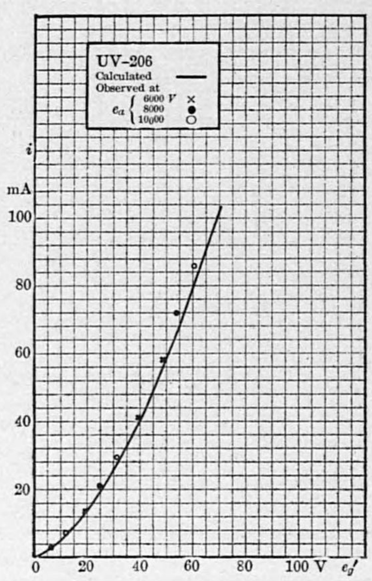
c=1 e_f=11.0

πa=1.22 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=.00285

$k=\frac{67\times.294}{.071}$=280

e_g'=56 g=.0021, r=133,000

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	22	.0084
4	16.51	44	.030
6	32.5	66	.059
8	53.0	88	.096

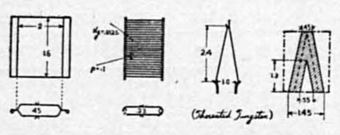


Example 65.

TRIODE TYPE: UX-201A Manufacturer: R. C. A.

Observations

Anode Grid Cathode A



x_a=.225 x_g=.115

Calculations

L_g=7.22 A=4.22

$\frac{x_a}{x_g}$=1.96 $\frac{A}{z_a z_g}$=163

$\log\frac{x_a}{x_g}$=.291 G=.38×10⁻³

c=1.3 e_f=5.0

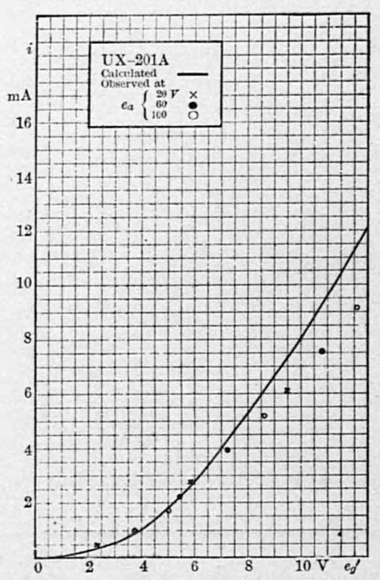
πa=.39 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=.0017

e_f=5.0 i_f=.248 e_a=80 e_g=0 k=7.2 g=.0010 r=7,200

$k=\frac{1.3\times7.22\times.291}{.432}=6.3$ e_g'=11 g=.0014 r=4,500

e_a	e_g	e_g'	i_a	i_g	i
20	0	2.4	.00042		.0004
	4	5.9	.0025	.00015	.0027
	8	9.5	.0055	.0006	.0061
60	−4	3.8	.0010		.0010
	−2	5.5	.0022		.0022
	0	7.3	.0039		.0039
	4	10.8	.0075	.0001	.0076
100	−8	5.1	.0017		.0017
	−4	8.7	.0052		.0052
	0	12.2	.0092		.0092

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
.50	.177	2.5	.0003
.75	.414	3.8	.0007
1.00	1.00	5.0	.0017
1.5	2.57	7.5	.0044
2.0	4.65	10.0	.0079

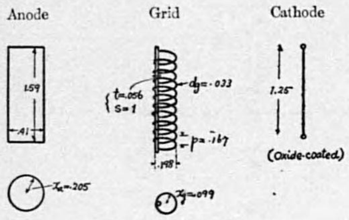


Example 66.

TRIODE TYPE: WD-11 Manufacturer: R. C. A.

Observations

Anode Grid Cathode



Calculations

L_g=4.38 A=2.05

$\frac{x_a}{x_g}$=2.07 $\frac{A}{z_a z_g}$=101

$\log\frac{x_a}{x_g}$=.316 G=.235×10⁻³

c=1 e_f=1.1

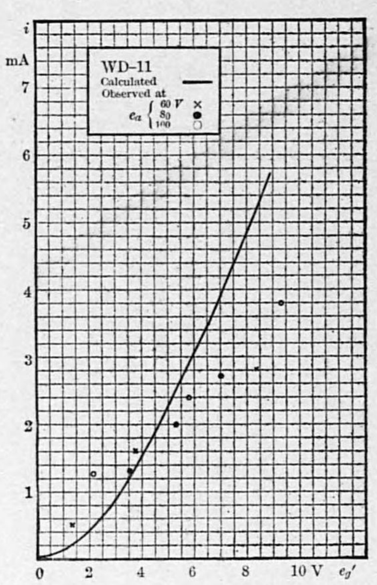
πa=.86 $\frac{2}{5}Ge_f^{\frac{3}{2}}$=.108×10⁻³

e_f=1.1 i_f=.25 e_a=60 e_g=−2 k=8.0 g=.00023 r=35,000

$k=\frac{4.38\times.316}{.157}=8.8$ e_g'=4.0 g=.0006 r=15,000

e_a	e_g	e_g'	i_a	i_g	i
60	− 6	1.3	.0005		.0005
	− 2	3.8	.0016		.0016
	2	8.4	.0028		.0028
80	− 6	3.6	.0013		.0013
	− 4	5.3	.0020		.0020
	− 2	7.1	.0027		.0027
100	−10	2.2	.0013		.0013
	− 6	5.8	.0024		.0024
	− 2	9.3	.0038		.0038

e_g'/e_f	$f(e_g'/e_f)$	e_g'	i
0	0	0	0
2	4.65	2.2	.00050
4	16.51	4.4	.00178
6	32.5	6.6	.00351
8	53	8.8	.00573
10	74	11.0	.00800



CHAPTER II.

DETERMINATION OF OPERATIONS OF A TRIODE FROM ITS STATIC CHARACTERISTICS.

(1) Preliminary Work.

The operations of a triode as an amplifier, oscillator, modulator, etc. can be determined from its static characteristics for a given circuit arrangement. The following descriptions are intended for rough estimation of these operating conditions, simplicity being aimed at instead of accuracy.

The static charateristic of a triode comprises two parts:—

1st. part: the anode current is determined from the equivalent grid voltage by the approximate relation,

$$i_a = G e_g'^{\frac{3}{2}}$$

2nd. part: anode current reaches saturation, and forms the upper limit of the characteristic.

The characteristic curve assumes the form as shown by a full line in Fig. 28.

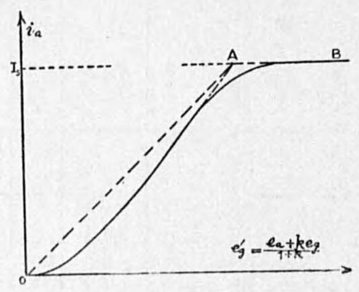


FIG. 28.

Now the 1st. part is represented as approximation by a straight line OA; in other words the anode current is assumed to be proportional to the equivalent grid voltage;

$$i_a = G' e_g' = G' \frac{e_a + k e_g}{1+k}$$

When grid voltage is zero,

$$i_a = G' \frac{e_a}{1+k} \quad \text{or} \quad \frac{e_a}{i_a} = \frac{1+k}{G'}$$

the latter corresponds to the mean anode impedance (actually resistance), so that

$$\bar{r} = \frac{1+k}{G'} \quad \text{or} \quad G' = \frac{1+k}{\bar{r}}$$

then the approximate characteristic becomes

$$i_a = \frac{e_a + k e_g}{\bar{r}} \qquad \cdots\cdots\cdots\cdots\cdots\cdots \quad (16)$$

The value of $\bar{r}$ can be determined from the following relations;

$$i_a = G e_g'^{\frac{3}{2}} = G\left(\frac{e_a}{1+k}\right)^{\frac{3}{2}} \quad \text{at} \quad e_g = 0,$$

when $i_a = I_s$

$$I_s = G\left(\frac{e_s}{1+k}\right)^{\frac{3}{2}} \quad \text{or} \quad \frac{e_s}{1+k} = \left(\frac{I_s}{G}\right)^{\frac{2}{3}}$$

but it is assumed that $I_s = G' \frac{e_s}{1+k}$

$$\therefore \quad \frac{I_s}{G'} = \left(\frac{I_s}{G}\right)^{\frac{2}{3}}$$

$$\therefore \quad \bar{r} = \frac{1+k}{G'} = \frac{1+k}{I_s^{\frac{1}{3}} G^{\frac{2}{3}}}$$

or $$(1+k)^3 = G^2 \bar{r}^3 I_s \qquad \cdots\cdots\cdots\cdots\cdots\cdots \quad (17)$$

This gives a relation among the parameters of a triode, from which $\bar{r}$ can be obtained.

From equation (16)

$$\frac{i_a}{I_s} = \frac{e_a + k e_g}{\bar{r} I_s} \qquad \cdots\cdots\cdots\cdots\cdots\cdots \quad (18)$$

This is the simplest and universal representation of the triode characteristic, in which the anode current is expressed in the unit of I_s and voltages in the unit of $\bar{r}I_s$. (Fig. 29)

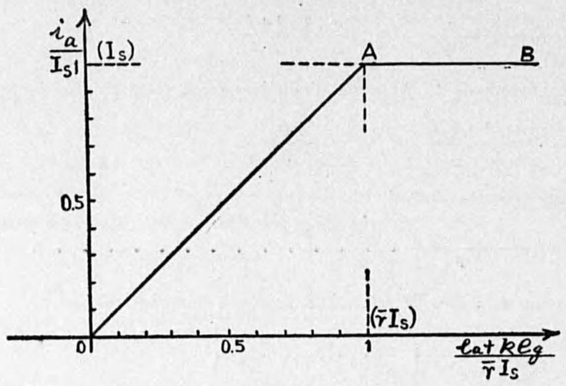


Fig. 29.

Let E_g=grid steady voltage,
E_a=anode steady voltage,
$\mathfrak{E}_g$=grid alternating voltage, maximum value,
$\mathfrak{E}_a$=anode alternating voltage, maximum value,
positive directions being taken in the direction of direct current. Put a load in anode circuit, which may be considered to act as a resistance $\mathfrak{R}$ at the operating frequency. (Fig. 30)

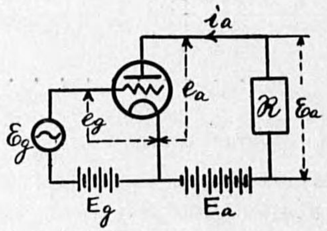


Fig 30.

Then in optimum operating conditions $\mathfrak{E}_g$ and $\mathfrak{E}_a$ are always in opposite phase, because when e_g is positive, i_a increases and the voltage drop on $\mathfrak{R}$ augments in such a direction as to reduce the direct anode voltage, and thus e_a becomes low.

If the instantaneous value of grid voltage be represented by

$$e_g=E_g+\mathfrak{E}_g\cos\theta,$$

anode voltage will be

$$e_a=E_a-\mathfrak{E}_a\cos\theta,$$

and for a given tube the instantaneous value of anode current will be determined by

$$\begin{aligned}e_a+ke_g&=E_a-\mathfrak{E}_a\cos\theta+k(E_g+\mathfrak{E}_g\cos\theta)\\&=E_a+kE_g+(k\mathfrak{E}_g-\mathfrak{E}_a)\cos\theta\end{aligned}$$

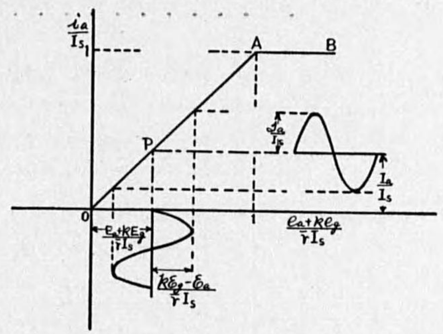


Fig. 31.

Thus in Fig. 31, a steady voltage $\frac{E+kE_g}{\bar{r}I_s}$ determines the working point P on the characteristic and the alternating component $\frac{k\mathfrak{E}_g-\mathfrak{E}_a}{\bar{r}I_s}$ gives the amplitude of oscillation, the working point being the center. The variation of anode current due to this oscillating voltage is sinusoidal when the amplitude of voltage is small, but becomes distorted when it is very large.

Let I_a=mean value or direct current component of anode current,

$\mathfrak{I}_a$=fundamental a. c. component of anode current, in maximum value, positive direction being taken as that of d. c.,

then in the undistorted range,

$$\frac{i_a}{I_s}=\frac{k\mathcal{E}_g-\mathcal{E}_a}{\bar{r}I_s}\cos\theta+\frac{E_a+kE_g}{\bar{r}I_s}=\frac{\mathfrak{I}_a}{I_s}\cos\theta+\frac{I_a}{I_s}$$

or $$I_a=\frac{E_a+kE_g}{\bar{r}} \quad \text{and} \quad \mathfrak{I}_a=\frac{k\mathcal{E}_g-\mathcal{E}_a}{\bar{r}}.$$

In the range of distorted wave form,

$$\frac{I_a}{I_s}=M\frac{k\mathcal{E}_g-\mathcal{E}_a}{\bar{r}I_s}. \quad \cdots\cdots\cdots\cdots (19)$$

$$\frac{\mathfrak{I}_a}{I_s}=F\frac{k\mathcal{E}_g-\mathcal{E}_a}{\bar{r}I_s}. \quad \cdots\cdots\cdots\cdots (20)$$

in which M and F are the factors to be multiplied to the undistorted amplitude of oscillation in order to obtain the mean and fundamental components of the distorted wave form, and are functions of the two quantities u and v that are determined by the amplitude of oscillation and the position of the working point, as shown in Fig. 33.

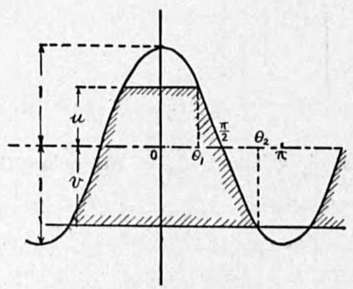


Fig. 32.

Analysis of the Distorted Wave Form.

Let a sinusoidal wave $\cos\theta$ as shown in Fig. 32 have an amplitude of unity. This wave is limited at the positive direction by an amount u and in the negative direction by v, and the negative limiting line is taken as datum.

Let $u=\cos\theta_1$, and $v=\cos\theta_2$

When these wave forms come in repetition, mean value becomes

$$M=\frac{1}{\pi}\left\{\int_{\theta_1}^{\theta_2}(v+\cos\theta)d\theta+(u+v)\theta_1\right\}$$

$$=\frac{1}{\pi}(u\theta_1-\sin\theta_1)+\frac{1}{\pi}(v\theta_2+\sin\theta_2)$$

$$=M_1+M_2$$

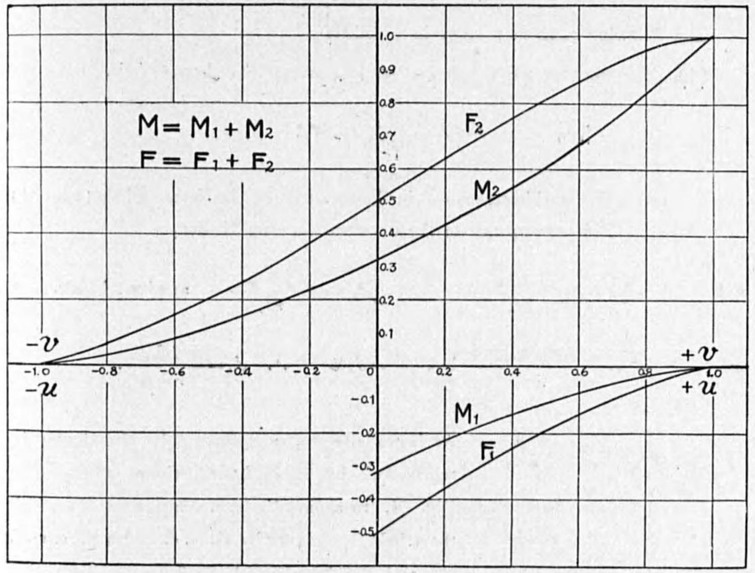


Fig. 33.

and fundamental amplitude becomes

$$F=\frac{2}{\pi}\left\{\int_0^{\theta_1}(u+v)\cos\theta\,d\theta+\int_{\theta_1}^{\theta_2}(v+\cos\theta)\cos\theta\,d\theta\right\}$$

$$=\frac{1}{\pi}\left(2u\sin\theta_1-\theta_1-\frac{1}{2}\sin 2\theta_1\right)+\frac{1}{\pi}\left(2v\sin\theta_2+\theta_2+\frac{1}{2}\sin\theta_2\right)$$

$$=F_1+F_2$$

Fig. 33 shows the values of M's and F's for various values of u and v.

For the anode current of a triode in operation, the undistorted amplitude is $\frac{k\mathcal{E}_g-\mathcal{E}_a}{\bar{r}I_s}$, and so in order to obtain the mean value or the d. c. component of anode current this amplitude must be multiplied by M corresponding to u and v determined by the relative conditions of working point and amplitude of oscillation. In the same way the fundamental component of anode current is obtained by multiplying the undistorted amplitude $\frac{k\mathcal{E}_g-\mathcal{E}_a}{\bar{r}I_s}$ by the value of F corresponding to u and v.

The following cases may occur in practice;

(1) The working point rests on the 1st. part of the characteristic.

i. e., $$0<\frac{E_a+kE_g}{\bar{r}I_s}<1$$

(a) The working range is in the 1st. part of the characteristic (Fig. 31) This corresponds to the distortionless amplification,

and $\frac{I_a}{I_s}=\frac{E_a+kE_g}{\bar{r}I_s}$ $\frac{\mathcal{I}_a}{I_s}=\frac{k\mathcal{E}_g-\mathcal{E}_a}{\bar{r}I_s}$ as given before.

or $\mathcal{I}_a=\frac{k\mathcal{E}_g-\mathcal{E}_a}{\bar{r}}$ but $\mathcal{E}_a=\mathcal{I}_a\mathcal{R}$ $\therefore$ $\mathcal{I}_a=\frac{k\mathcal{E}_g}{\bar{r}+\mathcal{R}}$.

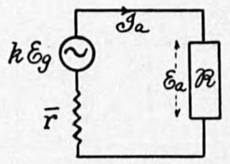


Fig. 34.

As is well known, a vacuum tube circuit may be represented by an equivalent circuit as shown in Fig. 34, regarding the a. c. components, in which the triode is replaced by an a. c. source of e. m. f. $k\mathcal{E}_g$ and of internal resistance $\bar{r}$.

(b) The working range outsteps the 1st. part.

(i) When the working point is in the middle of the 1st. part (Fig. 35),

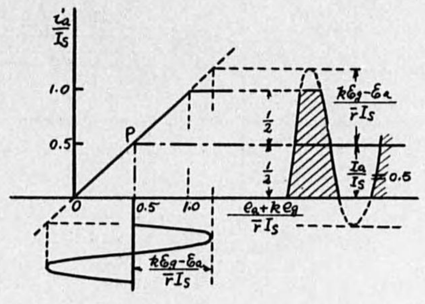


Fig. 35.

i. e. $\frac{E_a+kE_g}{\bar{r}I_s}=0.5$ and $\frac{k\mathcal{E}_g-\mathcal{E}_a}{\bar{r}I_s}>0.5$

then $u=v=\frac{1}{2}\cdot\frac{\bar{r}I_s}{k\mathcal{E}_g-\mathcal{E}_a}$

(ii) When the working point is below the middle point,

i. e. $\frac{E_a+kE_g}{\bar{r}I_s}<0.5$

1° Working range reaches the zero anode current (Fig. 36),

i. e. $\frac{k\mathcal{E}_g-\mathcal{E}_a}{\bar{r}I_s}>\frac{E_a+kE_g}{\bar{r}I_s}$

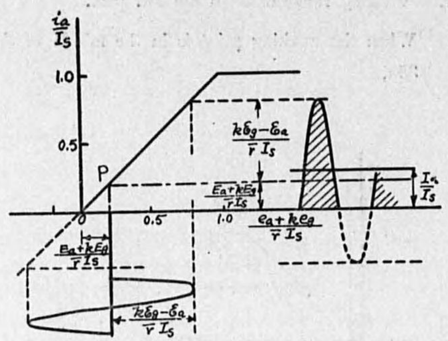


FIG. 36.

Here $u=1$, $\quad v=\dfrac{E_a+kE_g}{k\varepsilon_g-\varepsilon_a}$.

2° Working range reaches saturation (Fig. 37),

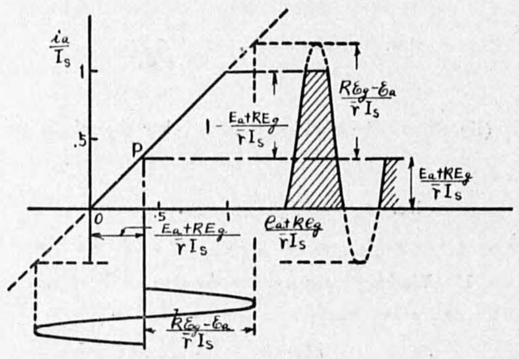


FIG. 37.

i.e. $\dfrac{k\varepsilon_g-\varepsilon_a}{\bar{r}I_s}>1-\dfrac{E_a+kE_g}{\bar{r}I_s}$.

$$u=\frac{\bar{r}I_s-(E_a+E_g)}{k\varepsilon_g-\varepsilon_a},\qquad v=\frac{E_a+kE_g}{k\varepsilon_g-\varepsilon_a}.$$

(iii) When the working point is above the middle point,

i.e. $\dfrac{E_a+kE_g}{\bar{r}I_s}>0.5$

1° Working point reaches saturation (Fig. 38),

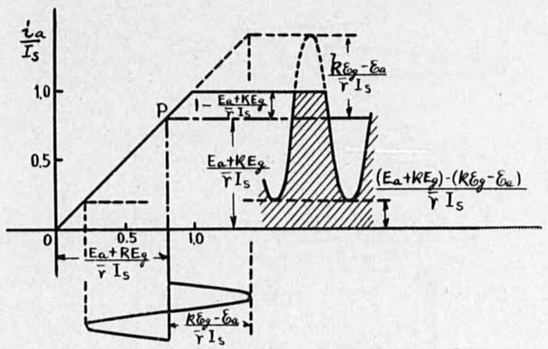


FIG. 38.

i.e. $\dfrac{k\varepsilon_g-\varepsilon_a}{\bar{r}I_s}>1-\dfrac{E_a+kE_g}{\bar{r}I_s}$

$$u=\frac{\bar{r}I_s-(E_a+kE_g)}{k\varepsilon_g-\varepsilon_a},\qquad v=1$$

and $\dfrac{(E_a+kE_g)-(k\varepsilon_g-\varepsilon_a)}{\bar{r}I_s}$ must be added to the resulting mean value in order to obtain $\dfrac{I_a}{I_s}$.

2° Working point reaches zero current (Fig. 39),

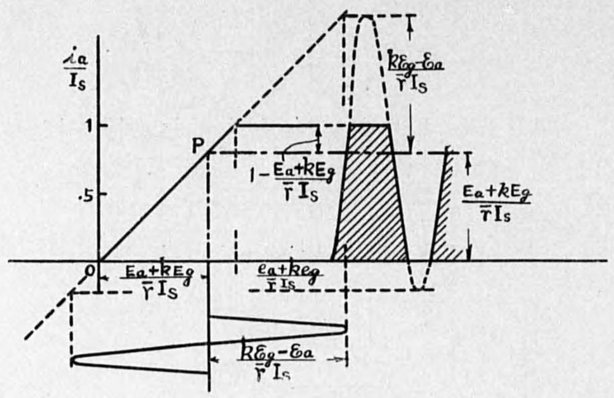


Fig. 39.

i. e. $$\frac{k\mathcal{E}_g-\mathcal{E}_a}{\bar{r}I_s}>\frac{E_a+kE_g}{\bar{r}I_s}.$$

$$u=\frac{\bar{r}I_s-(E_a+kE_g)}{k\mathcal{E}_g-\mathcal{E}_a}. \qquad v=\frac{E_a+kE_g}{k\mathcal{E}_g-\mathcal{E}_a}$$

(2) The working point is in the negative side,

i. e. $$\frac{E_a+kE_g}{\bar{r}I_s}<0$$

This corresponds to the condition $E_a+kE_g<0$ i. e. $-kE_g>E_a$ or the nagetive grid bias is so high as to entirely suppress the anode current. High efficiency operation of a power amplifier or an oscillator corresponds to this case.

(a) Peak voltage is limited within the 1st. part (Fig. 40),

i. e. $$0<\frac{(k\mathcal{E}_g-\mathcal{E}_a)+(E_a+kE_g)}{\bar{r}I_s}<1.$$

$$u=1, \quad v=\frac{E_a+kE_g}{k\mathcal{E}_g-\mathcal{E}_a} \quad \text{(which is negative)}.$$

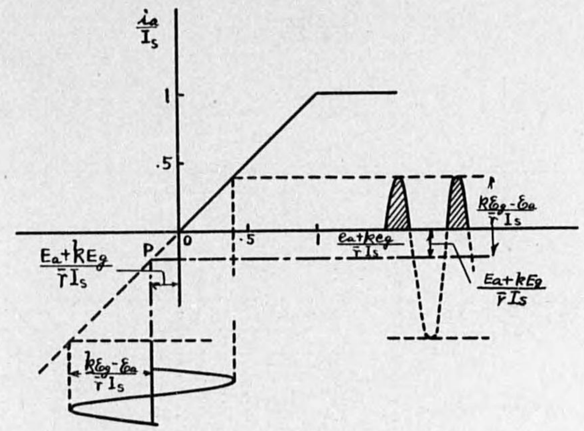


Fig. 40.

(b) Peak voltage outsteps the 1st. part (Fig. 41),

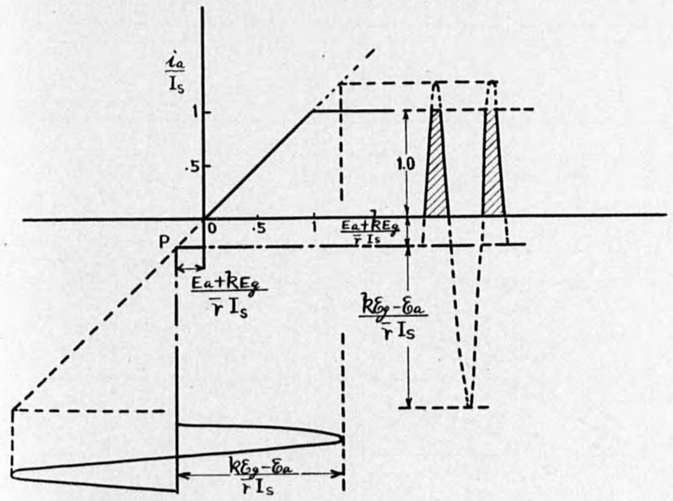


Fig. 41.

i. e. $$\frac{(k\mathfrak{E}_g-\mathfrak{E}_a)+(E_a+kE_g)}{\bar{r}I_s}>1.$$

$$u=\frac{\bar{r}I_s-(E_a+kE_g)}{k\mathfrak{E}_g-\mathfrak{E}_a}. \qquad v=\frac{E_a+kE_g}{k\mathfrak{E}_g-\mathfrak{E}_a} \quad \text{(which is negative)}$$

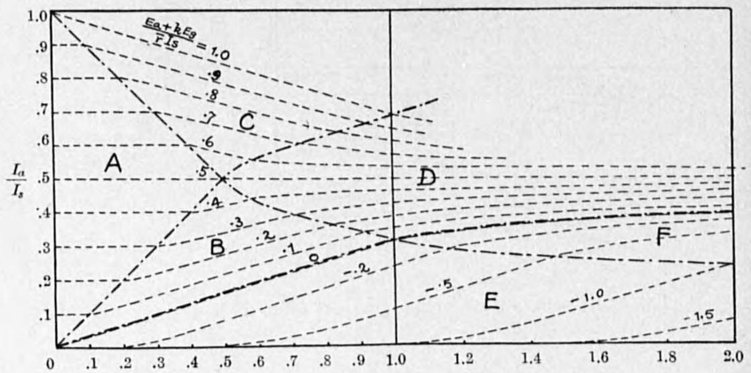


Fig. 42.

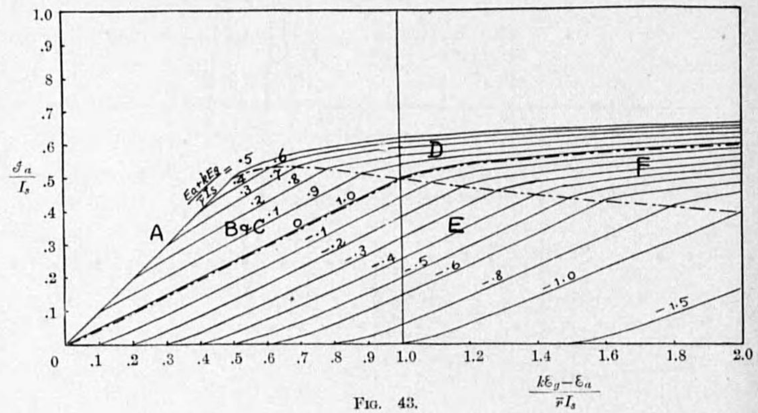


Fig. 43.

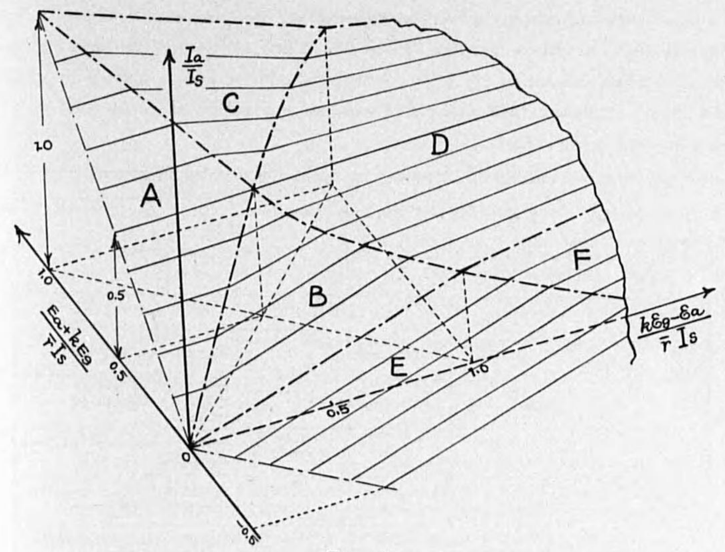


Fig. 44.

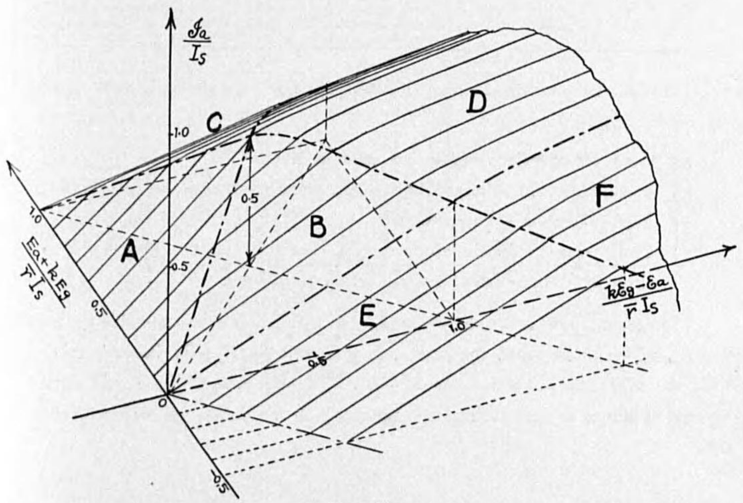


Fig. 45.

The results of calculations on the above given operating conditions are summarized in diagrams shown in Figs. 42 and 43. These curves give the d. c. and a. c. values of anode current at any given operating condition, and is universally applicable to any particular tube as long as voltages are expressed in the unit of $\bar{r}I_s$, and currents in the unit of I_s.

These dynamic characteristic curves represent the surfaces illustrated in Fig. 44 (d. c. component $\frac{I_a}{I_s}$) and Fig. 45 (a. c. component $\frac{\mathfrak{I}_a}{I_s}$). The two characteristic surfaces comprise the following six regions of practical importance;

Regions	Working point	Anode current	Practical value
A	On the slope of characteristics.	Not limited.	Distortionless amplification.
B	Ditto.	Limited by zero-line.	Self-oscillation practicable and effectively subjected to modulation.
C	Ditto.	Limited by saturation, D. C. component is relatively high.	Ditto, but lower efficiency of operation.
D	Ditto.	Limited by both zero-line and saturation.	Self-oscillation or amplification with large power.
E	At zero anode current with highly negative grid.	Lower portion entirely suppressed, upper portion not being limited.	Distortionless amplification of modulated waves.
F	Ditto.	Ditto, upper portion being limited by saturation. D. C. component is relatively low.	Self-oscillation or amplification with large power at high efficiency. (Impulse excitation)

It should be remembered that this diagram has been derived under the following assumptions :-

a) static characteristic curves are straight lines,
b) anode and grid voltages vary in sine wave form and just in opposite phase,
c) grid current is not appreciable,
d) load connected in the anode circuit does not produce appreciable voltage drop by direct current as well as by harmonics.

Thus the diagram is not strictly applicable when there is considerable grid current flowing, which arises when the maximum grid voltage $E_g+\hat{\mathfrak{E}}_g$ becomes comparable with the minimum anode voltage $E_a-\hat{\mathfrak{E}}_a$. In such a case the anode alternating current attains a drooping characteristic at high excitation as shown in Fig. 46.

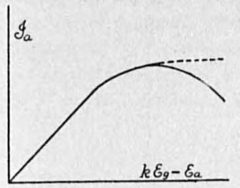


Fig. 46.

The diagram also gives erroneus results if it is applied to a case of very small amplitude of oscillation, as the curves have been derived with the mean anode resistance which is a little different from the differential resistance at lower part of characteristics. More accurate results can be obtained in such a case by deriving the particular value of anode resistance from the given static characteristics at the given voltages, the solution being made by the principle of the equivalent circuit shown in Fig. 34. But the diargram may be serviceable for studying at least qualitatively the various working conditions of a triode even if it is not strictly applicable.

Experimental Verification.

The dynamic characteristic curves were obtained by experiment in the following way.

A triode was used as a radio-frequency power amplifier in a circuit shown in Fig. 47.

A parallel resonance circuit with an inductance L and a capacity C was connected to the anode, and was adjusted to resonance at the frequency of the impressed grid voltage. A non-inductive resistance R' and a hot-wire ammeter were inserted in the resonance circuit in order to

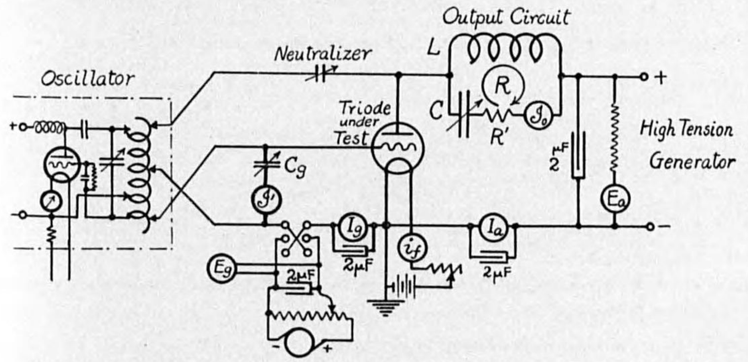


Fig. 47.

vary the resonance impedance as well as to obtain output power. The grid alternating voltage was impressed by a local oscillator, and a condenser C_g being shunted to the grid, the grid voltage was calculated from its capacity and the current passing through it. Neutralization was effected by a small capacity inserted between the anode and one end of the local oscillator inductance, and by this means regenerative action due to the inter-electrode capacity of the tube was eliminated.

The frequency was kept at

$$\omega = 2\pi f = 3\times 10^6 \qquad (\lambda = 628 \text{ m})$$

and at this frequency the resistance of the resonance circuit excluding R' was 3.0 ohms.

First the tube characteristics were taken and the constants k, I_s, $\bar{r}$ and $\bar{r}I_s$ were calculated, $\bar{r}$ being taken to comply with equation (17).

During the experiment, under constant filament current to give the predetermined I_s value, E_a and E_g were varied and at each step of variation, $\mathcal{E}_0$ and I_a were observed with variation of $\mathcal{E}'$ and C_g. Then calculations were made as follows,

$$\mathcal{E}_a = \frac{\mathcal{E}_0}{\omega C} \qquad R = \frac{L}{CR} = \frac{1}{\omega^2 C^2 R}$$

in which $R = R' + 3.0$

$$\mathcal{E}_a = \frac{\mathcal{E}_a}{R} \qquad \mathcal{E}_g = \frac{\mathcal{E}'}{\omega C_g}$$

Hence $\frac{k\mathcal{E}_g - \mathcal{E}_a}{\bar{r}I_s}$ could be calculated for each value of $\frac{E_a + kE_g}{\bar{r}I_s}$, and $\frac{\mathcal{E}_a}{I_s}$ and $\frac{I_a}{I_s}$ were plotted against $\frac{k\mathcal{E}_g - \mathcal{E}_a}{\bar{r}I_s}$ to obtain the dynamic characteristic curves.

All the alternating quantities are expressed in maximum values.

Example 67. Triode type **UV-204.**

Operated at $e_f = 8.5$ $i_f = 12.2$ $R = 27{,}100$ $E_a = 1500$ to 2500.

Static characteristics are shown in Fig. 48, from which we obtain

$$I_s = 0.071 \quad \bar{r} = 17{,}200 \quad \bar{r}I_s = 1{,}220 \quad k = 25$$

The resulting curves are shown in Fig. 49, which are in conformity to the theoretical diagram in the main.

Example 68. Triode type **RS-15.**

Static characteristics are shown in Fig. 50.

$$e_f = 13.3 \quad i_f = 15.8$$

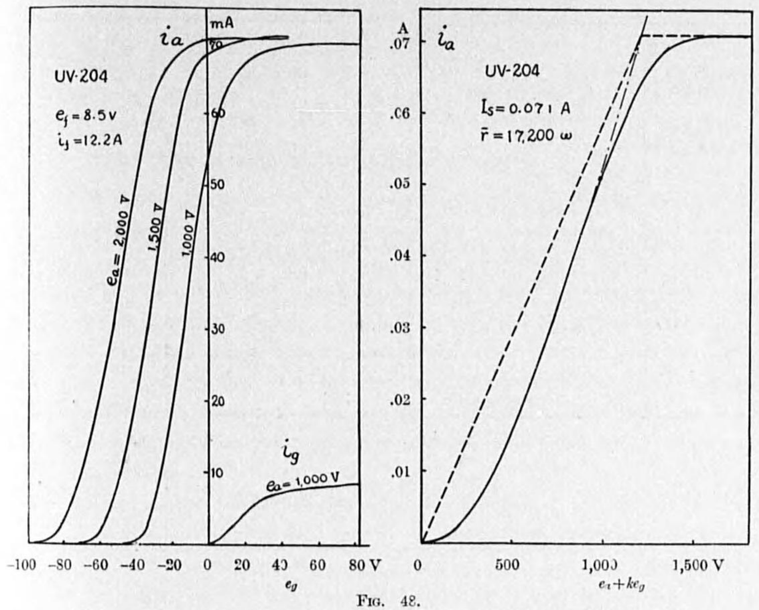


FIG. 48.

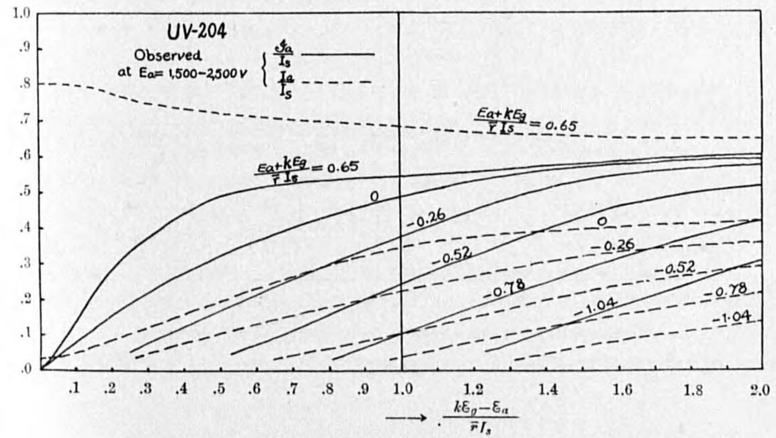


FIG. 49.

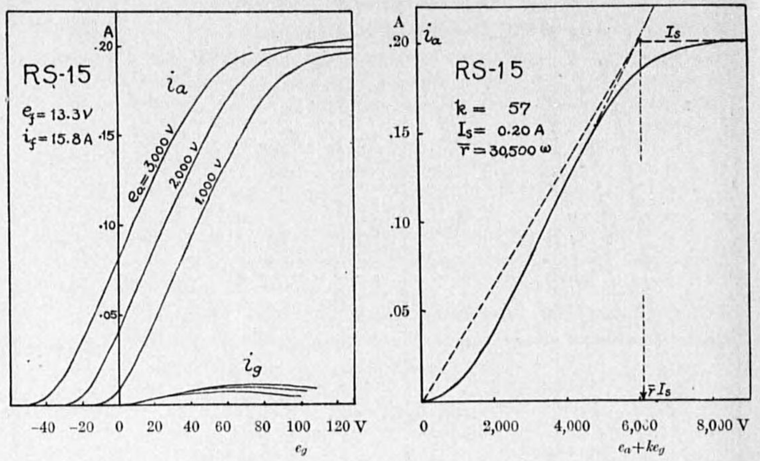


FIG. 50.

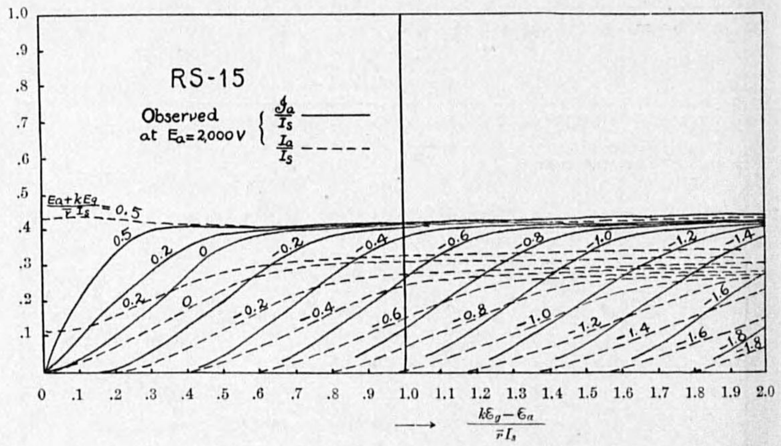


FIG. 51.

I_s=0.200 k=57 $\bar{r}$=30,500 $\bar{r}I_s$=6,100

tested at E_a=2,000 (the normal anode valtage of the tube is 4,000).

The result is shown in Fig. 51. Currents are rather low compared with the theoretical curves, but the general tendency is in agreement with them.

(2) The Dynamic Characteristic Diagram.

In CHART I annexed to this paper, the above given dynamic characteristics are reproduced with its left side extended to another diagram in which the ordinates give currents in the unit of I_s, and the abscissae give voltages in the unit of $\bar{r}I_s$. In this part of the diagram a group of straight lines starting at the origin represents the external impedance $\mathcal{R}$ in the unit of internal resistance $\bar{r}$, and hyperbolas give the contour lines of equal power.

This diagram, which is to be called the "Dynamic Characteristic Diagram," is applicable to any triode, if its parameters k, $\bar{r}$, and I_s are known and if currents, voltages, resistances and powers are expressed in the units of I_s, $\bar{r}I_s$, $\bar{r}$, and $\bar{r}I_s^2$ respectively.

The use of the diagram is explained in the following.

A vacuum tube of saturation current I_s, amplification constanct k, and mean anode impedance $\bar{r}$, which are all known, is used as an amplifier with an anode circuit impedance $\mathcal{R}$, and its operating conditions are to be predicted. First calculate the unit quantities $\bar{r}I_s$ and $\bar{r}I_s^2$ from the given unit quantities $\bar{r}$ and I_s, and express all the quantities in these units. In the following explanations quantities expressed in these manner are taken instead of actual values.

Let anode voltage be E_a and grid bias be E_g. Calculate E_a+kE_g and the corresponding dynamic characteristic curve of I_a and $\mathcal{I}_a$ are found on the diagram. For graphical evaluation of this, E_a and kE_g (E_g is considered to be negative) are taken on the left side abscissa such as the points a and b in Fig. 52. Draw a line at b with inclination of 45° to intersect the vertical line through a at point c, then the ordinate of c represents E_a+kE_g and the corresponding characteristic curves of I_a and $\mathcal{I}_a$ are obtained as the lines def and oeg in the figure. Line oh is drawn to represent the given external impedance. For a given grid exciting voltage $\mathcal{E}_g$, calculate $k\mathcal{E}_g$ and take this quantity on the right side abscissa such as the point i; from i a straight line is drawn parallel to the resistance line oh and

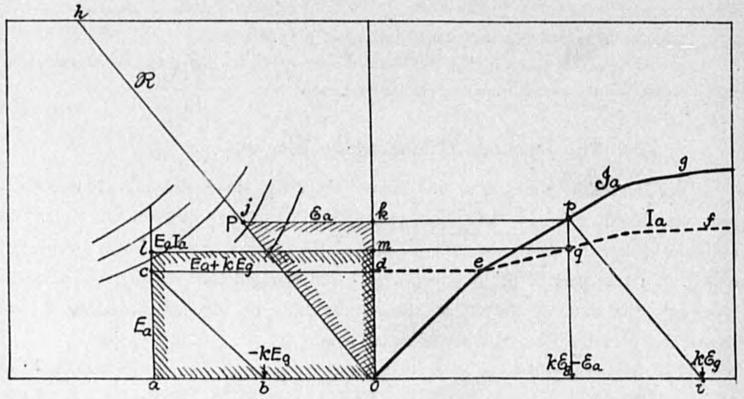


Fig. 52.

let this line intersect with the dynamic line *oeg* at p; then this gives the working point on the dynamic characteristic. The reason is as follows; the ordinate represents $\mathfrak{J}_a$, and let a level line through p intersect with the oh line at j and with the ordinate axis at k, then $\overline{ok}=\mathfrak{J}_a$ and $\tan\angle jok=\mathcal{R}$. Therefore $\overline{jk}=\mathfrak{J}_a\mathcal{R}=\mathfrak{E}_a$. But $\overline{pj}=\overline{oi}=k\mathfrak{E}_g$ and thus abscissa of the point p is $\overline{pk}=\overline{pj}-\overline{jk}=k\mathfrak{E}_g-\mathfrak{E}_a$, and is in conformity with that the dynamic characteristic curves have been expressed by the abscissa of $k\mathfrak{E}_g-\mathfrak{E}_a$.

The area of the triangle $\triangle ojk$ gives $\frac{1}{2}\mathfrak{E}_a\mathfrak{J}_a$ or $\frac{1}{2}\mathfrak{J}_a^2\mathcal{R}$ and represents the power output, which can be read by means of the power contour hyperbolas numbered at the top. The steady component I_a is obtained by drawing a line vertically from point p to intersect with the I_a dynamic line at a point q. A level line through q intersects with the vertical line through a at l, and with the ordinate axis at m. The rectangular area $omla$ is E_aI_a and represents the input power to the tube, which can be read from the position of the point l on the contour hyperbolas numbered at the left end. The efficiency of conversion can be calculated from the two power values.

When the triode is used as a self-oscillator, the grid voltage $\mathfrak{E}_g$ is in definite relation to the anode voltage $\mathfrak{E}_a$ as determined from the circuit conditions.

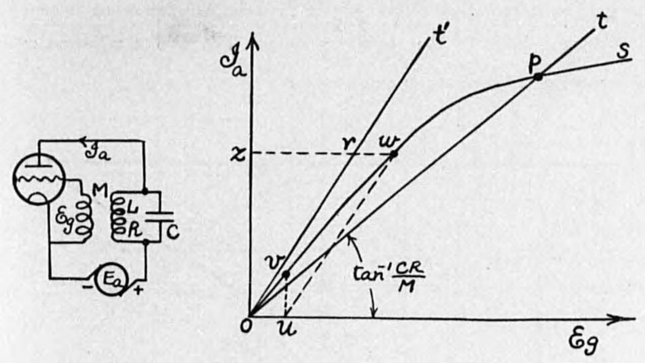


Fig. 53.

In an example shown in Fig. 53, $\mathfrak{J}_a$ is determined from $\mathfrak{E}_g$ by a dynamic line *ops*, while $\mathfrak{J}_a$ and external impedance $\mathcal{R}=\frac{L}{CR}$ determine $\mathfrak{E}_a=\mathfrak{J}_a\frac{L}{CR}$ and this induces an e. m. f. $\mathfrak{E}_g=\mathfrak{E}_a\frac{M}{L}$ in the grid circuit. Hence $\frac{\mathfrak{J}_a}{\mathfrak{E}_g}=\frac{CR}{M}$ is a straight line, the inclination of which is $\tan^{-1}\frac{CR}{M}$ as shown by a line *ot* in Fig. 53. Thus the dynamic characteristic curve *ops* gives the relation in which $\mathfrak{J}_a$ is determined by $\mathfrak{E}_g$ from the tube characteristics, while the excitation line *ot* gives the relation in which $\mathfrak{E}_g$ is determined by $\mathfrak{J}_a$ from circuit conditions. Then the point of intersection p shall be the working point of the self-oscillator. If the coupling becomes loose, the excitation line is shifted to left and finally will not intersect with the dynamic line, and in this case oscillation cannot be produced.

The regeneration can be explained in the same diagram. When regeneration is applied, anode circuit is coupled to grid circuit but not so close as to produce oscillation, such as a line *ot'* in Fig. 53. If the regenerative connection is not made, for a certain grid voltage such as $\overline{ou}$, the anode current is $\overline{ur}$. But on regenerative condition, a line is to be drawn from the point u parallel to the line *ot'* and the intersecting point w on the characteristic gives the working point. The reason is that the level line from w intersecting with *ot'* at r and with the ordinate axis at z repre-

sents the grid exitation which is the sum of the originally impressed voltage $\overline{ou}=\overline{rw}$ and the voltage induced by the anode current $\overline{oz}$. The ratio of regenerative amplification to non-regenerative one is expressed by $\frac{\overline{oz}}{\overline{uv}}$.

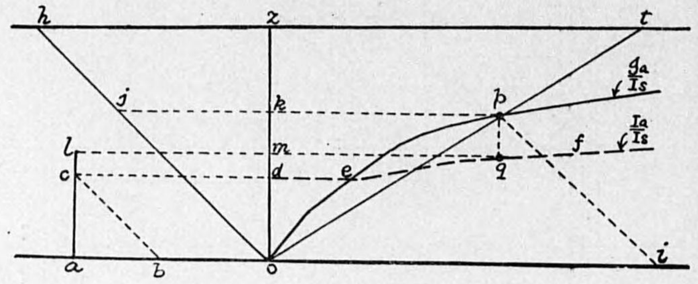


Fig. 54.

Now these ideas can be applied to the dynamic characteristic diagram in the following way (Fig. 54). Comparing the figure with Fig. 53, resistance line oh corresponds to the ordinate axis of Fig. 53, and the abscissa representing $k\mathcal{E}_g$ corresponds to that of Fig. 53. The excitation line ot in Fig. 53 is obtained in Fig. 54 by taking the quantity $\frac{k\mathcal{E}_g}{\mathcal{J}_a}$ from the point h to the right on the level line as a point t, and by connecting this point to the origin; in other words $\frac{\frac{k\mathcal{E}_g}{\mathcal{J}_a}-\mathcal{R}}{\bar{r}}$ shall be taken on right abscissa as $\overline{zt}$ in order to obtain the excitation line ot. The point of intersection of the excitation line with the dynamic characteristic curve gives the working point p and all the other quantities can be derived in the same way as explained before. In CHART I, $\left(\frac{k\mathcal{E}_g}{\mathcal{J}_a}\right)_c$ means that the relation is to be derived from the circuit conditions.

The modulation of a self-oscillating tube consists in altering the anode or grid steady voltage with audio frequency, hence producing the corresponding variations in the amplitude of oscillation. This means the variation of E_a+kE_g, other things being equal.

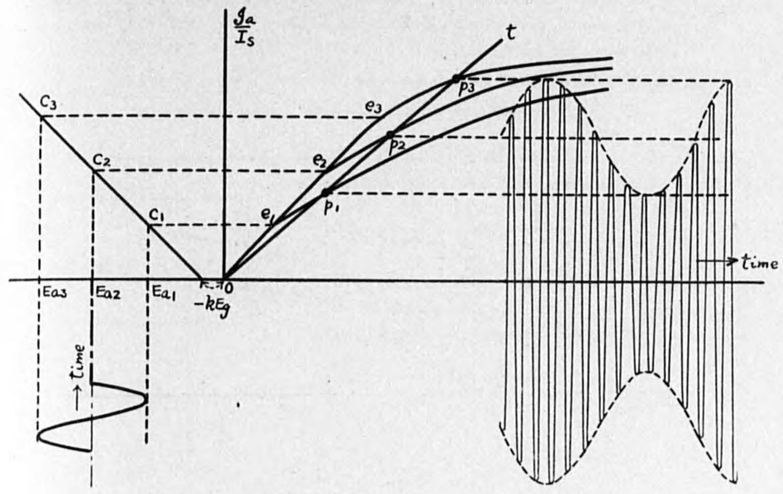


Fig. 55.

Thus, for example, if anode voltage E_a is varied in sinusoidal wave form as shown in Fig. 55, E_a+kE_g will vary accordingly and the dynamic characteristic curve is shifted up and down. The excitation line ot remaining unvaried, the working point p must travel on the ot line and the oscillating current $\mathcal{J}_a$ varies its amplitude in accordance with the variation of the anode voltage.

Applications of the dynamic characteristic diagram are further illustrated by the following examples

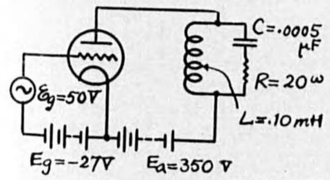


Fig. 56.

Example 69. A triode type **UX-210** has a characteristic represented by the following quantities at a certain filament voltage.

$k=7.5$ $\bar{r}=5{,}000\,\omega$ $I_s=0.20$ A

Its working conditions in the following cases are required.

(a) R. F. Amplifier.

In a circuit shown in Fig. 56, a radio-frequency voltage of $\mathcal{E}_g=50$ V is impressed on the grid, and the anode circuit is tuned to this frequency. The power output, power input, anode current, etc. are required.

Unit quantities;

$$\bar{r}=5{,}000 \qquad I_s=0.20 \qquad \bar{r}I_s=1{,}000$$

$$\bar{r}I_s^2=200$$

All the known quantities expressed in these units are.

$$\frac{E_a}{\bar{r}I_s}=0.350 \qquad \frac{kE_g}{\bar{r}I_s}=-0.203 \qquad \frac{E_a+kE_g}{\bar{r}I_s}=0.147$$

$$\frac{k\mathcal{E}_g}{\bar{r}I_s}=0.375$$

The resonance impedance of the anode circuit,

$$\mathcal{R}=\frac{L}{CR}=10{,}000 \qquad \frac{\mathcal{R}}{\bar{r}}=2.0$$

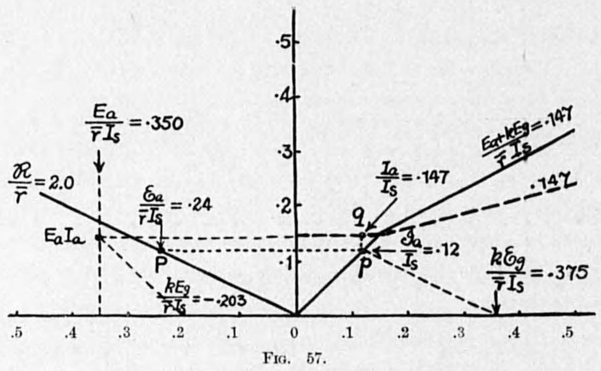


Fig. 57.

Fig. 57 shows the procedure to obtain the working points p and q, as explained before, and from the diagram the required quantities are obtained:

$$\mathcal{J}_a=0.12I_s=0.024 \text{ A.}$$

$$I_a=0.147I_s=0.029 \text{ A.}$$

$$\mathcal{E}_a=0.24\bar{r}I_s=240 \text{ V.}$$

Power output $P=\frac{1}{2}\mathcal{J}_a\mathcal{E}_a=2.88$ W.

Closed circuit current $\mathcal{J}_0=\sqrt{P/R}=0.38$ A. effective value.

Power input $=E_a I_a=10.2$ W.

Efficiency $\eta=\dfrac{2.88}{10.2}=0.28$ Loss$=E_a I_a-P=7.3$ W, at the working condition.

This working point is in the range of distortionless amplification.

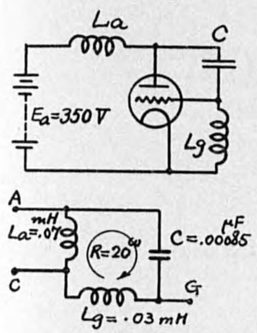


Fig. 58.

(b) Self-Oscillator.

The tube is used with the Hartley circuit as shown in Fig. 58. Its working condition is required.

$$I_s=0.20 \qquad \bar{r}=5{,}000 \qquad \bar{r}I_s=1{,}000$$

and $\bar{r}I_s^2=200$ as before.

The output impedance is approximately the resonance impedance of the closed circuit between the terminals A and C.

$$\mathcal{R}=\frac{L_a+L_g}{CR}\left(\frac{L_a}{L_a+L_g}\right)^2=2{,}880$$

$$\frac{\mathcal{R}}{\bar{r}}=0.58 \qquad \frac{E_a}{\bar{r}I_s}=0.35$$

$$\frac{kE_g}{\bar{r}I_s}=0 \qquad \frac{E_a+kE_g}{\bar{r}I_s}=0.35$$

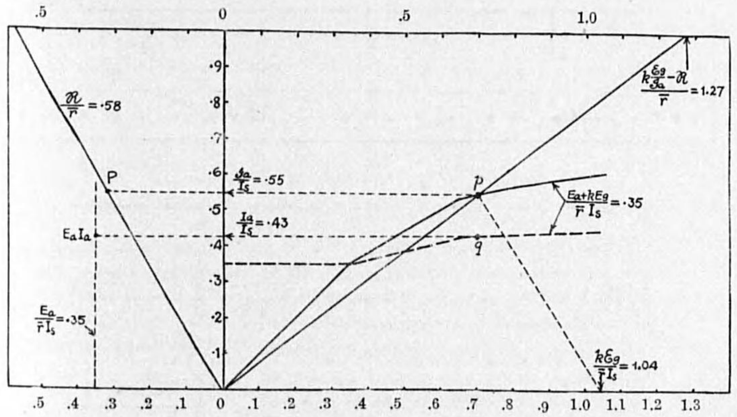


Fig. 59.

The relation determined from the circuit condition;

$$\frac{\mathcal{E}_a}{\mathcal{E}_g}=\frac{\omega L_a}{\omega L_g}=\frac{I_a}{I_g}. \qquad \mathcal{E}_a=\mathcal{I}_a\mathcal{R}$$

$$\therefore \frac{\mathcal{I}_a\mathcal{R}}{\mathcal{E}_g}=\frac{I_a}{I_g}. \qquad \therefore \frac{k\mathcal{E}_g}{\mathcal{I}_a}=\frac{k\mathcal{R}I_g}{I_a}=9{,}240$$

hence $$\frac{k\dfrac{\mathcal{E}_g}{\mathcal{I}_a}-\mathcal{R}}{\bar{r}}=1.27$$

The procedure to obtain the working points p and q are illustrated in Fig. 59.

The results obtained from the diagram;

$\mathcal{I}_a=0.55I_s=0.11$ A. $\quad I_a=0.43I_s=0.086$ A.

$\mathcal{E}_a=0.32\bar{r}I_s=320$ V.

Output $P=\frac{1}{2}\mathcal{E}_a\mathcal{I}_a=17.6$ W. Input $E_aI_a=30.1$ W.

Closed circuit current $=\sqrt{P/R}=0.94$ A. effective.

Ffficiency $\eta=0.58$ $\quad k\mathcal{E}_g=1.04\bar{r}I_s=1{,}040$ $\quad \mathcal{E}_g=139$ V.

In actual case, power output will be slightly reduced due to partial consumption for the grid excitation.

Example 70. A triode type **VM-100** has a rating as shown in the following table. Its optimum operating conditions used as power amplifier and oscillator in various cases are to be studied.

e_f	i_f	I_s	Permissible anode loss	E_a	k	$\bar{r}$
12.0 V.	24.0 A.	1.50 A.	1,000 W.	10,000 V.	75	28,000 ω

$\bar{r}I_s=42{,}000$ V $\quad \bar{r}I_s^2=63{,}000$ W $\quad \frac{E_a}{\bar{r}I_s}=0.24$

(a) Distortionless Amplifier or Modulator.

Connect a non-inductive resistance of $\mathcal{R}$ ohms as a load to the anode circuit. (Fig. 60.) When the tube is used as a modulator, this resistance corresponds to the equivalent a. c. resistance of the oscillalor to be modulated. In order to avoid the d. c. potential drop in $\mathcal{R}$, a choke coil and a blocking condenser are inserted, which is considered to give no appreciable effect on the value of the output impedance.

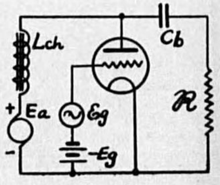


Fig. 60.

The distortionless amplification requires the conditions:—

1° That the working point rests in the region A or on the $\frac{\mathcal{I}_a}{I_s}$ characteristic line AO in Fig. 61, which represents lower portion of the dynamic characteristic diagram.

2° That the grid current is not appreciable, i.e. $E_g+\mathcal{E}_g\leqq 0$

3° That the minimum anode current does not come on the curved part of the static characteristic curves, i.e. $I_a-\mathcal{I}_a>\varepsilon I_s$, ε being a small quantity,

For the maximum available power output, we take

$$E_g+\mathcal{E}_g=0 \quad \text{and} \quad I_a-\mathcal{I}_a=10\text{ mA}=0.0067I_s$$

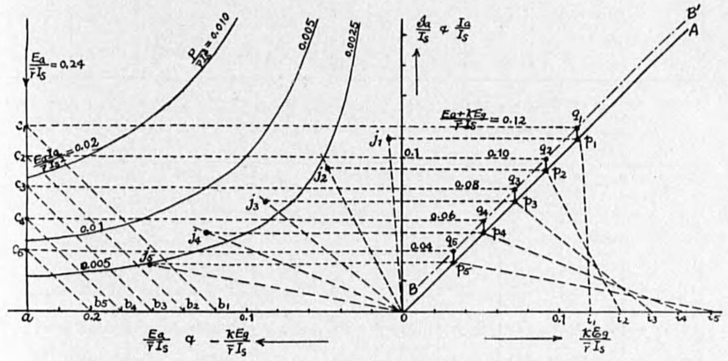


Fig. 61.

$\frac{E_a}{\bar{r}I_s}=0.24$ comes to a point a, in Fig. 61, and the condition $E_g+\mathcal{E}_g=0$ or $-kE_g=k\mathcal{E}_g$ requires that $\overline{ob}=\overline{oi}$ in Fig. 52. Another condition $\frac{I_a}{I_s}-\frac{\mathcal{I}_a}{I_s}=0.0067$ requires that the working point on the $\frac{I_a}{I_s}$ characteristics should rest on the line BB' in Fig. 61, which is taken above the line OA by an amount 0.0067.

Assume several values of $\frac{kE_g}{\bar{r}I_s}$, such as b_1, b_2, b_3, etc. in Fig. 61, and from them $\frac{E_a+kE_g}{\bar{r}I_s}$ can be determined such as c_1, c_2, c_3, etc., and the working points are obtained on each $\frac{I_a}{I_s}$ line such as q_1, q_2, q_3, etc., while working points on $\frac{\mathcal{I}_a}{I_s}$ line are such as p_1, p_2, p_3, etc. $\frac{k\mathcal{E}_g}{\bar{r}I_s}$ should be taken as equal to $-\frac{kE_g}{\bar{r}I_s}$ and the points i_1, i_2, i_3, etc., taken

in such a way are connected to p_1, p_2, p_3, etc. The resistance lines should be drawn from the origin parallel to these lines i_1p_1, i_2p_2, i_3p_3 and the working points on the left side diagram are obtained such as j_1, j_2, j_3, etc. These determine power output P and a. c. anode voltage $\mathfrak{E}_a$. On the other hand c_1, c_2, c_3, etc., give power inputs. All the quantities thus obtained are in the following table.

$\frac{E_a}{\bar{r}I_s}$	$\frac{kE_g}{\bar{r}I_s}$	$\frac{k\mathfrak{E}_g}{\bar{r}I_s}$	$\frac{I_a}{I_s}$	$\frac{\mathfrak{I}_a}{I_s}$	$\frac{\mathfrak{E}_a}{\bar{r}I_s}$	$\frac{\mathcal{R}}{\bar{r}}$	$\frac{P}{\bar{r}I_s^2}$	$\frac{E_aI_a}{\bar{r}I_s^2}$	η
	−0.12	0.12	0.12	0.112	0.008	0.072	0.00045	0.028	0.016
	−0.14	0.14	0.10	0.092	0.047	0.51	0.0022	0.024	0.093
0.24	−0.16	0.16	0.08	0.072	0.086	1.19	0.0032	0.019	0.167
	−0.18	0.18	0.06	0.052	0.125	2.40	0.0032	0.013	0.242
	−0.20	0.20	0.04	0.032	0.130	4.07	0.0025	0.0089	0.28

The above quantities given in actual values are as follows and the powers are plotted in curves in Fig. 62.

E_a	kE_g	E_g	$\mathfrak{E}_g$	I_a	$\mathfrak{I}_a$	$\mathfrak{E}_g$	$\mathcal{R}$	P	E_aI_a	η
	V	V	V	A	A	V	ω	W	W	%
	−5040	− 67	67	.180	.168	336	2,020	28	1,760	1.6
	−5880	− 78	78	.150	.138	1,970	14,300	140	1,510	9.3
V 10,000	−6720	− 90	90	.120	.108	3,610	33,400	198	1,200	16.7
	−7560	−100	100	.090	.078	5,250	67,200	198	820	24
	−8400	−112	112	.060	.048	5,470	114,000	157	560	28

In order to obtain maximum power output from the tube, the resistance $\mathcal{R}$ must be chosen such that $\mathcal{R}=2\bar{r}=56{,}000$ as shown in Fig. 62. This complies with the theory[9] that, for maximum output of distortionless amplification, the output impedance should be twice the anode impedance. In Fig. 62 the input to the tube is also plotted. In actual operating condition, when the tube is not amplifying alternating power, the

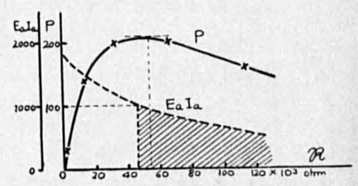


Fig. 62.

(9) E. W. Kellogg: J. I. E. E. p. 490, May, 1925.

total input power E_aI_a is dissipated at the anode. As the anode loss permissible is 1,000 watts, the safe working range must be in the hatched part of Fig. 62. The efficiency of power conversion increases with the increase of $\mathcal{R}$.

The above discussion is based on the condition that the grid input voltage $\mathfrak{E}_g$ can be obtained at any convenient amount. If this quantity be previously given, the solution will be somewhat different, and the maximum power output can be obtained at $\mathcal{R}=\bar{r}$ or at an output circuit impedance equal to the anode impedance, which is a well-known fact. But in this case the condition of distortionless amplification is disregarded, otherwise the anode voltage should be raised above normal value. Fig. 63 and the following table show this relation.

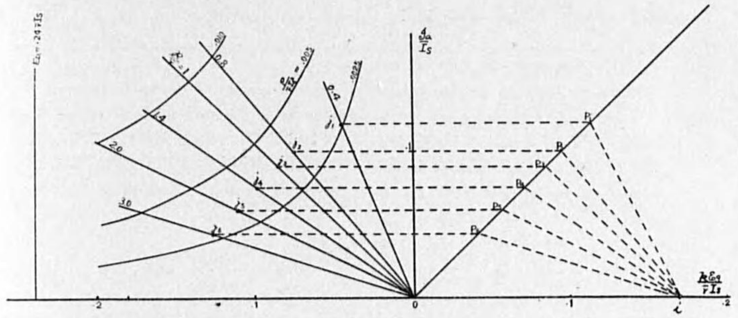


Fig. 63.

	$\frac{\mathcal{R}}{\bar{r}}$	$\frac{P}{\bar{r}I_s^2}$	$\mathcal{R}$	P
$\frac{E_a}{\bar{r}I_s}=.24$	0.4	.0026	11,200	164
	0.8	.0035	22,400	220
$\frac{k\mathfrak{E}_g}{\bar{r}I_s}=0.17$	1.0	.0038	28,000	240
$\left(\begin{matrix}E_a=10{,}000\\ \mathfrak{E}_g=95\end{matrix}\right)$	1.4	.0035	39,200	220
	2.0	.0028	56,000	176
	3.0	.0021	84,000	132

(b) Oscillator for Radio-telegraph Transmission.

The tube is used as a radio-telegraph transmitter and a maximum power output is required to be obtained at the highest possible efficiency, with a circuit as shown in Fig. 64.

The antenna circuit is assumed to have the constants; $L=0.32\text{mH}$ $C=.0023\mu\text{F}$ $R=10\omega$. Output circuit impedance can be adjusted by taking taps on the inductance, but first consider the case of maximum impedance such as

$$\mathfrak{R}=\frac{L}{CR}=13{,}900\omega$$

hence $\frac{\mathfrak{R}}{\bar{r}}=0.50$

and $\frac{E_a}{\bar{r}I}=0.24$ as before.

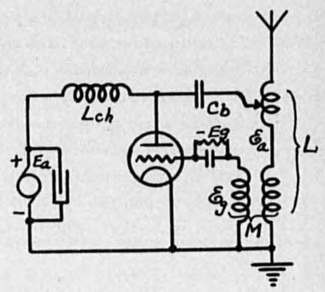


FIG. 64.

It is understood that the choke and the blocking condenser are designed to exert no appreciable effect on the total impedance.

For giving maximum power output as an oscillator, the anode minimum voltage $E_a-\mathfrak{E}_a$ should be equal or slightly higher than the maximum grid voltage $E_g+\mathfrak{E}_g$. This is because for too low $\mathfrak{E}_a$, the utilisation of E_a is low, while for too high $\mathfrak{E}_a$, $E_a-\mathfrak{E}_a$ is low, and, appreciable current flows in the grid and anode power is reduced. Thus let $E_a-\mathfrak{E}_a=E_g+\mathfrak{E}_g$

or $$\frac{\mathfrak{E}_g}{\bar{r}I_s}=\frac{E_a}{\bar{r}I_s}-\frac{\mathfrak{E}_a}{\bar{r}I_s}-\frac{E_g}{\bar{r}I_s}.$$

If $\frac{E_a+kE_g}{\bar{r}I_s}$ be assumed, $\frac{kE_g}{\bar{r}I_s}=\frac{E_a+kE_g}{\bar{r}I_s}-\frac{E_a}{\bar{r}I_s}$ can be derived and hence $\frac{E_g}{\bar{r}I_s}$ too, and again assuming $\frac{\mathfrak{E}_a}{\bar{r}I_s}$, $\frac{\mathfrak{E}_g}{\bar{r}I_s}$ can be derived by the above given relation.

On the other hand, for the assumed value of $\frac{\mathfrak{E}_a}{\bar{r}I_s}$, working point p can be determined on the dynamic characteristics and $\frac{k\mathfrak{E}_g}{\bar{r}I_s}$ or $\frac{\mathfrak{E}_g}{\bar{r}I_s}$ is known. Thus we can finally find such $\frac{\mathfrak{E}_a}{\bar{r}I_s}$ value as to give equal $\frac{\mathfrak{E}_g}{\bar{r}I_s}$ on both the cases and this is the required optimum condition.

The two procedures for deriving $\frac{\mathfrak{E}_g}{\bar{r}I_s}$ are shown in the following table.

$\frac{\mathfrak{E}_a}{\bar{r}I_s}$	$\frac{\mathfrak{I}_a}{I_s}$	$\frac{E_a+kE_g}{\bar{r}I_s}$	$\frac{k\mathfrak{E}_g}{\bar{r}I_s}$	$\frac{\mathfrak{E}_g}{\bar{r}I_s}$	$\frac{kE_g}{\bar{r}I_s}$	$\frac{E_g}{\bar{r}I_s}$	$\frac{\mathfrak{E}_g}{\bar{r}I_s}$	Difference $\frac{\mathfrak{E}_g}{\bar{r}I_s}$
0.22	0.45	0.4	0.70	0.0093	0.16	0.00214	0.0179	0.0086
		0.2	0.85	0.0113	0.04	0.00053	0.0194	0.0081
		0	1.12	0.0149	−0.24	−0.0032	0.0232	0.0083
		−0.2	1.32	0.0176	−0.44	−0.0059	0.0259	0.0083

In the above table both the values of $\frac{\mathfrak{E}_g}{\bar{r}I_s}$ do not coincide each other, and their difference is constant as shown in the last column. So there is no necessity of calculating for more than one value of $\frac{E_a+kE_g}{\bar{r}I_s}$.

Thus $\frac{E_a+kE_g}{\bar{r}I_s}=0.40$ being assumed, the following results are obtained for further variation of $\frac{\mathfrak{E}_a}{\bar{r}I_s}$.

$\frac{\mathfrak{E}_a}{\bar{r}I_s}$	$\frac{\mathfrak{E}_g}{\bar{r}I_s}$ from the diagram	$\frac{\mathfrak{E}_g}{\bar{r}I_s}=\frac{E_a}{\bar{r}I_s}-\frac{\mathfrak{E}_a}{\bar{r}I_s}-\frac{E_g}{\bar{r}I_s}$
0.20	0.0080	0.0379
0.22	0.0093	0.0179
0.23	0.0096	0.0079

From this we get the working point to give equal $\frac{\mathfrak{E}_g}{\bar{r}I_s}$ by interpolation:

$\frac{\mathfrak{E}_a}{\bar{r}I_s}=0.228$ $\frac{\mathfrak{E}_g}{\bar{r}I_s}=0.0095$ $\frac{k\mathfrak{E}_g}{\bar{r}I_s}=0.712$ at $\frac{E_a+kE_g}{\bar{r}I_s}=0.40$

and $\frac{\mathfrak{I}_a}{I_s}=0.458$ $\mathfrak{I}_a=0.69$ A. $P=\frac{1}{2}\mathfrak{E}_a\mathfrak{I}_a=3{,}290$ W.

Input depedns on $\frac{I_a}{I_s}$ which in turn depends on $\frac{E_a+kE_g}{\bar{r}I_s}$ as shown in the following table.

$\frac{\mathfrak{E}_a}{\bar{r}I_s}$	$\frac{\mathfrak{I}_a}{I_s}$	$\frac{E_a+kE_g}{\bar{r}I_s}$	$\frac{k\mathfrak{E}_g}{\bar{r}I_s}$	$\frac{\mathfrak{E}_g}{\bar{r}I_s}$	$\frac{kE_g}{\bar{r}I_s}$	$\frac{I_a}{I_s}$	$\frac{E_aI_a}{\bar{r}I_s^2}$	η
0.228	0.458	0.40	0.71	0.0096	0.16	0.47	0.113	0.46
		0.20	0.87	0.0116	0.04	0.32	0.077	0.67
		0	1.14	0.0152	−0.24	0.24	0.057	0.91
		−0.20	1.34	0.0179	−0.44	0.24	0.057	0.91
		−1.00	2.37	0.0316	−1.24	0.24	0.057	0.91

Then at a constant output of $P=3.29$ KW, the efficiency can be raised up to 91% with increase of the negative grid bias and exciting voltage. If the tube is separately excited, or used as a power amplifier, the optimum condition will be,

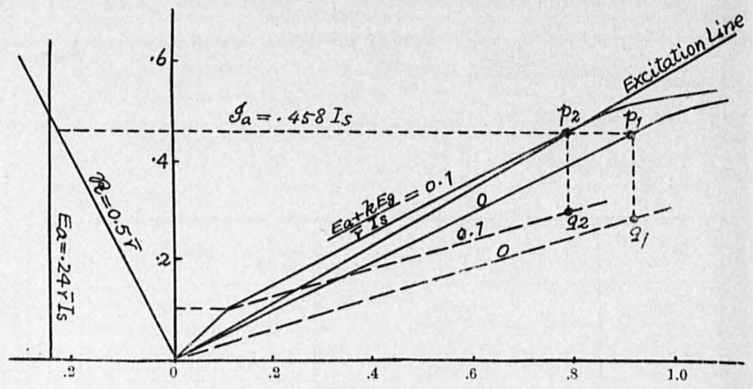


Fig. 65.

$$\frac{E_a + kE_g}{\bar{r} I_s} = 0 \qquad \frac{kE_g}{\bar{r} I_s} = -0.24$$

$$kE_g = -10{,}100 \qquad E_g = -135\ V. \qquad I_a = 0.36\ A.$$

The working points are shown in Fig. 65 as points p_1 and q_1. If the tube is used as a self-oscillator, the excitation line must intersect with the $\frac{\mathcal{J}_a}{I_s}$ line at the value of $\frac{\mathcal{J}_a}{I_s} = 0.453$. The above given working points do not fullfil this condition and another pair of working points such as follows must be taken; (p_2 and q_2 in Fig. 65)

$$\frac{E_a + kE_g}{\bar{r} I_s} = 0.1 \qquad \frac{kE_g}{\bar{r} I_s} = -0.14 \qquad kE_g = -5{,}800 \qquad E_g = -77.4$$

$I_a = 0.28 I_s = 0.42$ A.

Input $E_a I_a = 4{,}200$ W. Loss $= 1{,}000$ W. $\eta = 78\%$

Part of the output given above is consumed for the grid excitation. If this grid loss is neglected, the antenna current will be

$$\mathcal{J}_o = \sqrt{\frac{P}{R}} = 17.9 \text{ A. effective value.}$$

The oscillation circuit must be so arranged as to fullfil the following condition;

$$kE_g = 1.01 \bar{r} I_s = 4{,}250 \text{ V.}$$

or $\mathcal{E}_g = 57$ V must be induced by the antenna current of $\mathcal{J}_o = 17.9$ A. eff. $= 25.3$ A. max

But $\mathcal{E}_g = \omega M \mathcal{J}_o \qquad \omega = \frac{1}{\sqrt{CL}} = 1.17 \times 10^6,$

then $M = \frac{\mathcal{E}_g}{\omega \mathcal{J}_o} = 1.93 \times 10^{-6}$H.

In actual case greater value of M will be required in order to meet the grid loss.

The grid bias voltage $-E_g$ can be obtained by the adjustment of the grid leak resistance, the potential drop produced on it by the grid current being E_g.

This type of tube is usually operated at the input of 3 to 4 KW and the conversion efficiency of about 80% in C. W. transmitter.

(c) Self-Oscillator for Radio-telephone Transmission.

A radio-telephone transmitter is constructed by adding a modulator tube to the circuit shown in Fig. 64. (constant current system). The working condition of the oscillator tube is required.

As the modulation of the output radio-frequency current should effectively be done, the working point must be at such a point p shown in Fig. 66, when the tube is oscillating without modulation.

$$E_a = 0.24\ \bar{r} I_s \qquad E_a + kE_g = 0.15\ \bar{r} I_s \qquad \mathcal{J}_a = 0.26 I_s = 0.39\ \text{A.}$$

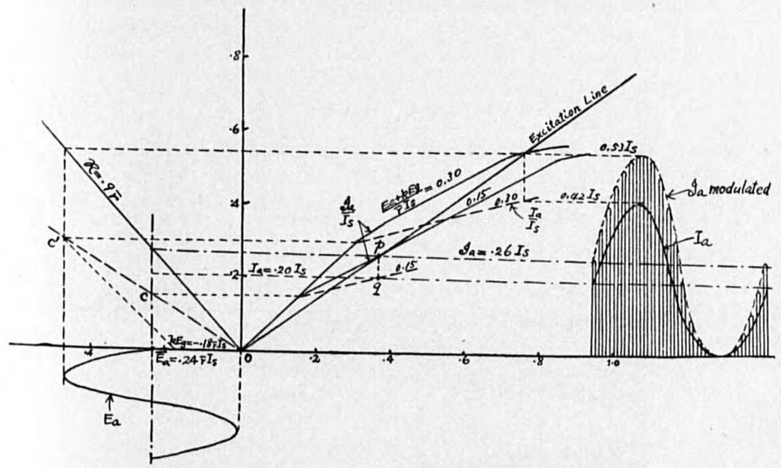


Fig. 66.

Let the grid bias be obtained by means of a grid leak resistance, and the biasing voltage be proportional to the output current; then the grid biasing voltage will follow a line such as *oce'* in Fig. 66, in accordance with the full variation of anode voltage for complete modulation.

At the instant of maximum e_a, $E_a+kE_g=0.3\ \bar{r}I_s$ and $\mathcal{I}_a=0.53\ I_s$. Output impedance must be of such a value as to give $\mathcal{E}_a$ slightly less than E_a at this instant. Thus let

$$\mathcal{R}=0.9\ \bar{r}=25{,}200\ \omega$$

Then at the unmodulated condition,

$\mathcal{E}_a=\mathcal{I}_a\mathcal{R}=9{,}850$ V.

$P=\frac{1}{2}\mathcal{E}_a\mathcal{I}_a=1{,}920$ V.

$I_a=0.20I_s=0.30$ A.

$E_aI_a=3{,}000$ W.

Loss$=1{,}080$ W.

When the anode voltage varies between 0 and 20,000 V, a. c. component of anode current will very between 0 and $0.53\ I_s=0.8$ A, and the d. c. component between 0 and $0.42\ I_s=0.63$ A. Then the oscillator will act as a resistance $\frac{20{,}000\text{ V.}}{0.63\text{ A.}}=31{,}800\ \omega$ against the modulator.

(d) Power Amplifier for Radio-telephone Transmission.

A modulated radio-frequency power is to be amplified by the tube. In order that the modulation wave-form may not be distorted and that the tube may work at the hightest possible efficiency, the working point must be such that

$$\frac{E_a+kE_g}{\bar{r}I_s}=0 \quad \text{or} \quad \frac{kE_g}{\bar{r}I_s}=-0.24 \qquad E_g=-134\text{ V.}$$

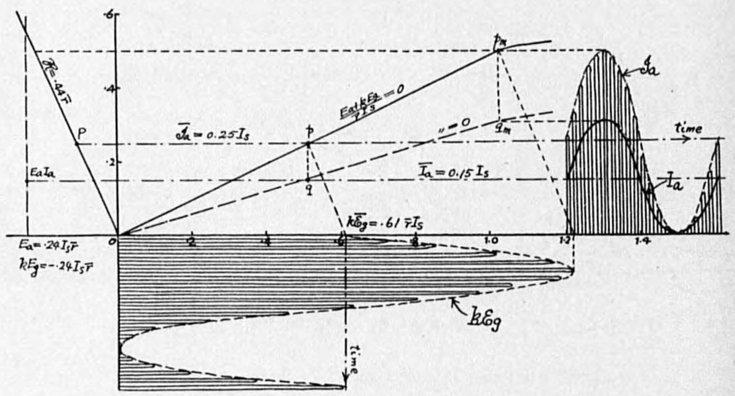


FIG. 67.

The maximum range for distortionless amplification of the modulated wave is $\frac{\mathcal{I}_a}{I_s}=0$ to 0.50 as seen from Fig. 67. The corresponding input grid voltage variation is

$$\frac{k\mathcal{E}_g}{\bar{r}I_s}=0 \text{ to } 1.22$$

$$\frac{\mathcal{R}}{\bar{r}}=0.44 \text{ being taken, } \mathcal{R}=12{,}300\ \omega$$

When modulation is not being given, that is at the carrier wave amplitude, the working condition will be

$\mathcal{I}_a=0.25I_s=0.375$ A. $\quad \frac{k\mathcal{E}_g}{\bar{r}I_s}=0.61 \quad \mathcal{E}_g=342$ V.

$I_a=0.15I_s=0.225$ A. $\quad \mathcal{E}_a=\mathcal{I}_a\mathcal{R}=4{,}610$ V.

$P=\frac{1}{2}\mathcal{E}_a\mathcal{I}_a=865$ W. $\quad E_aI_a=2{,}250$ W. $\quad \eta=0.38$

Loss$=1{,}385$ W.

The loss is above the permissible value, and there will be a necessity of reducing the maximum amplitude of oscillation in order to increase the efficiency by increasing the output impedance $\mathcal{R}$. If we take the maximum amplitude of $0.4\ I_s$, the working condition at the carrier wave will be,

$\mathcal{I}_a=0.2I_s=0.30$ A. $\quad \mathcal{R}=0.6\bar{r}=16{,}800\ \omega$.

$\mathcal{E}_a=\mathcal{I}_a\mathcal{R}=5{,}040$ V. $\quad P=\frac{1}{2}\mathcal{E}_a\mathcal{I}_a=850$ W.

$I_a=0.125I_s=0.187$ A. $\quad E_aI_a=1{,}870$ W.

Loss$=1{,}020$ W. $\quad \eta=0.45$

CHAPTER III.

THE DESIGN OF TRIODES.

(1) Working Points on the Dynamic Characteristic Diagram.

The design of a triode to satisfy specified conditions can be accomplished in the following way, which shows a typical case where the use of the triode is indicated and its power output is given.

Optimum working points can always be found on the dynamic characteristic diagram for any particular use of a triode. This has been explained in the last chapter, and here it will suffice to give a table showing these optimum conditions that the writer conceives to be appropriate.

Use of Triode	$\frac{E_a+kE_g}{\bar{r}I_s}$	$\frac{\mathcal{E}_a}{I_s}$	$\frac{\mathcal{R}}{\bar{r}}$
Low power amplifier.	0.3~0.5	0.2~0.4	1.0
Distortionless power amplifier and modulator.	0.3~0.5	0.2~0.4	2.0
Oscillator or power amplifier for radio-telegraphy.	—1.0	0.55	1.0
Self-oscillator for radio-telephony.	0.3	0.35	1.2
Power amplifier for radio-telephony, amplifying modulated waves.	0	0.25	1.0
Ditto, amplifying C. W. and being subjected to modulation.	0	0.25	1.4

If the above three quantities are decided, the followings may be directly obtained from the diagram:—

$$\frac{P}{\bar{r}I_s^2},\quad \frac{k\mathcal{E}_g}{\bar{r}I_s},\quad \frac{\mathcal{E}_a}{\bar{r}I_s},\quad \frac{I_a}{I_s}.$$

$\frac{E_a}{\bar{r}I_s}$ can roughly be estimated according to the use of the tube, and from this the approximate values of $\frac{E_aI_a}{\bar{r}I_s^2}$ and η can be found.

(2) Saturating Voltage and Saturation Current.

For a given power output P, $a=\frac{P}{\bar{r}I_s^2}$ having been known, $\bar{r}I_s^2$ can be obtained and next comes an important problem of splitting $\bar{r}I_s^2$ into the saturating voltage $\bar{r}I_s$ and the saturation current I_s, i.e. $\bar{r}I_s^2=\bar{r}I_s\times I_s$.

If one of any other operating conditions, such as anode voltage E_a or anode circuit impedance $\mathcal{R}$, is given at the same time, the solution is simple, as $\frac{E_a}{\bar{r}I_s}$ or $\frac{\mathcal{R}}{\bar{r}}$ has already been determined.

If this is not the case, most precise considerations must be taken for this from technical and economical points of view, especially in the design of standard types of tubes. The general considerations of the two alternatives, high $\bar{r}I_s$ tube or low $\bar{r}I_s$ tube for a given power output are as follows:

	High $\bar{r}I_s$ tube	Low $\bar{r}I_s$ tube	Remarks
Anode voltage	high	low	Anode voltage must be within a practicable limit from standpoint for insulations of the tube and other apparatuses.
Saturation current	low	high	
Cathode power consumption	little	large	Lower filament power is preferable as overall operating efficiency becomes higher and anode radiating area can also be reduced.
Internal and external impedances	high	low	
Amplification constant	high	low	

Anode power conversion efficiency is not very different as it is principally determined from the working points, but in a higher voltage tube anode voltage is more completely utilized and net efficiency will be a little higher than lower voltage tube.

This problem involves not only the economy of the tube itself but also that of apparatus with which the tube is to be used, such as output circuits, anode source of power, amplifiers preceding the tube under consideration, etc. The practicable

limits in the values of E_a, $\mathfrak{R}$, and cathode heating power should also be taken into consideration.

Regarding the oscillatory power output of a triode, following consideration is sometimes necessary. Output P somewhat larger than the required amount has to be taken as the designing basis in order to take effect of the grid current into account which were not done in the derivation of the dynamic characteristic diagram. The grid current affects the power output in two ways; first it reduces the anode current and hence the output, and secondly it absorbs some portion of the output in case of self-oscillators. An increase of P, 10 or 20% above the required value, will generally be sufficient, according as the tube is used as a power amplifier or a self-oscillator.

(3) Amplification Constant.

From equation (17),

$$(1+k)^3=G^2\bar{r}^3I_s$$

and $$P=a\bar{r}I_s^2$$

hence $$(1+k)^3=\left(\frac{Ga}{P}\right)^2(\bar{r}I_s)^5 \quad \ldots\ldots\ldots \quad (21)$$

G is not so much different with the type of tubes and is of the order of 10^{-4} as shown in the following table.

Tubes		No. of tubes examined	G	
Anode voltage	Electrode		Range	Average
6000–10,000	cylinder	14	$.08–.4\times10^{-3}$	0.15×10^{-3}
200–5,000	cylinder	8	$.08–.4\times10^{-3}$	0.17×10^{-3}
,,	plane	15	$.15–.9\times10^{-3}$	0.38×10^{-3}
below 100	cylinder	10	$.12–.5\times10^{-3}$	0.18×10^{-3}
,,	plane	5	$.28–.5\times10^{-3}$	0.33×10^{-3}

Total average; G for plane electrodes, 0.35×10^{-3}

G for cylindrical electrodes, 0.16×10^{-3}

G, a, and P having been known, k is in definite relation to $\bar{r}I_s$ as given by equation (21), and so once $\bar{r}I_s$ is determined, k can be directly derived.

In case of oscillators, self or separately-excited, power lost in the excitation depends on the value of k. In a self-excited oscillator, this power is converted from the output of the tube and too much exciting power results in the lowering of net output and overheating of the grid. In a separately-excited oscillator or power amplifier, the grid loss is to be supplied from the preceding tube. In these cases the value of k will be estimated as follows; for the most favorable operation at a given anode voltage, the minimum anode voltage $E_a-\mathfrak{E}_a$ must be nearly equal to the maximum grid voltage $\mathfrak{E}_g+E_g$ (E_g is usually negative), and this requires that

$$E_a-\mathfrak{E}_a=E_g+\mathfrak{E}_g$$

or $$\frac{E_a}{\bar{r}I_s}-\frac{\mathfrak{E}_a}{\bar{r}I_s}=\left(\frac{kE_g}{\bar{r}I_s}+\frac{k\mathfrak{E}_g}{\bar{r}I_s}\right)\frac{1}{k}.$$

hence $$k=\frac{\frac{k\mathfrak{E}_g}{\bar{r}I_s}+\frac{E_a+kE_g}{\bar{r}I_s}-\frac{E_a}{\bar{r}I_s}}{\frac{E_a}{\bar{r}I_s}-\frac{\mathfrak{E}_a}{\bar{r}I_s}}. \quad \ldots \quad (22)$$

in which all quantities except $\frac{E_a}{\bar{r}I_s}$ are already known. Thus if k is given, $\frac{E_a}{\bar{r}I_s}$ can be accurately determined and $\frac{E_aI_a}{\bar{r}I_s^2}$ and η are accordingly known.

For a rough estimation of the grid excitation loss in the above working condition, the grid current may be assumed to have a triangular wave-form as shown in Fig. 68, and its peak value to reach $\frac{1}{2}I_s$ in a severe case of excitation. The results of calculations are as follow.

Grid current d. c. component

$$I_g=\mu I_s$$

Grid leak loss (or grid battery charging loss)

$$W_l = -\mu E_g I_s$$

E_g being negative.

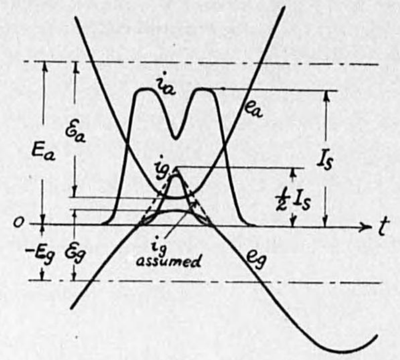


Fig. 68.

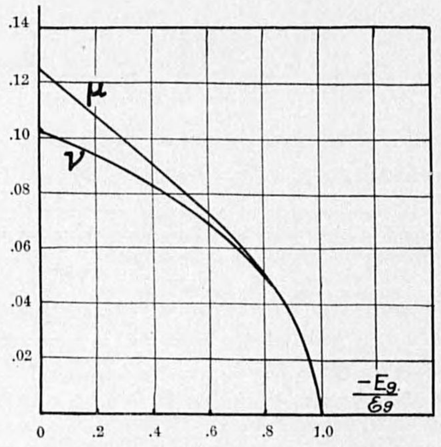


Fig. 69.

Grid loss inside the tube $W_g = \nu \mathcal{E}_g I_s$

Grid leak resistance required $R_g = \dfrac{-E_g}{I_g}$

in which μ and ν are the functions of $-\dfrac{E_g}{\mathcal{E}_g}$ as given in Fig. 69.

If the total grid excitation loss is allowed up to 10% of the anode loss;

$$\frac{1}{10}\left(\frac{E_a I_a}{\bar{r} I_s^2} - \frac{P}{\bar{r} I_s^2}\right) \geqq \frac{1}{k}\left(\nu \frac{k\mathcal{E}_g}{\bar{r} I_s} - \mu \frac{kE_g}{\bar{r} I_s}\right)$$

or

$$k \geqq 10 \frac{\nu \dfrac{k\mathcal{E}_g}{\bar{r} I_s} - \mu \dfrac{kE_g}{\bar{r} I_s}}{\dfrac{E_a I_a}{\bar{r} I_s^2} - \dfrac{P}{\bar{r} I_s^2}} \quad \cdots\cdots\cdots (23)$$

The approximate value of $\dfrac{E_a}{\bar{r} I_s}$ being known, $\dfrac{kE_g}{\bar{r} I_s}$ and $\dfrac{E_a I_a}{\bar{r} I_s^2}$ can be roughly estimated and from this relation lower limit of k can be determined. The exact value of $\dfrac{E_a}{\bar{r} I_s}$ will be derived by equation (22), after the value of k is determined.

It is advisable to calculate the required quantities for several values of k or $\bar{r} I_s$ and to select among them a most preferable one.

(4) Dimensions of the Electrodes.

Anode loss W_a is known from the working condition as $(E_a I_a - P)$. But in the case of amplifiers or modulators for radio-telephony, the dead anode loss corresponding to the working point on the static characteristics, i.e. $\dfrac{E_a + kE_g}{\bar{r}} \times E_a$ must be taken as the anode loss, as this amount of loss actually takes place when speech is not being transmitted.

The allowable limit of anode loss is dependent on the material of anode and its cooling condition. The following data giving the maximum limit of the loss continuously applicable to the anode may be taken as the designing basis.

Material	Allowable loss, watt/cm²
Nickel	$w=3$
Molybdenum	5
Tunsgsten	8
Water-cooled copper anode	20

The filament heating power W_f must also be considered, as some portion of it will dissipate through the anode. Suppose q part of the filament power is radiated through the anode, then

$$A \geqq \frac{W_a + q W_f}{w}$$

q depends on the degree at which the filament is hidden in the anode, and in ordinary cases in which anode is open on both ends, q may be taken as about 0.5. The writer deems it reasonable to take the effective area A explained in Chapter I, instead of the actual area, in the above expression.

Examples in the existing tubes ($q=0.5$ being assumed and W_a being the test anode loss):

Nickel anode tubes					Molybdenum anode tubes				
Type	W_a	W_f	A	w	Type	W_a	W_f	A	w
211-A	65	30	34	2.4	MS-III	50	32	16	4.1
MT-1	150	54	43	4.1	MT-7A	1000	310	119	9.7
MT-2	600	250	200	3.6	MT-9	1500	370	117	14.4
MT-4	200	79	93	2.6	UV-204	250	170	38	8.8
UV-203A	100	31	25	4.6	UV-206	300	160	99	3.9

For anode voltages less than 4,000 V, plane anode is preferable, while for higher voltages cylindrical one is more convenient.

In high voltage tubes grid voltage also becomes high with respect to the cathode, and appreciable distance must be kept between grid and cathode in order to avoid severe electro-static attraction. On the other hand, in low voltage tubes x_g can be reduced, and if the cathode is made of W-shaped filament arranged in a plane, A may be greatly increased without difficulty in construction.

The order of x_a in the existing tubes are as follows;

Receiving tubes E_a below 100 V.	$x_a=0.2$–0.5 cm.
$E_a=100$–$1{,}000$ V.	0.3–1.0 cm.
$E_a=1{,}000$–$10{,}000$ V.	0.6–3.5 cm.

The actual anode surface area should be made as effective as possible in order to reduce the mass of the anode and hence to minimize the adsorbed gas evolving in the evacuation process, as well as from economical point of view. The plate should be as thin as mechanically allowable, but not so thin as to avoid free conduction of heat, otherwise local over-heating or melting may occur at accidental overload of the anode.

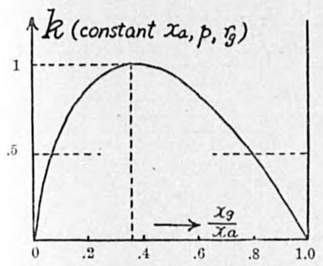


Fig. 70.

The anode area A, anode-to-cathode distance x_a or z_a, and the span l_f of the filament must be in conformity with one another to give the predetermined value of G by the expression,

$$G=2.33\times10^{-6}\frac{A}{z_a z_g}.$$

The grid construction is determined from amplification constant. When x_a is given and other dimensions p and d_g remain unvaried, k is maximum at $x_g \fallingdotseq 0.4\,x_a$ (Fig. 70). It is therefore advisable to take as $x_g=0.4x_a$ in order to reduce the mass of the grid as well as to minimize the effect of non-uniformity of x_g on the value of k.

Thus
$$\frac{k}{\log\frac{x_a}{x_g}}=\frac{k}{0.4}=\frac{cL_g}{\log\coth\pi a}.$$

TABLES II, III, and IV on pages 160-161 are to be referred to for the calculation and the following table shows the ranges of actual values of L_g and πa in exsiting tubes. It is interesting to note that L_g and k are of equal magnitude in average.

k	Range of L_g	Range of πa
3	2– 7	0.25–0.50
5	3– 12	
8	4– 17	
10	5– 20	0.30–0.60
15	7– 28	
20	8– 35	
25	10– 40	
30	11– 45	
40	14– 60	
50	16– 70	0.35–0.74
60	19– 80	
80	23–100	
100	28–120	0.40–0.90
150	40–200	
300	60–300	0.55–1.20

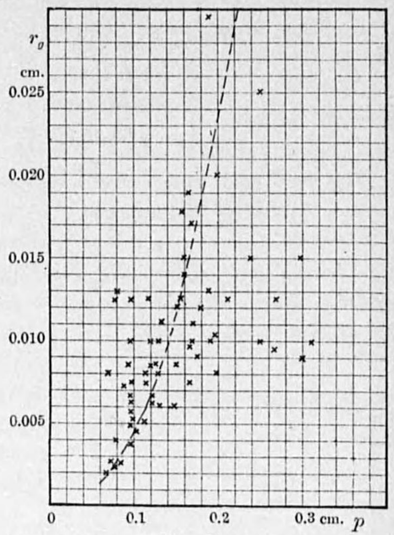


FIG. 71.

L_g and πa having been determined, the next problem is to determine p and d_g. This means whether to use thick wires at broad pitch or to use thin wires closely arranged.

It is preferable to take πa small in order to reduce the mass of the grid and to facilitate evacuation. This is effected by thin grid wires at comparatively narrow pitch, but in extreme cases mechanical rigidity of grid will be lost and deformation or break down will occur during operation by the heating of grid due to either the radiated heat from other electrodes or the grid loss.

Materials best suited for grid are molybdenum and nickel, but the latter has a remarkable effect of secondary emission and often causes the "blocking" of power oscillators.

The pitch p of grid wires exerts a most remarkable effect on k. Fig. 71 shows actual values of p and r_g in existing tubes, from which general tendency can be observed.

(5) Design of the Cathode.

Design of a tungsten cathode to give the required emission I_s can be accomplished by means of the CHART II annexed to this paper. It is preferable to design the filament to give a slightly higher value of emission than desired in order to give allowance for the discrepancies which might take place.

For a strict estimation of the filament life L, which is the life of the tube in ideal case, an economical condition must be dealt with in such a way that the total running cost of a tube is a minimum for a given power output. This condition is given by the following relations;

Total cost per watt output per hour

$$T=\frac{C_t}{PL}+\left(\frac{1}{\eta}+\frac{W_f}{P}\right)C_p$$

in which C_t=cost of the tube.

C_p=cost of power per watt hour.

On the other hand, for the filament of a certain diameter the life L depends on its temperature, which in turn is determined at what filament efficiency $\frac{I_s}{W_f}$ it is operated, thus

$$L=\phi\left(\frac{W_f}{I_s}\right)^{\sigma}$$

Minimum of the operating cost T occurs at a life

$$L_{opt}=\phi^{\frac{1}{1+\sigma}}\left(\frac{\sigma C_t}{C_p I_s}\right)^{\frac{\sigma}{1+\sigma}}$$

For tunsgsten filaments, the two constants σ and ϕ are of the following orders.

$$\sigma \fallingdotseq 2.6$$

d_f	ϕ
for i_f=3 A	0.0010
8	0.0048
20	0.037

It is general practice to take 2,000 to 5,000 hours, as the order of reasonable life, except for special cases in which the life must be sacrificed for other conditions.

Determination of filament dimensions by means of the chart is explained in the following table. This chart has been worked out by Kato[10] from the data given by Forsythe and Worthing[11] and the life is assumed to be the time in which 10% of the initial diameter of the filament is lost by evaporation.

l=total length of the filament,

l'=effective length of the filament, that is, the length which will give the emission I_s, if it be at a uniform temperature equal to that on its middle portion.

$l=l'+m\Delta l$. Δl=length of a cooled end.

m=no. of leads and anchored points.

e_f=terminal voltage of the filament,

e_f'=potential drop on the effective length l',

$e_f=e_f'+m\Delta e_f$ Δe_f=voltage at a cooled end.

$\frac{e_f}{l}=\frac{e_f'}{l'}$ approximately.

r_f=radius of the filament,

L=life of the filament.

I_s=total emission.

Given quantities	Procedure to obtain other quantities
l, r_f, i_f,	Chart IIa, from r_f and i_f ..... I_s, $\left(\frac{e_f'}{l'}\right)$, $\left(\frac{I_s}{l'}\right)$ Chart IIc, from r_f and i_f ..... Δl, Δe_f $l'=l-m\Delta l$. $I_s=\left(\frac{I_s}{l'}\right)l'$ $e_f=\left(\frac{e_f'}{l'}\right)l'+m\Delta e_f$

(10) N. Kato: "Graphs for the Design of Bright-Emitting Tungsten Filament," Circulars of the Electrotechnical Laboratory, No. 50, April, 1928

(11) W. E. Forsythe and A. G. Worthing: Astrophysical J., 61. p. 146, 1925.

Given quantities	Procedure to obtain other quantities
l, e_f, I_s	Assume $\Delta e_f=1$, $\left(\frac{I_s}{e_f'}\right)=\frac{I_s}{e_f-m\Delta e_f}$, $\left(\frac{l'}{e_f'}\right)\fallingdotseq\left(\frac{l}{e_f}\right)$ Chart IIb, from $\left(\frac{l'}{e_f'}\right)$ and $\left(\frac{I_s}{e_f'}\right)$, ... i_f, r_f, I Chart IIc, Δe_f assured.
l, r_f, e_f	$\left(\frac{e_f'}{l'}\right)\fallingdotseq\frac{e_f}{l}$, Chart IIa, from r_f and $\left(\frac{e_f'}{l'}\right)$ ..... I_s, i_f, $\left(\frac{I_s}{l'}\right)$ Chart IIc, from i_f and r ..... Δl, Δe_f $l'=l-m\Delta l$, $I_s=\left(\frac{I_s}{l'}\right)l'$
r_f, i_f, I_s	Chart IIa, from i_f and r_f ..... I_s, $\left(\frac{e_f'}{l'}\right)$, $\left(\frac{I_s}{l'}\right)$ Chart IIc, from i_f and r_f ..... Δl, Δe_f $l'=\frac{I_s}{\left(\frac{I_s}{l'}\right)}$, $l=l'+m\Delta l$, $e_f=\left(\frac{e_f'}{l'}\right)l'+m\Delta e_f$
r_f, e_f, I_s	Assume $\Delta e_f=1$, $\left(\frac{I_s}{e_f'}\right)=\frac{I_s}{e_f-m\Delta e_f}$. Chart IIb, from r_f and $\left(\frac{I_s}{e_f'}\right)$ ..... i_f, $\left(\frac{l'}{e_f'}\right)$, L Chart IIc, ... Δl, Δe_f assured $l'=\left(\frac{l'}{e_f'}\right)(e_f-m\Delta e_f)$, $l=l'+m\Delta l$
r_f, e_f, L	Chart IIb, from r_f and L ..... i_f, $\left(\frac{l'}{e_f'}\right)$, $\left(\frac{I_s}{e_f'}\right)$ Chart IIc. from r_f and i_f ..... Δl, Δe_f $e_f'=e_f-m\Delta e_f$, $I_s=\left(\frac{I_s}{e_f'}\right)e_f'$, $l'=\left(\frac{l'}{e_f'}\right)e_f'$
e_f, i_f, I_s	Assume $\Delta e_f=1$, $\left(\frac{I_s}{e_f'}\right)=\frac{I_s}{e_f-m\Delta e_f}$ Chart IIb, from i_f and $\left(\frac{I_s}{e_f'}\right)$ ..... r_f, L, $\left(\frac{l'}{e_f'}\right)$ Chart IIc, from i_f and r_f ..... Δl, Δe_f assured $l=\left(\frac{l'}{e_f'}\right)(e_f-m\Delta e_f)+m\Delta l$

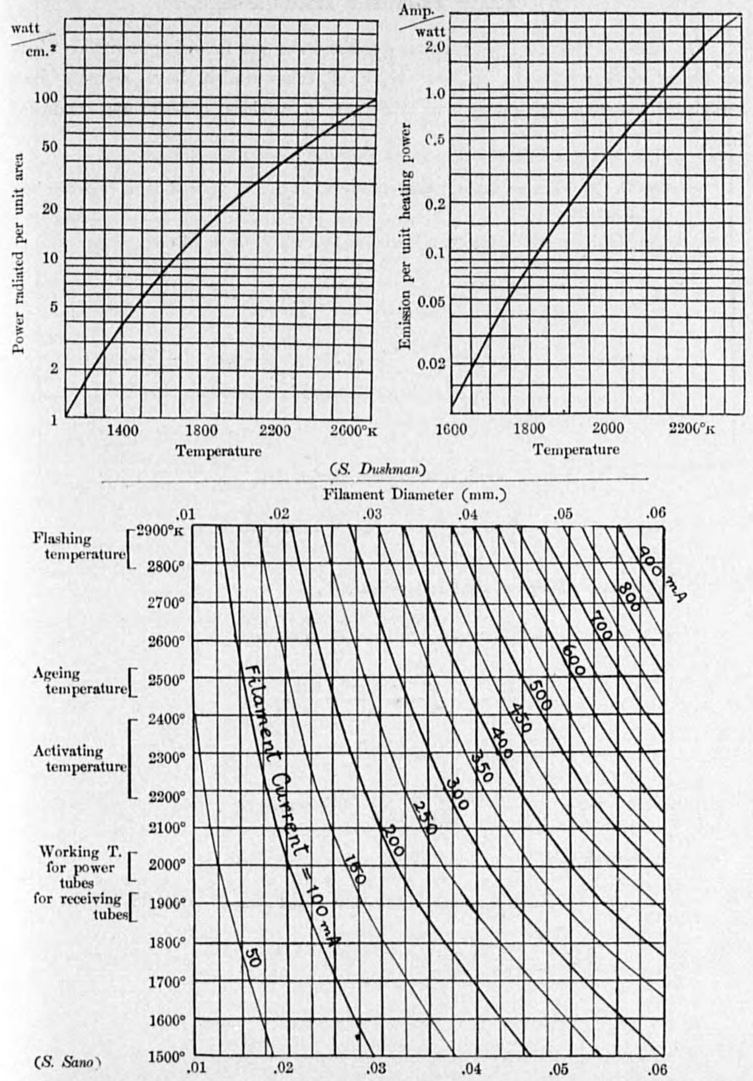
Given quantities	Procedure to obtain other quantities
e_f, i_f, L	Chart IIb, from i_f and L ..... r_f, $\left(\frac{I_s}{e_f'}\right)$, $\left(\frac{l'}{e_f'}\right)$ Chart IIc, from i_f and r_f ..... Δe_f, Δl $e_f'=e_f-m\Delta e_f$, $I_s=\left(\frac{I_s}{e_f'}\right)e_f'$, $l=\left(\frac{l'}{e_f'}\right)e_f'+m\Delta l$
i_f, I_s, L	Chart IIa, from i_f and L ..... r_f, $\left(\frac{I_s}{l'}\right)$, $\left(\frac{e_f'}{l'}\right)$ Chart IIc, from i_f and r_f ..... Δe_f, Δl $l'=\frac{I_s}{\left(\frac{I_s}{l'}\right)}$, $l=l'+m\Delta l$, $e_f'=\left(\frac{e_f'}{l'}\right)l'$, $e_f=e_f'+m\Delta e_f$
e_f, I_s, L	Assume $\Delta e_f=1$, $\left(\frac{I_s}{e_f'}\right)=\frac{I_s}{e_f-m\Delta e_f}$ Chart IIb, from L and $\left(\frac{I_s}{e_f'}\right)$ ..... r_f, i_f, l' Chart IIc, from i_f and r_f ..... Δl, Δe_f assured $l=l'+m\Delta l$

The filament efficiency which is usually expressed by milliamperes per watt, can be increased with increase of the filament diameter, because the working temperature of a thicker filament can be made higher than that of a thinner one without shortening its life. But in an extreme case of the former the filament becomes too short to obtain the required anode effective area. On the other hand, a thin filament suffers from the unevenly heated effect of superposed anode current and the life will be shorter, especially when a direct current is used for the heating. In this respect the filament current should be larger than 30 times the working anode current I_a.

The design of thoriated tungsten filaments can not be considered accurately, as the emission is very much affected by the degree of activation and the residual gas, but the curves shown in Fig. 72, which were taken from the data published by Dushman[12] and Sano[13], will be of use in obtaining general conception on this type of filament.

(12) S. Dushman: Phys. Rev., June 1927, p. 857.
(13) S. Sano: "Properties of a Thoriated Tungsten Filament etc.," Circular of the Electrotechnical Laboratory No. 43, Feb., 1927.

Fig. 72. Operation of Thoriated Tungsten Filament.



(6) Examples on the Triode Design.

The design procedure is further explained in the following examples where the design data are given on four types of tubes which have actually been constructed at the Laboratory for the use in various experiments conducted there.

Example 71. To design an oscillator tube of 250 watt output to be used in a radio-telephone transmitter.

The working points on the dynamic characteristics are chosen as follows;

$$\frac{E_a+kE_g}{\bar{r}I_s}=0.30 \qquad \frac{\mathcal{E}_a}{I_s}=0.35 \qquad \frac{\mathcal{R}}{\bar{r}}=1.20$$

and hence $$\frac{P}{\bar{r}I_s^2}=0.075 \qquad \frac{\mathcal{E}_a}{\bar{r}I_s}=0.43 \qquad \frac{I_s}{I_s}=0.32 \qquad \frac{k\mathcal{E}_g}{\bar{r}I_s}=0.80$$

As $P=250$, $$\bar{r}I_s^2=\frac{250}{0.075}=3{,}340$$

Assume $\frac{E_a}{\bar{r}I_s}=0.45$ which is taken slighty higher than $\frac{\mathcal{E}_a}{\bar{r}I_s}$,

then $$\frac{E_aI_a}{\bar{r}I_s^2}=0.144 \qquad \eta=\frac{P}{E_aI_a}=\frac{0.075}{0.144}=0.52$$

The grid loss being considered by equation (23),

$$\frac{kE_g}{\bar{r}I_s}=\frac{E_a+kE_g}{\bar{r}I_s}-\frac{E_a}{\bar{r}I_s}=-0.15$$

$$\frac{-E_g}{\mathcal{E}_g}=\frac{-kE_g}{\bar{r}I_s}\cdot\frac{\bar{r}I_s}{k\mathcal{E}_g}=\frac{0.15}{0.80}=0.188$$

$\mu=0.109$ $\nu=0.095$

hence $$k\geqq\frac{0.095\times0.80+0.109\times0.15}{0.144-0.075}\times10=13.4$$

In equation (21),

$$\alpha=\frac{P}{\bar{r}I_s^2}=0.075 \qquad P=250 \qquad \text{and assume} \qquad G=0.35\times10^{-3}$$

then $$\frac{G\alpha}{P}=1.05\times10^{-7}$$

and $$(1+k)^3=\left(\frac{G\alpha}{P}\right)^2(\bar{r}I_s)^5$$

$$=1.10\times10^{-14}\ (\bar{r}I_s)^5$$

or $$\bar{r}I_s=\sqrt[5]{\frac{(1+k)^3}{1.10}\times10^{14}}$$

Let three values of k larger than 13.4 be assumed and further calculations are made as follows;

k	$\bar{r}I_s$	$I_s=\frac{\bar{r}I_s^2}{\bar{r}I_s}$	$\frac{E_a}{\bar{r}I_s}$ by Eqn. (22)	E_a	I_a	E_aI_a	η	$\bar{r}$	$\mathcal{R}$	approximate filament power
15	3,260	1.02	0.471	1,540	0.33	510	0.49	3,200	3,800	* 200
20	3,840	0.87	0.462	1,770	0.28	500	0.50	4,400	5,300	* 175
25	4,360	0.77	0.457	1,990	0.25	500	0.50	5,700	6,800	* 150

* based on 5 mA/watt.

The anode voltage up to 2,000 V can be obtained from a d. c. generator with convenience. Overall efficiency including the filament loss is improved with increase of k, and the filament power becomes less appreciable compared with the anode loss.

So that $k=25$ is to be taken,

then $E_a=2{,}000$ $\mathcal{R}=6{,}800$ $\bar{r}=5{,}700$ $I_s=0.77$

Molybdenum plate is to be used with the effective area:

$$A=\frac{250+150\times0.5}{5}=65$$

Let $x_g=0.4\ x_a$ then $\frac{A}{x_ax_g}=\frac{160}{x_a^2}$.

$G=0.35\times10^{-3}$ as assumed before,

$\therefore$ $$2.33\times10^{-6}\times\frac{160}{x_a^2}=0.35\times10^{-3}$$

$\therefore$ $x_a=1.00$ $x_g=0.40$

Dismensions of the grid is determined from

$$\frac{k}{\log\frac{x_a}{x_g}}=\frac{eL_g}{\log\coth\pi a}.$$

in which $k=25$, $\log\frac{r_a}{r_g}=0.40$ $e=1.7$ (W-shaped filament)

Grid is to be formed of a system of parallel wires.

Assume		$l_g=25$	20	15
then	$\log\coth \pi a=$	0.680	0.545	0.408
from Table IV	$\pi a=$	0.22	0.30	0.39
$\pi a=\frac{l_g r_g}{r_g}$.	$\therefore\ r_g=$	0.0040	0.0060	0.010

Take $l_g=15$ and $r_g=0.010$, as thinner wires are liable to deformation,

then $$p=\frac{2\pi r_g}{l_g}=0.17$$

Design of the filament;

tungsten is to be used, and assume the life to be

$$L=2{,}000.$$

Working anode current $I_a=0.25$ $\therefore\ i_f>30\,I_a=7.5$

Take $i_f=10$.

From Chart IIa,

$$r_f=0.017 \qquad \frac{I_s}{l'}=0.07 \qquad \frac{e_f'}{l'}=0.89$$

and from Chart IIc,

$$\Delta e_f=1.05 \qquad \Delta l=1.2$$

Filament is designed with 20% increase of I_s, or

$$I_s=0.77\times1.2=0.90$$

then $$l'=\frac{I_s}{\left(\frac{I_s}{l'}\right)}=13$$

If th's effective length of the filament is divided into sections arranged in four rows, anode effective area can be obtained as

$$A=(2r_a l'+4\pi r_a^2)\times2=77$$

which shows that the required value of $A=65$ can be easily obtained.

$l'=13$ $\Delta l=1.2$ $m=5$

(number of leads=2, and number of anchored points=3)

Total length $l=13+5\times1.2=19$

and $$e_f'=\left(\frac{e_f'}{l'}\right)\times l'=11.6$$

$$e_f=e_f'+m\Delta e_f=11.6+5.3=16.9$$

The dimensions of the tube will be such as shown in Fig. 73, and rating of the tube as follows;

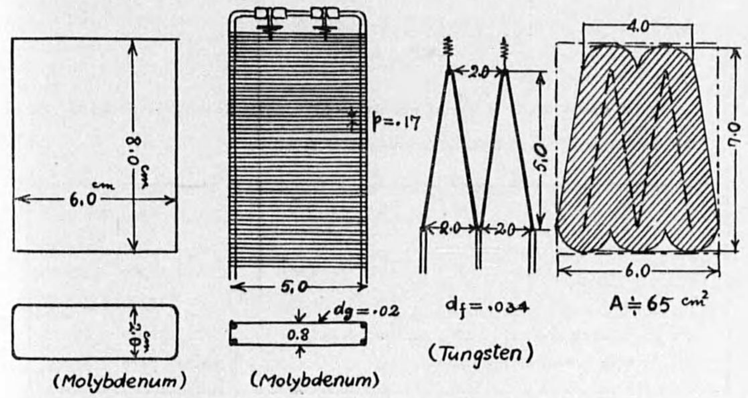


FIG. 73.

$e_f=17$ V $i_f=10$ A

$E_a=2{,}000$ V $P=250$ W $E_a I_a=500$ W

$\eta=50\%$ $E_g=-27$ V

$k=25$ $\bar{r}=5{,}700$ $R=6{,}800$

A well-known type of tube UV-204, which was originally put on the market by the Radio Corporation of America, has the rating of 250 watt output to be used in a radio telephone transmitter, and is similar in this respect to the tube under consideration. The dimensions of the tube are as shown in Fig. 5 on page 17 and ratings of the tube are as follows:

e_f=11 V i_f=14.75 A k=20.

E_a=2,000 V P=250 W I_a=0.25 A E_aI_a=500 W

Example 72. Design data of a triode type **PAM**, manufactured at the Laboratory.

Given Conditions: the tube is to be used in radio-frequency measurements as an oscillator.
Anode voltage: up to 1,000 V.
Power output: 30 W.
Filament current: about 3 A.

Design: Working points on the dynamic characteristic diagram are chosen as follows, so as to give the largest power with the least possible distortion of wave form in self-exciting condition:

$$\frac{E_a+kE_g}{\bar{r}I_s}=0.50 \qquad \frac{\vartheta_a}{I_s}=0.58 \qquad \frac{I_a}{I_s}=0.50$$

Output circuit impedance $\frac{R}{\bar{r}}$ is not determinable from the required conditions, and so their several values are tried for further calculations as follows:

$\frac{R}{\bar{r}}$	$\frac{\varepsilon_a}{\bar{r}I_s}$	$\frac{P}{\bar{r}I_s^2}$	$\bar{r}I_s^2$ (P=30)	$\frac{E_a}{\bar{r}I_s}$	$\bar{r}I_s$ (E_a=1000)	I_s	$\bar{r}$	R
0.6	0.34	0.10	300	0.35	2,860	0.105	27,300	16,400
1.0	0.58	0.17	177	0.60	1,670	0.106	15,800	15,800
1.5	0.87	0.25	120	0.90	1,110	0.107	10,400	15,600
2.0	1.16	0.34	89	1.20	835	0.107	7,800	15,600

Higher $\frac{R}{\bar{r}}$ gives lower $\bar{r}I_s^2$, and the tube may be of lower power capacity.

Take $\frac{R}{\bar{r}}$=2.0, then $\bar{r}$=7,800 I_s=0.107 $\bar{r}I_s$=835 $\bar{r}I_s^2$=89

Assume $G=0.35\times10^{-3}$

then from equation (17),

$$(1+k)^2=G^2\bar{r}^2I_s=6{,}440$$

$$k=17.6$$

Working conditions predicted from these data:

power input $=\frac{E_a}{\bar{r}I_s}\times\frac{I_a}{I_s}\,\bar{r}I_s^2=53.5$ W

power output =30 W
loss =23.5 W
efficiency =56%

Filament is designed, taking slightly higher emission than required,

thus I_s=0.15 A
let i_f=3 A as given and L=2,000 hours

then from Chart IIa,

$$r_f=0.0077 \text{ cm} \qquad \frac{I_s}{l'}=0.015 \qquad \text{and} \qquad \frac{e_f'}{l'}=1.18$$

and from Chart IIc, Δl=0.8 Δe_f=1.05
Filament is spanned in W-shape, m=5 (no. of leads=2, no. of anchored points=3)

then $$l'=\frac{I_s}{\left(\frac{I_s}{l'}\right)}=10 \qquad l=l'+m\Delta l=14 \text{ cm}$$

$$e_f'=\left(\frac{e_f'}{l'}\right)l'=11.8 \qquad e_f=e_f'+m\Delta e_f=17 \text{ V} \qquad W_f=e_fi_f=51 \text{ W}$$

The nearest radius of filament obtainable is r_f=0.0085 and this is to be actually used.
Molybdenum plate being used, its anode area:

$$A>\frac{W_a+0.5W_f}{5}=7 \text{ cm}^2$$

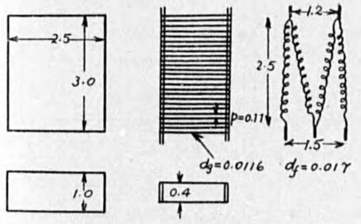


FIG. 74 (PAM)

If the filament length of 14 cm is spanned straight in W-shape, the anode area becomes unnecessarily large, so that filament is curled into spiral and spanned in W-shaped as shown in Fig. 74.

Anode area taken in accordance with this arrangement of filament becomes,

$$A=2\times3.0\times2.5=15 \text{ cm}^2$$

This curling of filament results in slight reduction of emission and so the total length is increased to l=20 cm.

Let x_a=0.5 cm and x_g=0.2 cm $(z_a=x_a,\ z_g=x_g)$

then $$G=2.33\times10^{-6}\frac{A}{x_ax_g}=0.35\times10^{-3}$$

which is consistent with the previously assumed value.

$k=17.6$ and $\log\frac{r_a}{r_g}=0.4$ $\quad\frac{cL_g}{\log\coth\pi a}=44.$

Grid being formed of parallel wires,

$c=1.5$ $\quad L_g\frac{2\pi r_g}{p}=\frac{1.26}{p}$ $\quad \pi a=\frac{\pi d_g}{p}.$ $\quad\frac{L_g}{\log\coth\pi a}=29$

Taking different values of p,

p	L_g	$\log\coth\pi a$	πa	d_g	r_g
0.07	18.0	0.62	0.25	0.0056	0.0028
0.10	12.6	0.43	0.39	0.0124	0.0062
0.15	8.4	0.29	0.57	0.0271	0.0135

Tungsten filaments actually obtainable are of diameters:

0.007 0.012 0.016 0.020 0.025 0.030

Taking the nearest diameter, $d_g=0.012$ then $p=0.10$

Tubes of this type were actually constructed at the Laboratory with dimensions shown in Fig. 74, photograph of a completed tube being shown in Fig. 75 (facing page 158).

Test data:

Filament characteristics,

e_f	i_f	I_s
16.0 V	2.85 A	0.013 A
17.0	2.95	0.029
18.0	3.05	0.058
19.2	3.15	0.150

Normal operating condition, $e_f=19.5$ V. $\quad i_f=3.2$ A.

Static characteristics are shown in Fig. 76.

Parameters; at $e_a=500$ and $e_g=0$,

$k=11$ $\quad g=0.00160$ $\quad r=6{,}650$

Its optimum condition as a self-oscillator, the circuit being adjusted to give maximum power with reasonable efficiency is:—

$E_a=950$ V.

Power input, anode d. c. $I_a=0.080$ A.

power $E_a I_a=76$ W.

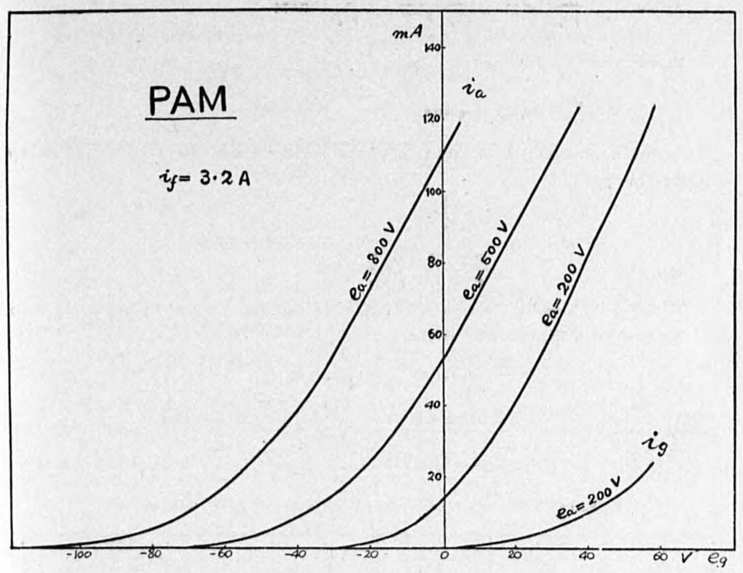


FIG. 76.

Power output, closed circuit current $\mathfrak{I}_0=2.65$ A efl.

closed circuit resistance $R=6.0\omega$

power $\mathfrak{I}_0^2 R=42$ W

Efficiency, $\eta=55\%$ Loss=34 W

Anode loss test: no defects were found at 80 W. loss for 5 min.

Example 73. Design data of a triode type **PAK**, manufactured at the Laboratory.

Given conditions: the tube is to be used as an oscillator in a radio-telephone transmitter of 100 watt output, and also to be used as a modulator in the same transmitter. Anode voltage is up to 3,000 V (this is the rated voltage of a direct current generator installed at the Laboratory)

Design: working points on the dynamic characteristic diagram when operating as an oscillator:

$\frac{E_a+kE_g}{\bar{r}I_s}=0.30$ $\quad\frac{\mathfrak{I}_a}{I_s}=0.35$ $\quad\frac{\bar{R}}{\bar{r}}=1.2$

then $\frac{\varepsilon_a}{\bar{r}I_s}=0.42$ $\frac{I_a}{I_s}=0.31$ $\frac{P}{\bar{r}I_s^2}=0.074$

Taking $\frac{E_a}{\bar{r}I_s}=0.50$

$\frac{E_aI_a}{\bar{r}I_s^2}=0.155$ $\eta=0.48$

Equivalent alternating-current resistance of the oscillator against the modulator will be approximately

$$\mathfrak{R}_t=\frac{E_a}{I_a}.$$

or $$\frac{\mathfrak{R}_t}{\bar{r}}=\frac{E_a}{\bar{r}I_s}\Big/\frac{I_a}{I_s}=1.61$$

If, single tube is used as the modulator in the constant-current system of modulation, the working condition of the modulator will be

$$\frac{E_a}{\bar{r}I_s}=0.50 \qquad \frac{\mathfrak{R}_t}{\bar{r}}=1.61$$

In order that the modulation may be accomplished without distortion,

$\varepsilon_a<E_a$ and so $\frac{\vartheta_a}{I_s}<0.30$ and $\frac{E_a+kE_g}{\bar{r}I_s}>\frac{\vartheta_a}{I_s}$ at maximum amplitude.

Trying various values of the maximum allowable amplitude of anode current,

$\frac{\vartheta_a}{I_s}$	$\frac{E_a+kE_g}{\bar{r}I_s}$	$\frac{kE_g}{\bar{r}I_s}$	$\frac{k\varepsilon_g}{\bar{r}I_s}$	$\frac{\varepsilon_a}{\bar{r}I_s}$	Degree of Modulation $\fallingdotseq\varepsilon_a/E_a$
0.30	0.32	−0.18	0.78	0.48	0.96
0.25	0.27	−0.23	0.65	0.40	0.80
0.20	0.22	−0.28	0.52	0.32	0.64
0.15	0.17	−0.33	0.39	0.24	0.48
0.10	0.12	−0.38	0.26	0.16	0.32

The grid voltage must not be positive at any instant, so that

$$-E_g>\varepsilon_g \qquad \text{or} \qquad -\frac{kE_g}{\bar{r}I_s}>\frac{k\varepsilon_g}{\bar{r}I_s}$$

thus the amplitude of anode current must be limited to about 0.15 in the table and the distortionless limit of modulation is 50%.

Anode loss in this working condition is

$$\frac{W_a}{\bar{r}I_s^2}=\frac{E_a}{\bar{r}I_s}\cdot\frac{E_a+kE_g}{\bar{r}I_s}=0.50\times0.17=0.085 \qquad \left(\frac{I_a}{I_s}=\frac{E_a+kE_g}{\bar{r}I_s}\right)$$

If two tubes are used as the modulator, they can be replaced by single a tube of the following parameters in considering the operation:

saturation current $I_s'=2I_s$

anode impedance $\bar{r}'=\frac{1}{2}\bar{r}$

amplification constant $k'=k$

Then $\bar{r}'P=\bar{r}I_s \qquad \bar{r}'I_s'^2=2\bar{r}I_s^2$

and the working conditions are

anode voltage $\frac{E_a}{\bar{r}'I_s'}=\frac{E_a}{\bar{r}I_s}=0.50$

anode circuit impedance $\frac{\mathfrak{R}_t}{\bar{r}'}=\frac{2\mathfrak{R}_t}{\bar{r}}=3.22$

In order that there is no distortion,

$\varepsilon_a<E_a$ and $\frac{\vartheta_a}{I_s'}<0.15$ $\frac{E_a+k'E_g}{\bar{r}'I_s'}>\frac{\vartheta_a}{I_s'}$

Taking various amplitudes of anode current,

$\frac{\vartheta_a}{I_s'}$	$\frac{E_a+k'E_g}{\bar{r}'I_s'}$	$\frac{k'E_g}{\bar{r}'I_s'}$	$\frac{k'\varepsilon_g}{\bar{r}'I_s'}$	$\frac{\varepsilon_a}{\bar{r}'I_s'}$	Degree of Modulation
0.15	0.17	−0.33	0.63	0.48	0.96
0.12	0.14	−0.36	0.50	0.39	0.78
0.09	0.11	−0.39	0.33	0.29	0.58
0.06	0.08	−0.42	0.25	0.19	0.38

In order that $-E_g>\varepsilon_g$, $\frac{\vartheta_a}{I_s'}$ must be within about 0.10, which gives 64% as the maximum distortionless modulation obtainable.

Total anode loss, $\frac{W_a'}{\bar{r}'I_s'^2}=0.50\times0.12=0.06 \qquad W_a'=2W_a \qquad \bar{r}'I_s'^2=2\bar{r}I_s^2$

Anode loss per tube $\frac{W_a}{\bar{r}I_s^2}=0.06$

Thus compared with the single tube operation, the two-tube system gives 30% higher degree of distortionless modulation with 30% lower anode loss per tube.

The design is further proceeded as follows;

$$\frac{E_a}{\bar{r}I_s}=0.50 \quad \text{and} \quad E_a=3{,}000 \qquad \therefore \quad \bar{r}I_s=6{,}000$$

Considering effects of grid current, 20% higher value of power output is taken as the designing basis,

$P=120$ $\quad \frac{P}{\bar{r}I_s^2}=0.074$ $\quad \therefore\ \bar{r}I_s^2=1{,}620$

$I_s=\frac{\bar{r}I_s^2}{\bar{r}I_s}=0.27$ $\quad \bar{r}=22{,}000$

Design of the cathode:

assume $L=2{,}000$ and take 5 A tungsten filament which has a diameter of $d_f=0.0235$ or $r_f=0.0118$

From Chart II a, $\frac{e_f'}{l'}=0.97$ $\quad \frac{I_s}{l'}=0.025$ $\quad i_f=5.7$

and from Chart II c, $\Delta l=1.0$ $\quad \Delta e_f=1.05$

Filament is to be spanned in W-form, thus $m=5$

$I_s=0.27$ $\quad l'=I_s\Big/\left(\frac{I_s}{l'}\right)=10.8$ $\quad l=l'+m\Delta l=15.8$

$e_f'=\left(\frac{e_f'}{l'}\right)l'=10.5$ $\quad e_f=e_f'+m\Delta e_f=15.5$

Summarizing the filament data,

$l=16$ cm $\quad d_f=0.0235$ cm

$e_f=15.5$ V $\quad i_f=5.7$ A $\quad W_f=88$ W

Smallest value of x_g practically attainable being taken,

$x_g=0.3$ and $x_a=0.7$

Anode loss

$$W_a=0.081\,\bar{r}I_s^2=130\ \text{W}$$

Anode area required,

$$A=\frac{130+44}{5}=35\ \text{cm}^2$$

Taking a molybdenum plate of 3.5×4.5 cm. as the anode,

$$A=2\times3.5\times4.5=32\ \text{cm}^2$$

and $\quad G=2.33\times10^{-6}\times\frac{32}{0.7\times0.3}=0.35\times10^{-3}$

From equation (17),

$$(1+k)^3=G^3\bar{r}^3I_s=0.35\times10^6 \qquad k=69$$

Design of the grid:

$\log\frac{x_a}{x_g}=0.4$ $\quad c=1.7$ $\quad L_g=\frac{1.8}{p}$ $\quad \log\coth\pi a=\frac{L_g}{102}$

p	L_g	$\log\coth\pi a$	πa	d_g
0.08	23.5	0.23	0.63	0.018
0.10	18 8	0.18	0.79	0.025
0.11	17.1	0.17	0.84	0.030

Tungsten wire of the nearest diameter is $d_g=0.017$ and hence $p=0.08$

Working conditions of the tube are predicted as follows:

As an oscillator,

$E_a=3{,}000$ V $\quad P=100$ W

$R=1.2\,\bar{r}=26{,}500\ \omega$

$I_a=0.31\ I_s=0.084$ A

$E_aI_a=250$ W $\quad \eta=0.48$

As a modulator, single tube operation,

$E_a=3{,}000$ V $\quad I_a=0.17\ I_s=0.046$ A

$E_aI_a=140$ W $\quad E_g=-29$ V $\quad \xi_g\leqq 29$ V $\quad$ modulation $\leqq 50\,\%$

Ditto, two tube operation,

$E_a=3{,}000$ V $\quad I_a$ per tube $=0.032$ A

E_aI_a per tube $=96$ W $\quad E_g=-33$ V

$\xi_g\leqq 33$ V $\quad$ modulation $\leqq 65\,\%$

One of the tubes constructed at the Laboratory is shown in Fig. 77 (photograph facing page 158), of which the dimensions are shown in Fig. 78.

Test data: Characteristics were obtained as shown in Fig. 79.

Working test was made at the anode valtage $E_a=2{,}450$ V, the tube being operated in its full power:

$I_a=0.165$ A $\quad$ Input $E_aI_a=400$ W

Oscillatory current $\mathfrak{I}_0=4.7$ A $\quad$ Resistance $=11\ \omega$

Output $=250$ W $\quad$ Efficiency $\eta=0.62$

Wavelength $=1{,}400$ m.

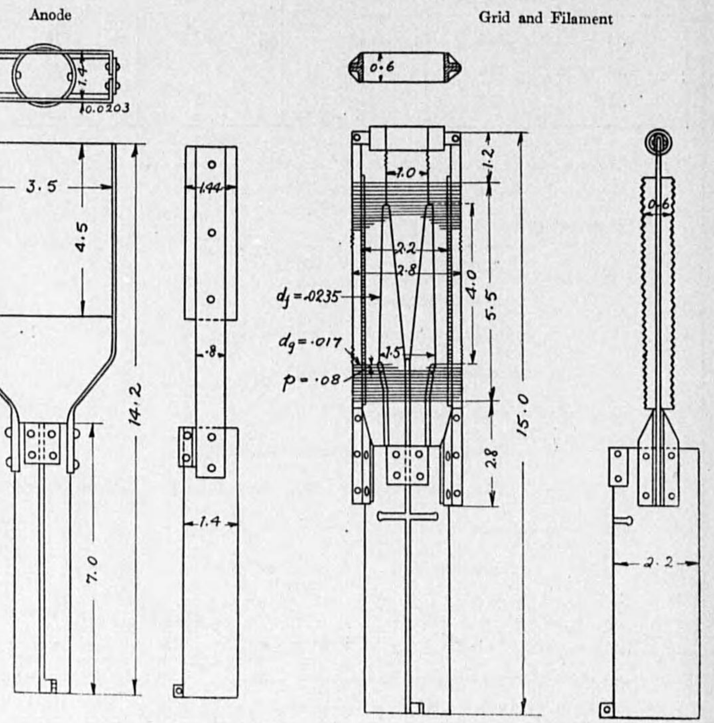


FIG. 78 (PAK)

When the tube is used as an oscillator in a radiophone transmitter, the working anode current must be lower than the above value so as to permit further increase in case of modulation. If 60% modulation is attained at peak oscillatory current of 4.7 A as in the above data, the carrier amplitude will be $\frac{4.7}{1.6}=2.9$ A and the power output $(2.9)^2\times 11=93$ W. If the anode voltage is raised up to 3,000 V, the power output over 100 W will be obtained.

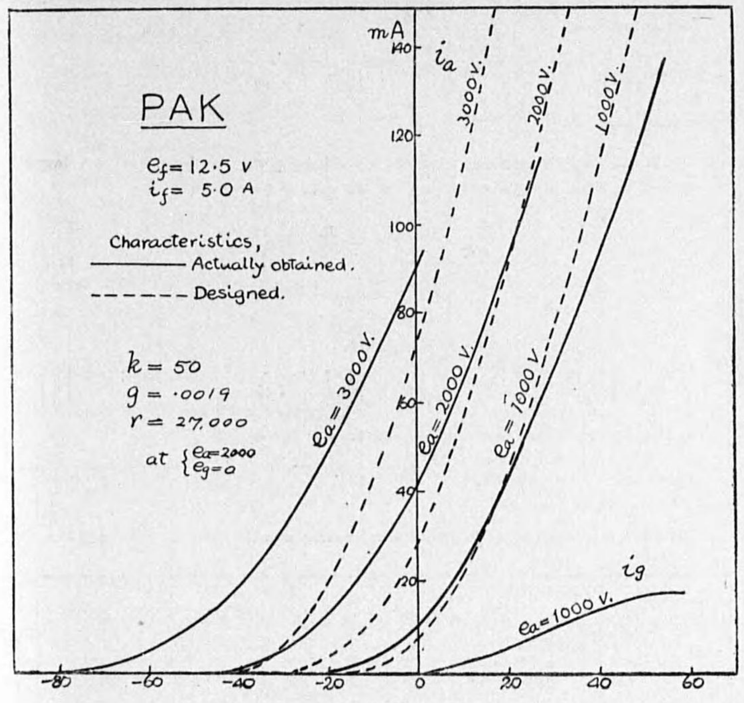


FIG. 79.

Example 74. Design data of a triode type **PBN**, manufactured at the Laboratory.

Given conditions: The tube is to be used as a radio-telephone power amplifier, modulated wave being impressed on the grid.

Output at the carrier amplitude, P=1 KW.

Anode voltage E_a=10,000 V.

Distortionless range of modulation, 80%.

Design: Linear amplification of radio-frequency amplitude is obtained at

$$\frac{E_a+kE_g}{rI_a}=0$$

Take $\frac{R}{\bar{r}}=1.0$ and let the 80 % modulated anode current reach $\frac{\vartheta_a'}{I_s}=0.50$, then at the carrier amplitude,

$$\frac{\vartheta_a}{I_s}=\frac{1}{1.8}\cdot\frac{\vartheta_a'}{I_s}=0.28 \qquad \frac{\varepsilon_a}{\bar{r}I_s}=\frac{\vartheta_a}{I_s}\cdot\frac{R}{\bar{r}}=0.28$$

$$\frac{I_a}{I_s}=0.18 \qquad \frac{P}{\bar{r}I_s^2}=0.039 \qquad P=1{,}000 \qquad \therefore\ \bar{r}I_s^2=25{,}600$$

In order that the maximum amplitude of oscillating power may be obtained at a favorable working condition, as explained on page 129, the value of k should be

$$k=\frac{\frac{k\varepsilon_g'}{\bar{r}I_s}+\frac{E_a+kE_g}{\bar{r}I_s}-\frac{E_a}{\bar{r}I_s}}{\frac{E_a}{\bar{r}I_s}-\frac{\varepsilon_a'}{\bar{r}I_s}} \qquad \text{. . . . . (22)}$$

and

$$k\geqq 10\,\frac{\nu\frac{k\varepsilon_g'}{\bar{r}I_s}-\mu\frac{kE_g}{\bar{r}I_s}}{\frac{E_aI_a'}{\bar{r}I_s^2}-\frac{P'}{\bar{r}I_s^2}} \qquad \text{. . . . . (23)}$$

working condition at the maximum amplitude being as follows,

$$\frac{\varepsilon_a'}{\bar{r}I_s}=0.50 \qquad \frac{k\varepsilon_g'}{\bar{r}I_s}=1.50 \qquad \frac{P'}{\bar{r}I_s^2}=0.125 \qquad \frac{I_a'}{I_s}=0.32$$

The values of k which meet the requirements will vary with the value of $\frac{E_a}{\bar{r}I_s}$ as follows:

$\frac{E_a}{\bar{r}I_s}$	Equation (22)			Equation (23)						
	Numerator	Denominator	k	$\frac{kE_g}{\bar{r}I_s}$	$-\frac{E_g}{\varepsilon_g}$	ν	μ	$\nu\frac{k\varepsilon_g'}{\bar{r}I_s}$	$\mu\frac{kE_g}{\bar{r}I_s}$	Limit of k
0.51	0.99	0.01	99	−0.51	0.34	.087	.097	.130	−.049	47
0.52	0.98	0.02	49	−0.52	0.34	.087	.097	.130	−.050	43
0.54	0.96	0.04	24	−0.54	0.36	.086	.095	.129	−.051	38

The results are plotted in Fig. 80, from which it is known that $\frac{E_a}{\bar{r}I_s}$ must be less than 0.523 and k be higher than 43.

Take $\frac{E_a}{\bar{r}I_s}=0.515$ then $k=67$

As $E_a=10{,}000$ $\bar{r}I_s=19{,}400$

$I_s=\frac{\bar{r}I_s^2}{\bar{r}I_s}=1.32$ $\bar{r}=14{,}700$

From equation (17)

$$G^2=\frac{(1+k)^3}{\bar{r}^3I_s}=7.53\times10^{-8}$$

$$G=0.274\times10^{-3}$$

Design of the cathode:

Let $I_s=1.4$ A

and take $L=5000$

and $r_f=0.0325$

(25 A tungsten filament)

From Chart II a,

$\frac{e_f'}{l'}=0.55$ $\frac{I_s}{l'}=0.08$ $i_f=27$

and from Chart IIc, $\Delta l=1.5$ $\Delta e_f=1.05$

Filament is to be spanned in V-shape, $m=3$

$l'=\frac{I_s}{\left(\frac{I_s}{l'}\right)}=17.5$ $l=l'+m\Delta l=22$

$e_f'=\left(\frac{e_f'}{l'}\right)l'=9.65$ $e_f=e_f'+m\Delta e_f=12.8$

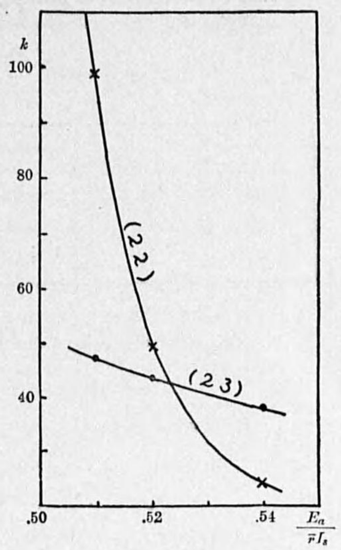


FIG. 80.

$W_f=460$

Water-cooled type is to be adopted, as the anode loss is rather high as 1.4 KW, and also for the convenience of using the tube at still higher power for other purposes.

Anode area required:

$$A>\frac{1400+460}{20}=92 \text{ cm}^2$$

Available copper tube has an inner diameter of 4 cm, so that $x_a=2.0$; and let $x_g=1.0$.

Actual area obtainable:

$$A=2\pi x_a\cdot\frac{l}{2}=138 \text{ cm}^2$$

Assume $z_a=1.7$ and $z_g=0.7$, as the filament is in V-shape.

Taking the above obtained value of A,

$$G=2.33\times10^{-6}\frac{A}{z_a^2z_g}=0.27\times10^{-3}$$

which is consistent with that previously derived from parameters.

Design of the grid: molybdenum wire mesh is to be used.

$$k=67 \qquad \log\frac{\pi a}{x_g}=0.301 \qquad L_g\fallingdotseq\frac{4\pi x_g}{p}=\frac{12.6}{p} \qquad \log\coth\pi a=\frac{L_g}{67}\times 0.301$$

p	L_g	$\log\coth\pi a$	πa	r_g	d_g
0.2	63	0.283	0.58	0.0092	0.018
0.3	42	0.189	0.77	0.018	0.036
0.4	31	0.141	0.91	0.029	0.058

Nearest available mesh of $p=0.3$ and $d_g=0.030$ is to be used.

Working conditions predicted from the design data:

$$\bar{r}=14{,}700 \qquad I_s=1.32 \qquad \bar{r}I_s=19{,}400 \qquad \bar{r}I_s^2=25{,}600$$

At the carrier amplitude, i. e. when not modulated:

Power input	$E_aI_a=0.515\times 0.18\times 25{,}600=2{,}370$ W
Power output	$P=1{,}000$ W
Efficiency	$\eta=0.42$ Loss$=1{,}370$ W
Anode currents	$\mathfrak{I}_a=0.28\times 1.32=0.37$ A $\quad I_a=0.18\times 1.32=0.24$ A
Grid excitation	$k\mathfrak{E}_g=0.85\times 19{,}400=16{,}500$ $\quad \mathfrak{E}_g=246$ V
Grid bias voltage	$kE_g=-E_a=-10{,}000$ $\quad E_g=-150$ V

At the maximum amplitude of modulated wave amplification, or on the full-power working condition:

Power input	$E_aI_a'=0.515\times 0.32\times 25{,}600=4{,}200$ W
Power output	$P'=0.125\times 25{,}600=3{,}200$ W
Efficiency	$\eta=0.76$ Loss$=1{,}000$ W
Anode currents	$\mathfrak{I}_a'=0.50\times 1.32=0.66$ A $\quad I_a=0.32\times 1.32=0.42$ A

A tube actually constructed is shown in Fig. 81 (photograph facing page 158), its dimensions being shown in Fig. 82.

Test data: Static characteristics actually obtained are shown in Fig. 83, together with those predicted from the design data.

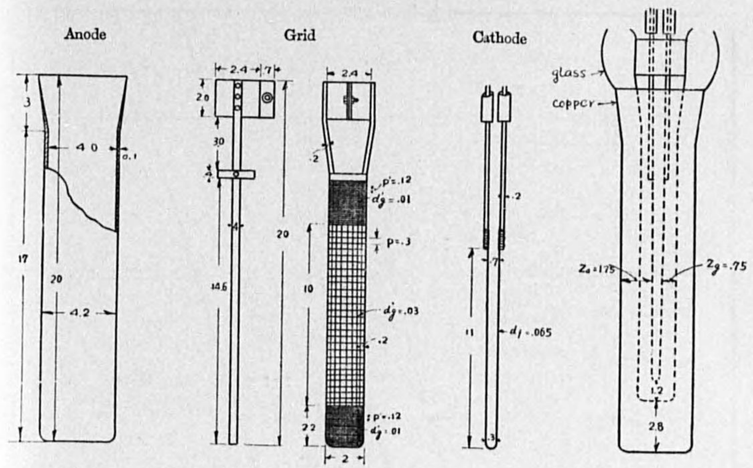


FIG. 82. (PBN)

Working test; the tube was operated as a self-oscillator and adjusted to give full power, the result was as follows:

Filament,	$e_f=13.2$ V	$i_f=24.7$ A
Power input,	$E_a=9{,}600$ V	$I_a=0.52$ A
	$E_aI_a=5{,}000$ W	
Power output,	oscillatory current	$\mathfrak{I}_0=31.6$ A eff.
	resistance	$R=3\omega$
	$P=3{,}000$ W	
Efficiency	$\eta=0.60$	
Grid current	$I_g=0.035$ A	
Grid leak	$R_g=20{,}000\ \omega$	$E_g=-700$ V

The tube has not yet been submitted to its proper use, but the charcteristics actually obtained show that it meets the requirements for a radiophone power amplifier giving the rated power output.

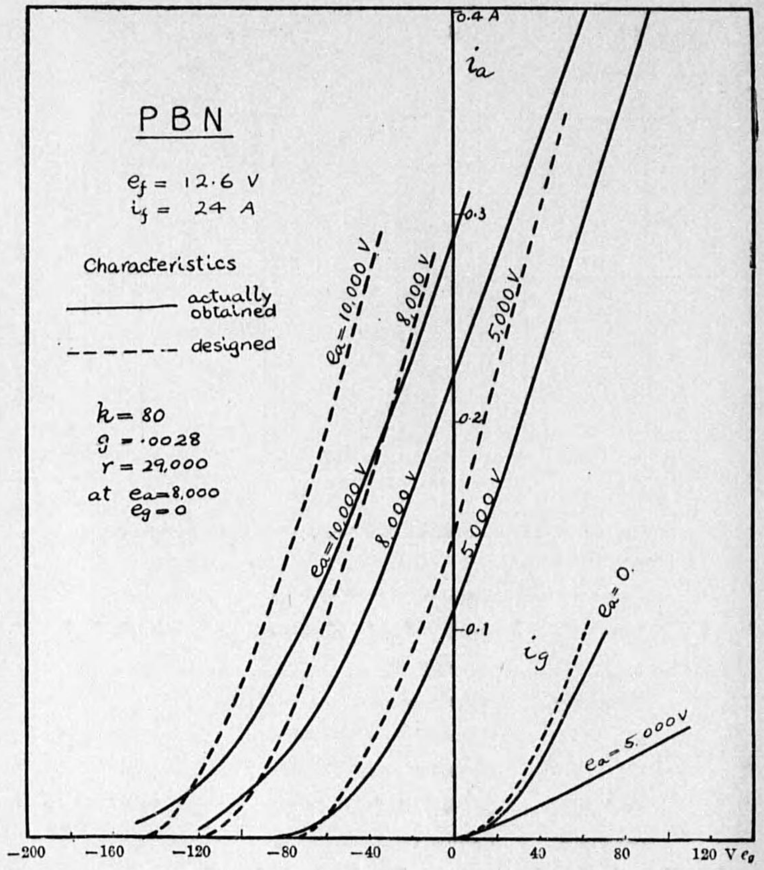


FIG. 83.

SUMMARY.

(1) Calculations on Vacuum Tubes.

A. Diode characteristics:

$$i_a = G e_a^{\frac{3}{2}} \qquad \text{for} \quad e_f = 0 \quad \text{or} \quad e_a \gg e_f$$

$$i_a = \frac{2}{5} G e_f^{\frac{3}{2}} \cdot f\left(\frac{e_a}{e_f}\right) \qquad \text{(TABLE I)}$$

$$G = 2.33 \times 10^{-6} \frac{A}{x_a^2}$$

B. Triode characteristics:

$$i = i_a + i_g = \frac{2}{5} G e_f^{\frac{3}{2}} \cdot f\left(\frac{e_g'}{e_f}\right) \qquad \text{(TABLE I)}$$

$$e_g' = \frac{e_a + k e_g}{1+k}$$

$$G = 2.33 \times 10^{-6} \frac{A}{z_a z_g}$$

$$e_g < 0: \quad i_a = i$$

$$e_a \gg e_g > 0: \quad i_a = \frac{i}{1 + 1.5\, a \sqrt{\frac{e_g}{e_a}}}$$

C. Triode parameters:

$$k = \frac{c L_g \log \frac{x_a}{x_g}}{\log \coth \pi a} \qquad \text{(TABLES II, III \& IV)}$$

$$g = 1.5\, G \frac{k}{1+k} \left(\sqrt{e_g'} - \frac{1}{4} \cdot \frac{e_f}{\sqrt{e_g'}} \right)$$

$$r=\frac{k}{g}$$

$$(1+k)^{\frac{1}{2}}=G^{\frac{1}{2}}\bar{r}^{\frac{1}{2}}I_s$$

D. Saturation current I_s is calculated by CHART II for a tungsten filament.

E. Operating conditions are determined by the dynamic characteristic diagram shown in CHART I.

TABLE I

$\frac{e_g'}{e_f}$	$f\left(\frac{e_g'}{e_f}\right)$
0	0
0.25	0.031
0.50	0.177
0.75	0.414
1.00	1.00
1.5	2.57
2.0	4.65
2.5	7.13
3.0	9.94
4.0	16.51
5.0	24.1
6.0	32.5
8.0	53.0
10	74.0
15	138
20	211
40	622
$\frac{e_a}{e_f}$	$f\left(\frac{e_a}{e_f}\right)$

TABLE II

Values of c

Cylindrical-electrode tubes; $c=1$		
Plane-electrode tubes, grid of a mesh; $c=1$		
Plane-electrode tubes, grid of parallel wires;		
$\frac{x_a}{x_g}$	c	
	Filament	
	W-shaped	V-shaped
1	1.0	1.0
2	1.5	1.3
3	1.9	1.6
4	2.4	1.9
5	2.8	2.1

TABLE III

Grid construction	L_g	πa
Wires parallel to the filament	n	$\frac{nd_g}{2x_g}$ or $\frac{L_g r_g}{x_g}$
Parallel wires or spiral, no support	$\frac{2\pi x_g}{p}$	$\frac{\pi d_g}{p}$ or $\frac{L_g r_g}{x_g}$
Ditto, with supports in the stream of electron	$\frac{2\pi x_g}{p}+s\left(1-\frac{t}{p}\right)$	$\frac{(L_g-s)d_g+st}{2x_g}$
Square mesh, with or without support	$\frac{4\pi x_g}{p}\left(1-\frac{r_g}{p}\right)$	$\frac{\pi d_g}{p}\left(2-\frac{d_g}{p}\right)$ or $\frac{L_g r_g}{x_g}$
These are equally applicable to tubes of cylindrical or plane electrodes.		

TABLE IV

πa	log coth πa	Difference per 0.01 of πa
0.10	1.002	
		29,
0.20	0.714	
		17,
0.30	0.542	
		12,2
0.40	0.420	
		8,5
0.50	0.335	
		6,6
0.60	0.269	
		5,1
0.70	0.218	
		4,0
0.80	0.178	
		3,0
0.90	0.145	
		2,7
1.00	0.118	
		2,2
1.10	0.096	
		1,6
1.20	0.080	
		1,5
1.30	0.065	

(2) The Design of a Triode.

Design procedure;

1) The working points are determined on the dynamic characteristic diagram, CHART I, so as to satisfy the specified working conditions. (Refer to the table on page 126.)

The following quantites will then be determined:—

$$a=\frac{P}{\bar{r}I_s^2},\quad \frac{\mathfrak{E}_a}{\bar{r}I_s},\quad \frac{\mathfrak{I}_a}{I_s},\quad \frac{I_a}{I_s},\quad \frac{k\mathfrak{E}_g}{\bar{r}I_s},$$

$$\frac{E_a+kE_g}{\bar{r}I_s},\quad \frac{\mathfrak{R}}{\bar{r}}.$$

Approximately determined:—

$$\frac{E_a}{\bar{r}I_s},\quad \frac{E_aI_a}{\bar{r}I_s^2},\quad \eta,\quad \frac{kE_g}{\bar{r}I_s}.$$

2) If power output P is given, $\bar{r}I_s^2$ is known; $\bar{r}I_s^2$ is then split into $\bar{r}I_s$ and I_s, considering the practicable limits of E_a, $\mathfrak{R}$, W_f, etc. as well as economical conditions.

3) A value of G being assumed (refer to the table on page 128), k is known from

$$(1+k)^3=\left(\frac{G\alpha}{P}\right)^2(\bar{r}I_s)^5 \quad \text{or} \quad (1+k)^3=G^2\bar{r}^3I_s.$$

At a full-power working condition of power amplifier or oscillator, the following relations should be considered for the evaluation of k;

$$k=\frac{\frac{k\mathfrak{E}_g}{\bar{r}I_s}+\frac{E_a+kE_g}{\bar{r}I_s}-\frac{E_a}{\bar{r}I_s}}{\frac{E_a}{\bar{r}I_s}-\frac{\mathfrak{E}_a}{\bar{r}I_s}}$$

and

$$k\geqq 10\frac{\nu\frac{k\mathfrak{E}_g}{\bar{r}I}-\mu\frac{kE_g}{\bar{r}I_s}}{\frac{E_aI_a}{\bar{r}I_s^2}-\frac{P}{\bar{r}I_s^2}}$$

in which ν and μ are given in Fig. 69 on page 130.

Calculations have to be tried for several values of k or G, and the most favorable one be selected among them.

4) Dimensions of the Electrodes.

a) Effective anode area

$$A\geqq\frac{W_a+qW_f}{w}$$ (Refer to page 132)

b) Distance between electrodes must satisfy the relations:

$$x_g\doteqdot 0.4\ x_a$$

$$G=2.33\times10^{-6}\frac{A}{z_a^2z_g}$$

c) Grid construction is determined by

$$\frac{k}{\log\frac{x_a}{x_g}}=\frac{cI_g}{\log\coth\pi a}$$

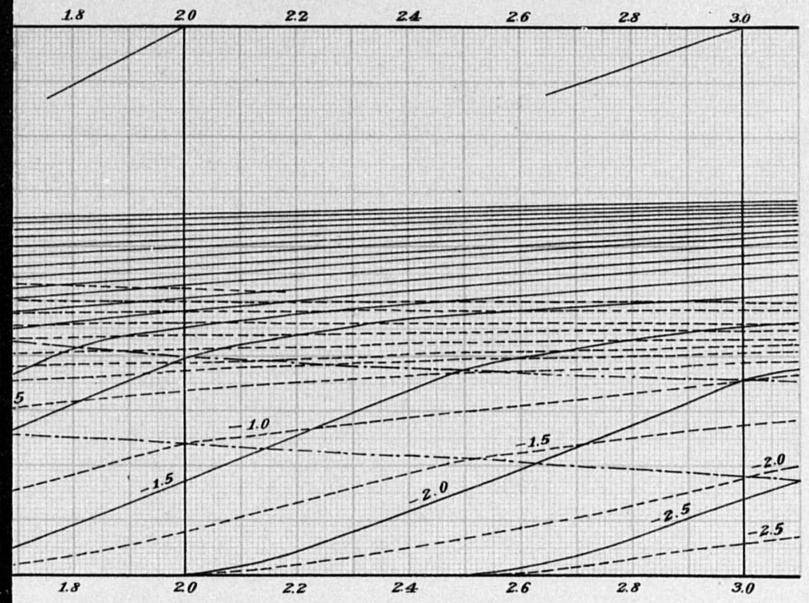
(Refer to the table on page 134 and TABLES II, III and IV)

p, d_g, etc. are finally determined.

d) Cathode is designed by means of CHART II for tungsten giving a slightly higher value for I_s than required.

The design procedure as shown above is for a typical case, and alterations will be needed according to the specified conditions.

——(the end)——


1.8
2.0
2.2
2.4
2.6
2.8
3.0
.5
1.0
1.5
2.0
2.5

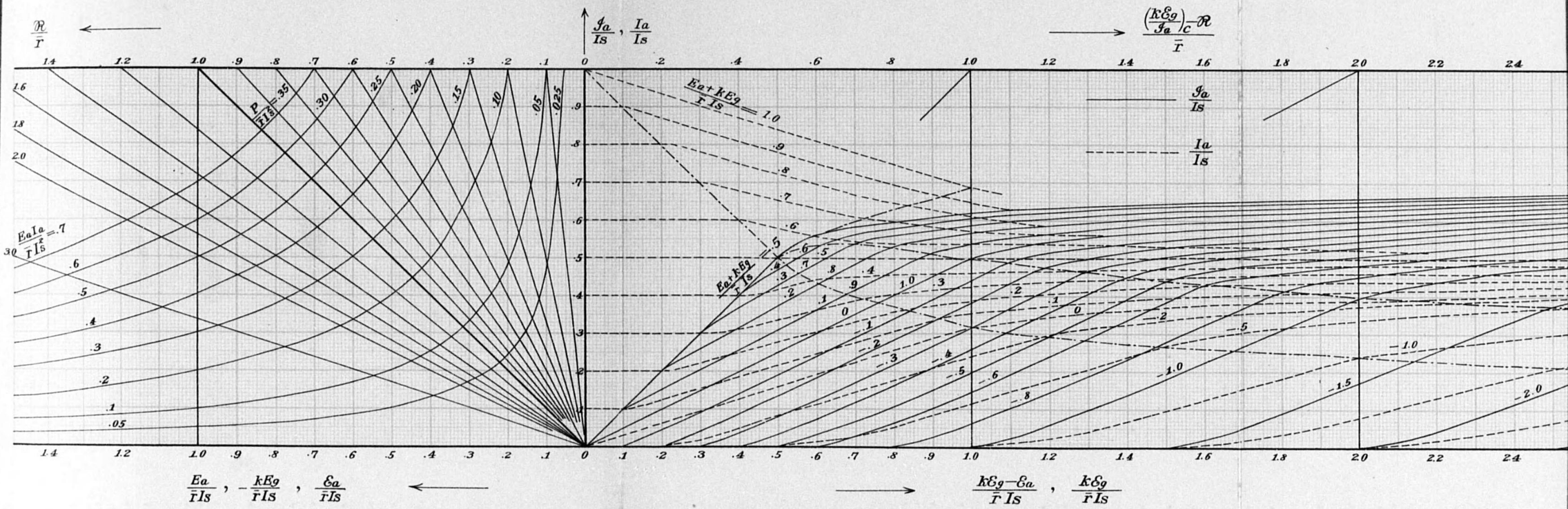


CHART I. DYNAMIC CHARACTERISTIC DIAGRAM

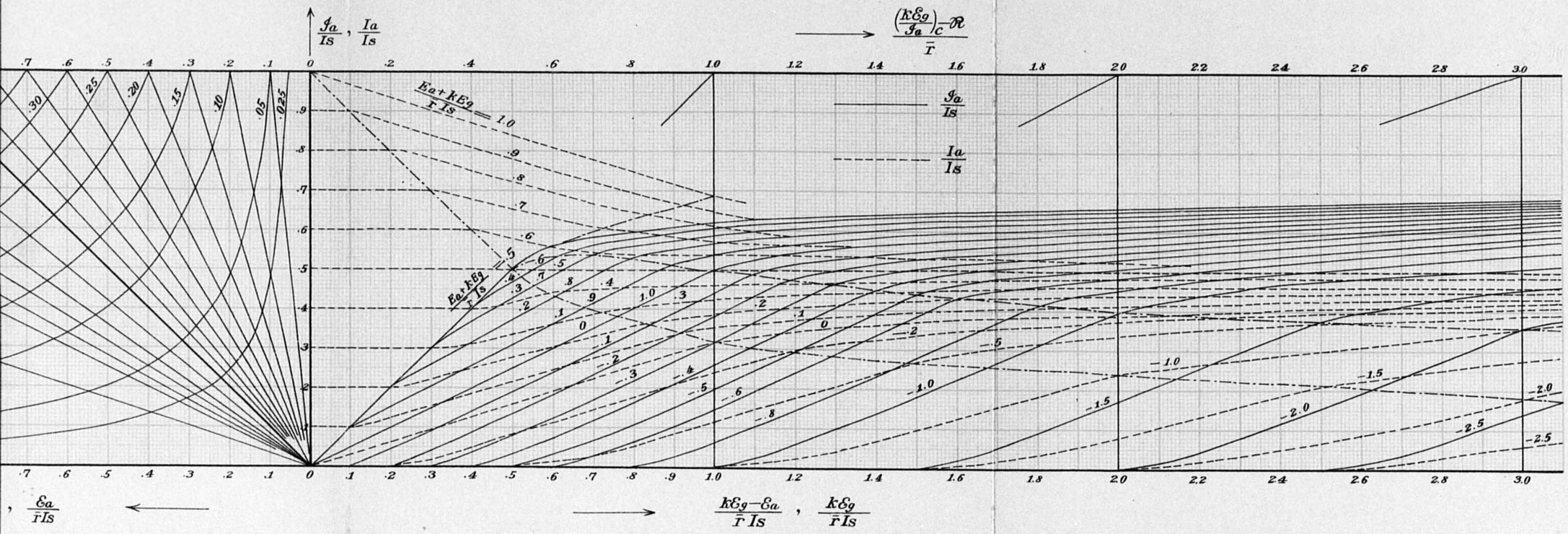
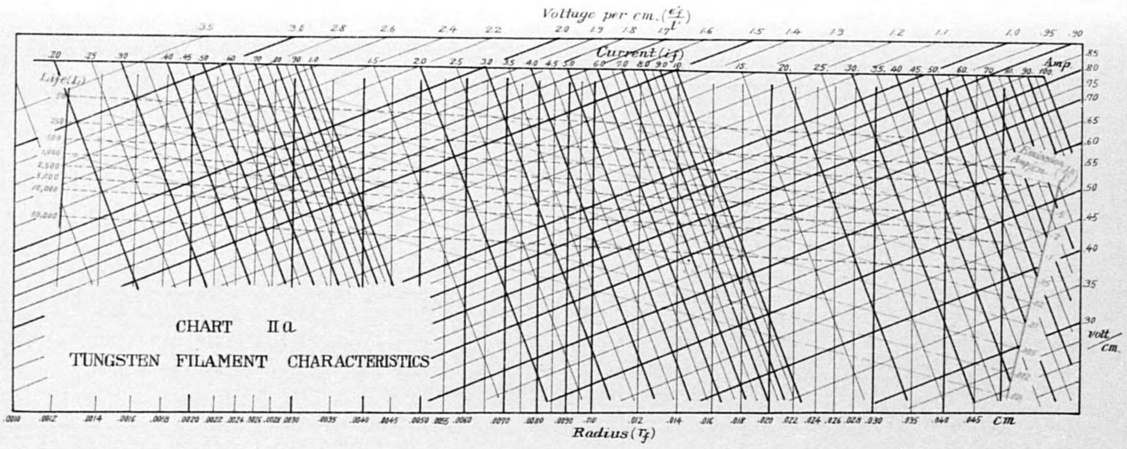
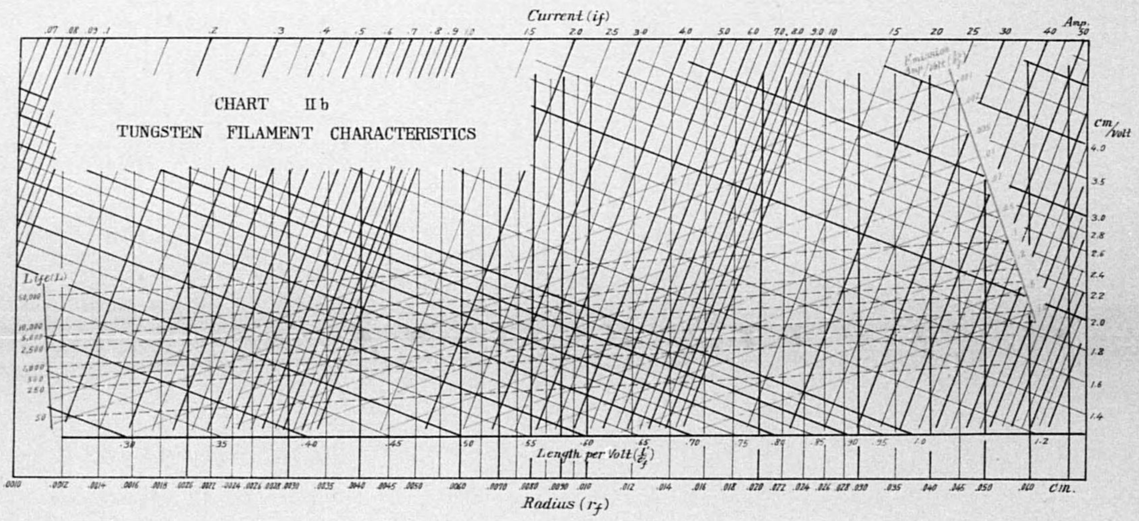
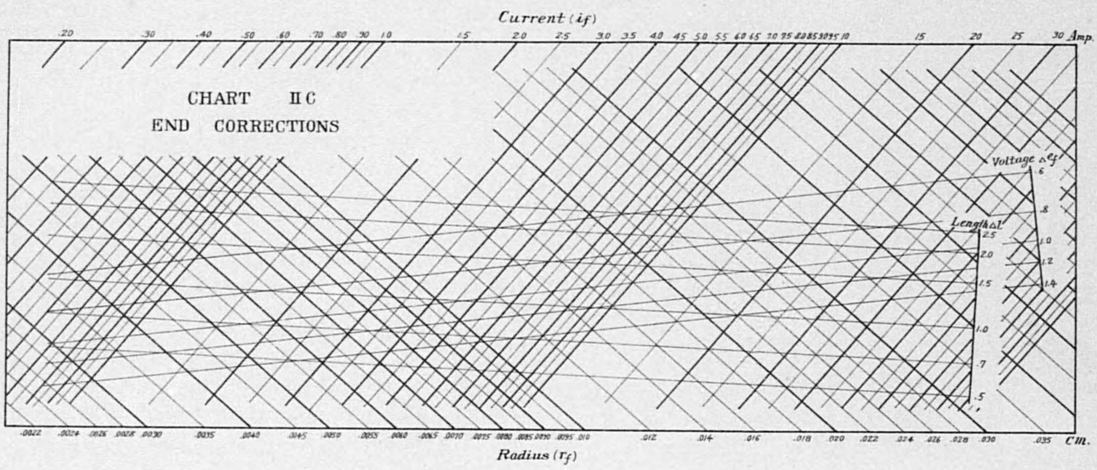


CHART I. DYNAMIC CHARACTERISTIC DIAGRAM


Voltage per cm. (e_f)
Current (i_f)
Life (L)
Amp
volt / cm.
CHART IIa
TUNGSTEN FILAMENT CHARACTERISTICS
Radius (r_f)
Cm.


Current (i_f)
Amp.
cm. / volt
Life (L)
CHART IIb
TUNGSTEN FILAMENT CHARACTERISTICS
Length per Volt ($\frac{L}{e_f}$)
Radius (r_f)
Cm.

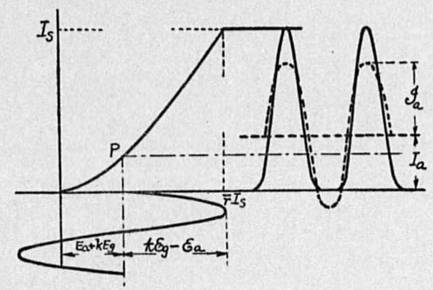

Current (i_f)
Amp.
CHART IIC
END CORRECTIONS
Voltage e_f
Length L
Radius (r_f)
Cm.

APPENDIX

After this paper had been put to press, the writer worked out the dynamic characteristic diagram in a more rigorous way than described in the text.

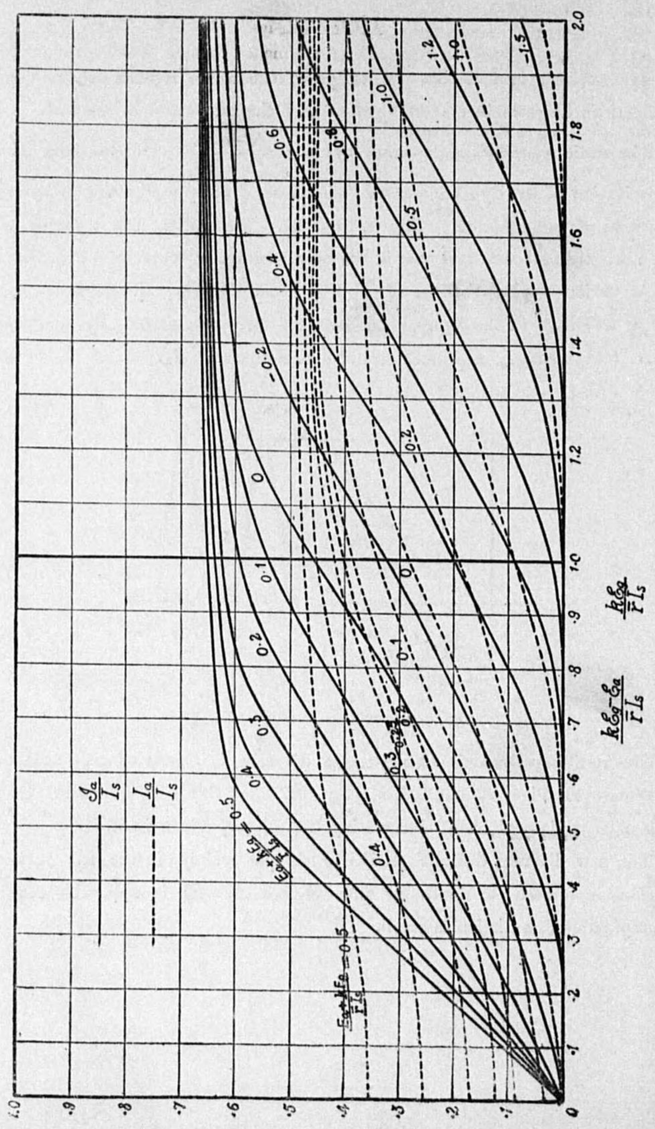
The static charactristic expressed by $\frac{i_a}{I_s}=\left(\frac{e_a+ke_g}{\bar{r}I_s}\right)^{\frac{3}{2}}$ bas been taken for the derivation of the dynamic charactristics, instead of approximating it by a linear relation as given in equation (18) on page 91. Saturation was assumed to take place abruptly as before and this is the only assumption which still remains.

At various applied voltages of E_a+kE_g and $k\mathfrak{E}_g-\mathfrak{E}_a$ the anode current was depicted as shown in the figure, and its wave form was graphically analyzed into its d. c. component I_a and fundamental a. c. component $\mathfrak{I}_a$.



The resulting dynamic characteristic diagram is shown on next page, which co responds to Figs. 42 and 43 on page 102, and it is recommended that this diagram be used in CHART I replacing that already given in it.

The new diagram differs from the former one mainly in the left part of it, and gives more accurate results for d. c. component, and is applicable even when the amplitude of oscillation is small.



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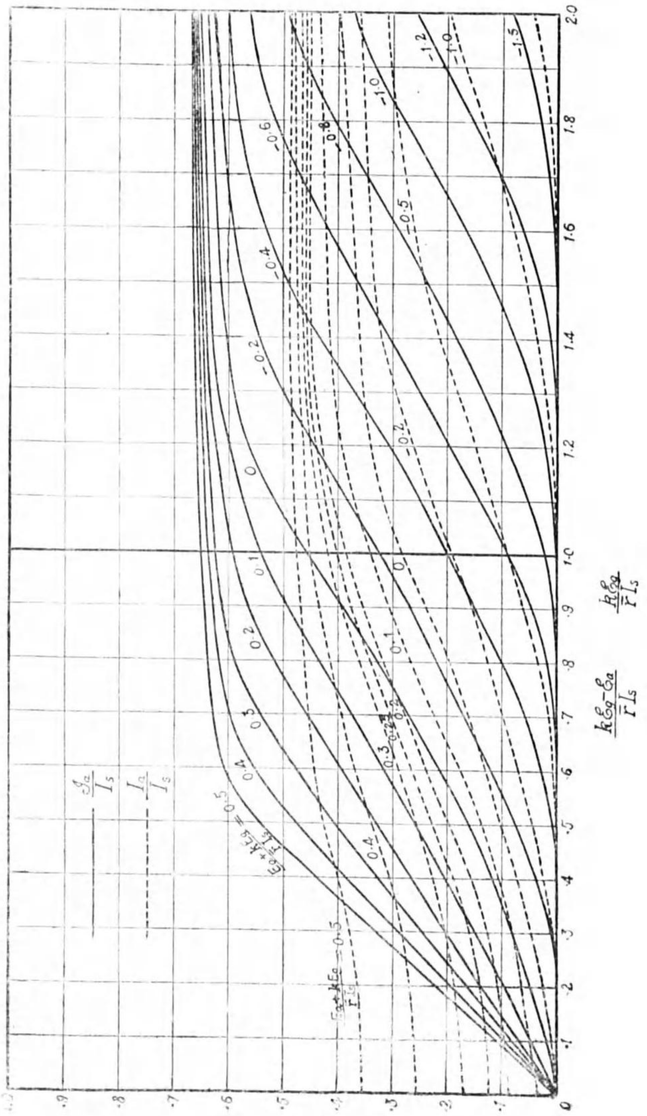

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