REPORT

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Yue Chor Fong for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

H. M. Turner
Chairman

Geo. W. S. Shepardson

W. E. Brooke

L. W. McKeehan

May 31, 1917

REPORT

of

COMMITTEE ON EXAMINATION

This is to certify that we the undersigned, as a Committee of the Graduate School, have given Yue Chor Fong final oral examination for the degree of Master of Science. We recommend that the degree of Master of Science be conferred upon the candidate.

Minneapolis, Minnesota

May 31, 1917

H. M. Turner
Chairman

Geo D Shepardson

W E Brooke

L W McKeehan

A STUDY OF THE OPERATING CHARACTERISTICS OF THE AUDION

A Thesis Submitted to the

Faculty of the Graduate School of the

University of Minnesota

by

YUE CHOR FONG

(In Collaboration with Nathaniel R. Mori)

In Partial Fulfillment of the Requirements

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CONTENTS

ACKNOWLEDGEMENT.

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SYMBOLS USED.

I_w indicates current that flows in the wing circuit.

E_{wf} indicates the voltage between wing and the filament.

E_{gf} the voltage applied to the grid and filament.

I_f indicates filament current.

INTRODUCTION.

Since the outbreak of the world war, radio signaling has become of paramount importance as a means of directing forces on land and sea. It is the only means by which isolated nations can communicate with other countries today.

The radio signaling system can be divided into two sets of apparatus, one for sending and the other for receiving. The sending station equipment consists of a generator, with its accessary apparatus, an elevated system of wires called antenna. The receiving station equipment consists of antenna, various induction coils, condensers, a receiver and a detector.

A simple damped wave receiving station set-up is shown in the Diagram I. The incoming oscillations which reach this antenna circuit are of too high frequency to affect the telephone receiver directly. Therefore the function of the condensers and the audion in this circuit is to group several grid circuit wave oscillations into a single low-frequency telephone current. There are two ways of doing this; one is by the use of the rectifying property of the audion, and the other is by the use of the non-linear operating characteristic of the audion in connection with condensers. In the circuit shown in Diagram I, probably both actions are going on simultaneously.

An audion is a small incandescent lamp bulb with a tungsten filament. In parallel with this filament there are one or two metal plates. Between filament and plate there is a coarse grid-shaped wire. A tube type of audion has grid and wing of cylindrical form, mounted concentrically with the filament. Although audions of various types are used by the thousands at present, few articles have been written on their characteristics. While many scientists have studied the emission of electricity from hot plates, and developed elaborate formulae applicable to the special conditions of their experiments, little work along this line has been done on the commercial tube known as the audion. In order to study the operating characteristics of the audion, an analytical study of it was made from an engineering point of view.

OUTLINE OF WORK.

I. CALIBRATION OF INSTRUMENT.

II. VARIATION OF WING CURRENT, I_w:

With wing-filament potential, E_{wf} (Filament current, I_f and grid-filament potential E_{gf}, remaining constant).

With grid-filament potential, E_{gf}. (I_f and E_{wf} remaining constant).

With filament current, I_f. (E_{wf} and E_{gf} remaining constant).

III. COMPARISON OF GENERAL CHARACTERISTICS OF DIFFERENT AUDIONS.

(Repetition of tests II.)

IV. AUDIONS OPERATED IN PARALLEL.

Two lamps in parallel

Four lamps in parallel

(Repetition of tests II.)

V. VARIATION OF WING CURRENT.

With change of direction filament current.

(Repetition of tests II.)

AUDIONS TESTED.

Lamps Nos. 1 and 2 (Standard or S-grade Audions).

Lamps Nos. 3 and 4 (Extrasensitive or X-grade Audions).

Four of the Ultra Audion type.

EQUIPMENT USED.

AMMETERS:

Weston direct current ammeter, 0-5.

Weston direct current ammeter, 0-5.

VOLTMETERS:

Weston direct current voltmeter, 0-1.

Weston direct current voltmeter, 0-1.

Weston alternate current voltmeter, 0-150.

Weston alternate current voltmeter, 0-75.

Kelvin static voltmeter, 20-80.

BATTERIES:

9 Exide storage battery, rating 20 volts.

8 Edison storage battery, rating 12 volts.

36 Eveready Tungsten dry cells, rating 48 volts.

12 Eveready Tungsten dry cells, rating 16 volts.

CONDENSERS:

3 Murdock Variable Condensers Type No. 366. (Capacities 0,0005 microfarads each).

1 Blitzen Rotary Variable Condenser, Type No.W775. (Capacity 0,0008 microfarads).

2 General Radio Variable Air Condensers, Type No. 124A (Capacities 0,0008 microfarads).

RESISTANCE:

4 Ten-ohm coils, Lab. Nos. 1480 to 1485.

MISCELLANEOUS:

Kolster Decremeter, Type C, No. 100.

De Forest Amplifier, No. 45217.

Cambridge Tuner, No. W 610.

Clapp Eastman X type coil, No. W 773.

General Electric Oscillograph, No. 91114.

De Forest Radio Telephone Generator.

(2 kw., 110 volts, 2500 R. P. M., 3000 Cycles).

Westinghouse, D. C. Motor, No. 40, Type S. K.

Potential Auto Transformer.

Holtzer Cabot Receiver, 3000 ohms.

PROCEDURE.

CALIBRATION OF INSTRUMENTS.

Since the magnitude of the wing current was of the order of micro-amperes, ordinary laboratory instruments could not be used. Two millivoltmeters were calibrated and used as milli-ammeters.

The alternating electromotive force applied to the grid and filament was often less than four or five volts. These voltages were obtained by means of the calibrated auto transformer, stepping down from 110 volts.

Later when using De. Forest Radio generator. only electro-static or hot wire instruments could be used on account of the high frequency.

A low voltage was again encountered. The use of low reading direct current voltmeter with a condenser in shunt was thought to be only means to meet this situation.

VARIATION OF WING CURRENT.

The audion was connected up as shown in the Diagram II.

The relations among various factors E_{gf}, E_{wf}, I_f were studied as outlined above.

The General Electric oscillograph did not respond to the wing current from one audion, so later on four ultra-audions were connected in parallel as shown in Diagram III. The electromotive force for the grid was obtained from a De Forest telephone generator running about 1000 cycles per second. The reason why the generator was driven at lower than rated frequency was to operate the moving element of the oscillograph below its natural period of frequency and also to cut down the noise of the generator.

Investigation of the relation between the wing current and the direction of the filament current was suggested from the operation of the De Forest Audion Receiver Set in the Radio Laboratory of the Electrical Engineering Department. In the operation of this set considerable differences in pitch and intensity of received signal were observed when the direction of filament current was changed by means of a double throw switch. (p. 14)

DISCUSSION OF CURVES.

VARIATION OF WING CURRENT WITH WING FILAMENT POTENTIAL.

The relation between the wing current and wing filament potential are shown by the curves 1 to 5 and 12 to 15. In the audion, as well as in similar apparatus, Ohm's law does not hold true, but the flow of current depends upon various factors, such as applied potential, gas pressure, radius of cylinder, radius of wire and temperature.*

For the sake of comparison, some of the results obtained by Wilson are plotted on curve sheets I. The comparison of this with others show similarity of character, except a few curves on the Curve Sheets 4 and 5.

Curves 2, 3, 12 and 14 shows more clearly that at lower voltage the current is independent of the wing and filament potential. According to the authors Pawlow** E. v. Bahr, and J. Franck*** these phenomena can be explained by the fact that ionization at lower potential is not so intense as at higher potential.

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* H. A. Wilson, Phil. Tran. Vol. CCII, p. 243 (1903) O. W. Richardson, Emission of Electricity from Hot Bodies (p. 23 - 24).

** Pawlow, Royal Soc. Proc. A. Vol XC. p 398 (1914)

*** Bahr and Franck, Verh. d. Deut. Phys. Ges. vol. XII. p. 79, (1914) consequently the wing current is small at lower values of wing-filament potential.

A few words may be said here concerning the irregularity of Curves 4, 5 and some others, compared with the other curves of the same lamp operated under apparently the same condition. The reason is that while taking data for Curves 4, 5, 9, 10 and 11 the steady value of wing current was taken; on the other hand, for the Curve 1 to 3 an instantaneous value of wing current was recorded. When the wing-filament potential was increased beyond a certain value the blue glow appears and the momentary wing current is very great, but after this discharge takes place once or twice the wing current becomes smaller and steady. The point at which the blue glow occurs is called the critical point.

The Curves 4 and 5 have saturation points. Langmuir* names this "space charge effect" and explains that when a given potential difference between a plate and a hot body is reached the number of electrons that are transmitted can not be increased further on account of saturation. He points out that this space charge effect is absent when the conditions are ideal, and the current follows Richardson's thermionic equation.**

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* Langmuir Phys. Rev. ser. 2 vol. II, p 450, (1913)
** Pawlow, Royal Soc. Proc. A Vol. XC. p. 398. (1914)

Curves 6 to 11 show the relation between wing current and grid potential. Curves 6 to 8 show the characteristics of S-grade audions and the Curves 9 to 11, those of X-grade. On account of the fact that the S-grade audions were burned out and could not be replaced, few curves were obtained. However, the results show that in most cases wing current increases with the increase of impressed voltage up to a certain point, then it decreases and approaches a constant value. In the operation of an audion the variation of wing current is of more importance than its magnitude; for the operation of telephone receiver depends upon the variation of current strength. Looking from this point of view, Lamp 3 can be most effectively operated when E_{gf} is between twenty and twenty-five volts, and when E_{wf} is at twenty-five volts (see Curve 10) while the Lamp 4 can be used to the best advantage when E_{gf} is between thirty and forty volts, and when E_{wf} is thirty-five volts.

The reason why the wing current increases up to the saturation points, and then decreases as shown by Curves 6 to 11, can be explained as follows: when E_{gf} voltage is increased, the current flowing in the grid will produce a magnetic field of such value as will facilitate the passage of electrons from filament to wing. But if the voltage is increased beyond a certain point this field becomes too strong and impedes the free passage of electrons and consequently the current decreases.

Edwin H. Armstrong* states that "the amplitude of the variation in the wing current is directly dependent on the variation of the grid potential. This indicates that the grid circuit should be made up of large inductance and small capacities to obtain the maximum voltage which it is possible to impress on grid."

Our results show conclusively that this increase of applied voltage on the grid can be carried too far. From the Curves 9 - 11 it is evident that the voltage should not exceed forty volts.

Curves 16 and 17 show the relation between wing current and filament current, that is, filament temperature. Investigations of the temperature variation on the electronic emission on various substances under different conditions have been conducted by scores of scientists. Tungsten, which is used in audions, was studied by Langmuir** and by K. K. Smith***. These two men made qualitative and extended investigations. No matter what substances are used, all agree in the general character of the rate of electronic emission. In all cases they found that the rate of emission of electrons increased with enormous rapidity as the temperature increased. The great rapidity with which the wing current increases is shown by the Curves 16 and 17.

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* Armstrong, Proc. Inst. Rad. Eng. Vol. 3 No. 3, 1915, p. 220

** Langmuir, Phys. Rev., Vol. II, p. 450, (1913)

*** Smith, Phil. Mag., Vol. XXIX, p. 811, (1915)

COMPARISON OF GENERAL CHARACTERISTICS OF DIFFERENT LAMPS.

Curves 12, 13 and 14 show the general characteristics of different lamps. Curve 12 shows very clearly that at voltages below the critical point the characteristics are not much different, but beyond that point they differ. Even a given lamp at different times, apparently operating under the same condition, may not follow the same curve exactly. In general, it may be said that all lamps tested show similar characteristics, (c. f. Proc. I. R. E. Vol. III, No. 3, 1915, Section on Discussion).

FOUR AUDIONS OPERATED IN PARALLEL.

The experiments on this subject showed nothing new, since the total wing current was the sum of individual wing currents. From the engineering point of view the parallel operation is inefficient when two or more lamps of different characteristics are used, for the resulting current necessarily has a smaller variation than in the case of an individual lamp operating at its most favorable point.

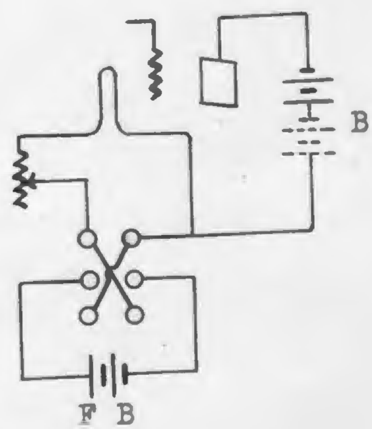
Four ultra audions were connected in parallel in taking oscillograms. Oscillograms Curves 18 and 19 show the grid and wing-voltage, wing and grid-currants. The wing current curve shows that the wing current is composed of alternating current and direct current.

From this curve it is clear that the audion does not act entirely like the mercury rectifier, but it allows both waves of alternating current to pass. Therefore it also may be used as a repeator of radio frequency oscillations, that is, as a repeating relay.

VARIATION OF WING CURRENT WITH THE CHANGE OF DIRECTION OF FILAMENT CURRENT.

In the connection shown in Diagram II the filament current flowing in one direction caused a greater wing current than when in the other direction, but when all the factors which affect the filament current when the switch position is changed are entirely eliminated then the wing current did not change according to position of the switch.

The partial diagram of De Forest audion Set is shown:



From the above diagram it is evident that the relative position of B battery and F B battery is changed when the switch is changed, therefore, the change of the position of the switch will change the potential of the wing.

CONCLUSION.

The curves herewith presented show the relation existing among the various mutually dependent factors. The independent variable in each case was purposely varied through wide limits in order to bring out more clearly the relation.

A slight increase in the filament current causes a marked increase in wing current; however, if the filament is operated at too high a temperature, its life will be very much decreased. On account of the fact that the critical point occurs at lower values of wing-filament potential, when operated at high temperature, it is usually not possible to adjust the wing-filament battery to its best value. The slope of the curve increases with increase of filament current, as the grid-filament potential is increased, the point of the blue glow occurs at lower values of wing-filament potential up to a certain point; but if it is increased still further, the critical point occurs at higher value of wing-filament potential. At low values of grid-filament potential, the wing current increases quite rapidly with wing-filament potential. Attention is particularly called to the fact that the curves plotted between grid potential and wing current show a maximum at a definite value of grid potential and if the grid-filament potential is increased still further, the wing current is decreased. As the wing-filament potential is increased, the maximum wing current occurs lower and lower at lower value of grid potential.

When a high value of wing-filament potential is used, the wing current is practically independent of grid-filament potential.

The operation of audions in parallel is not recommended. While the amplitude of wing current is increased, the rate of change remains the same. Also it is difficult to obtain tubes having identical characteristics.

Attention is called to the fact that so far as the commercial form of the audion is concerned, no similar sets of curves have ever been published.

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Data for Curve 1 (Lamp 1).

Showing The Effect of Variation of E_{wf} on I_w.

E_{gf}= 0.

I_f= .4 Amp.		I_f= .45 Amp.		I_f= .5 Amp.	
E_{wf}	I_w	E_b	I_w	E_b	I_w
17.0	0.043	17.0	0.043	17.0	0.043
21.5	0.051	21.0	0.059	21.0	0.085
25.5	0.076	25.5	0.085	25.0	0.100
29.5	0.120	29.5	0.145	29.5	0.170
34.0	0.150	34.0	0.210	34.0	0.220
38.5	0.200	38.5	0.290	38.0	0.340
43.0	0.235	42.5	0.365	43.0	0.470
47.0	0.295	47.0	0.430		

Data for Curve 2 (Lamp 3).

Showing the Effect of Variation of E_{wf} on I_w.

I_f= .4 Amp.

	E_{gf}= 0	E_{gf}= 5.32	E_{gf}= 10.6	E_{gf}= 15.9
E_{wf}	I_w	I_w	I_w	I_w
18.0	0.042	0.067	0.093	0.135
22.0	0.047	0.072	0.120	0.155
26.0	0.093	0.093	0.155	0.177
30.5	0.152	0.152	0.177	0.220
35.0	0.210	0.210	0.220	0.270
40.0	0.295	0.256	0.930	1.020

Data for Curve 3 (lamp 4).

Showing the Relation between I_w and E_{wf}

With Different Constant E_{gf}

I_f= .4 amp. = Const.

	E_{gf}= 5.32	E_{gf}= 10.6	E_{gf}= 15.9	E_{gf}= 32.9
E_{wf}	I_w	I_w	I_w	I_w
18.0	0.025	0.059	0.077	0.051
22.0	0.042	0.067	0.085	0.067
26.0	0.068	0.085	0.102	0.085
30.5	0.085	0.295	0.237	0.110
35.0	0.730	0.930	0.847	0.155
40.0				0.220
44.0				0.405
48.0				0.675

Data for Curve 4 (lamp 3).

Showing The Relation between I_w and E_{wf}

With Different Constant E_{gf}

I_f=.4 amp.= Const.

	E_{gf}=0	E_{gf}=28.25	E_{gf}=56.5	E_{gf}=84.8	E_{gf}=113
E_{wf}	I_w	I_w	I_w	I_w	I_w
17	0.059	0.255	0.085	0.051	0.026
21	0.076	0.312	0.094	0.068	0.026
25	0.095	0.355	0.100	0.076	0.042

Data for Curve 4 (continued).

E_{gf}= 0		E_{gf}= 28.25		E_{gf}= 56.5	
E_{wf}	I_w	E_{wf}	I_w	E_{wf}	I_w
29.0	0.145	29.0	0.422	29.0	0.127
33.0	0.170	33.0	0.480	33.0	0.155
37.0	0.228	37.0	0.517	37.0	0.213
41.0	0.295	40.0	0.465	41.0	0.255
45.5	0.370	44.5	0.593	45.0	0.295
47.0	0.398	50.0	0.720	50.0	0.330
49.0	0.430	55.0	0.635	55.0	0.345
51.0	0.482	60.0	0.593	59.5	0.380
53.0	0.543	64.0	0.593	63.0	0.390
55.0	0.635	68.0	0.568	67.0	0.415
57.0	0.625	72.0	0.558	71.0	0.422
60.5	0.593	76.0	0.568	74.5	0.450
65.0	0.593	79.0	0.576	78.0	0.550
69.5	0.576	83.0	0.585	82.0	0.550
72.5	0.593			84.0	0.545

Data for Curve 4 (continued).

E_{gf}= 84.8		E_{gf}= 113	
E_{wf}	I_w	E_{wf}	I_w
29.0	0.085	29.0	0.051
33.0	0.138	33.0	0.076
37.0	0.153	37.0	0.085

Data for Curve 4 (continued).

E_{gf} = 84.8		E_{gf} = 113	
E_{wf}	I_w	E_{wf}	I_w
41.0	0.170	41.0	0.110
45.0	0.195	45.0	0.138
50.0	0.202	50.0	0.145
55.0	0.237	55.0	0.160
59.5	0.255	59.5	0.170
63.0	0.255	63.0	0.170
67.0	0.280	67.0	0.185
71.0	0.305	71.0	0.192
74.0	0.320	74.0	0.220
78.0	0.337	78.0	0.228
81.5	0.380	82.0	0.235
84.0	0.497	84.0	0.245

Data for Curve 5 (lamp 4).

Showing The Relation between I_w and E_{wf}

with Different Constant E_{gf}

I_f = .4 amp.= Const.

E_{gf} = 26.6		E_{gf} = 53.2		E_{gf} = 79.7		E_{gf} = 106.4	
E_{wf}	I_w	E_{wf}	I_w	E_{wf}	I_w	E_{wf}	I_w
17.0	0.170	17.0	0.094	17.0	0.034	17.0	0.017
21.0	0.180	21.0	0.100	21.0	0.043	21.0	0.025
25.0	0.210	25.0	0.110	25.0	0.067	25.0	0.025

Data for Curve 5 (continued)

E_{gf} = 26.6		E_{gf} = 53.2		E_{gf} = 79.7		E_{gf} = 106.4	
E_{wf}	I_w	E_{wf}	I_w	E_{wf}	I_w	E_{wf}	I_w
27.0	0.238	29.0	0.135	29.0	0.076	29.0	0.034
30.0	0.255	33.5	0.160	33.0	0.085	33.5	0.070
33.0	0.305	38.0	0.170	37.5	0.128	37.5	0.085
36.0	0.295	42.0	0.205	42.0	0.170	40.0	0.100
38.0	0.295	43.0	0.210	46.0	0.185	42.0	0.120
40.0	0.322	45.0	0.253	51.0	0.210	46.0	0.130
41.0	0.355	46.0	0.270	55.0	0.254	50.0	0.145
42.0	0.365	47.0	0.270	56.0	0.254	55.0	0.154
44.0	0.423	48.0	0.338	57.0	0.320	60.0	0.170
45.0	0.450	49.0	0.355	58.0	0.338	61.5	0.170
46.0	0.465	50.0	0.380	59.0	0.355		
48.0	0.533	51.0	0.440	60.0	0.370		
50.0	0.525	52.0	0.440	61.0	0.370		
52.0	0.525	53.0	0.465				
55.0	0.509	55.0	0.475				
57.0	0.483	56.0	0.478				
58.0	0.465	57.0	0.465				
60.0	0.465	58.0	0.457				

Data for Curve 6 (lamp1)

Showing The Relation between I_w and E_{gf}

With Different Constant E_{wf}

I_f= .45 amp.-Const.

E_{wf}= 17.5 V.		E_{wf}= 17.5 V.		E_{wf}= 48 V.	
E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w
0	0.085	58.0	0.694	0	0.390
5.8	0.110	59.3	0.720	5.8	0.405
11.6	0.145	60.7	0.736	11.6	0.466
17.4	0.202	62.4	0.760	17.5	0.550
23.2	0.245	63.8	0.796	23.3	0.677
29.0	0.313	65.3	0.796		
34.8	0.380	66.8	0.805		
40.7	0.457	68.2	0.830		
46.4	0.550	71.2	0.847		
52.3	0.660				

Data for Curve 7 (lamp 1).

Showing The Relation between I_w and E_{gf}

With Different Constant E_{wf}.

I_f=.5 amp.-Const.

E_{wf}=17.5 V		E_{wf}=30 V.		E_{wf}= 48. V.	
E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w
0	0.125	0	0.202	0	0.440
5.8	0.125	5.8	0.210	5.8	0.440

Data for Curve 7 (continued)

E_{wf} = 17.5 V.		E_{wf} = 30 V.		E_{wf} = 48 V.	
E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w
11.6	0.185	11.6	0.287	11.6	0.510
17.4	0.235	17.5	0.380	17.5	0.626
23.2	0.320	23.3	0.508	23.3	0.762
29.0	0.398	29.1	0.574	29.1	0.950
34.8	0.465	34.9	0.670	34.4	1.090
40.7	0.550	40.7	0.745		
46.4	0.645	46.6	0.847		
52.3	0.745	52.4	0.960		
58.0	0.867	58.2	1.165		
59.3	0.875	64.1	1.200		
60.7	0.900	69.8	1.370		
62.4	0.950	75.7	1,400		
63.8	0.970	81.5	1.570		
		87.4	1.75		

Data for Curve 8 (lamp 2)

Showing The Relation between I_w and E_{gf}

with Different Constant E_{wf}

	E_{wf} = 17.5	E_{wf} = 30		E_{wf} = 17.5	E_{wf} = 30
E_{gf}	I_w	I_w	E_{gf}	I_w	I_w
0	0	0.017	5.8	0.008	0.051

Data for Curve 8 (continued).

E_{wf}= 17.5 V.		E_{wf}= 30 V.		E_{wf}= 17.5 V.		E_{wf}= 30 V.	
E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w
11.6	0.042	11.6	0.110	52.3	0.365	52.4	0.677
17.4	0.085	17.5	0.170	58.0	0.560	58.2	0.830
23.2	0.110	23.3	0.235	59.3	0.618	64.1	1.200
29.0	0.160	29.1	0.295	60.7	0.592	69.8	1.480
34.8	0.202	34.9	0.372	62.4	0.626	75.7	1.560
40.7	0.228	40.7	0.457	63.8	0.635	81.5	1.780
46.4	0.280	46.6	0.551			87.4	1.85

Data for Curve 9 (lamp 3).

Showing The Relation between I_w and E_{gf}.

with Different Constant E_{wf}.

E_{wf}= 16 V.		E_{wf}= 20 V.		E_{wf}= 35 V.		E_{wf}= 40 V.	
E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w
0	0	0	0	0	0.034	0	0.034
5.7	0.017	5.6	0.017	2.8	0.043	1.4	0.051
11.3	0.059	11.3	0.059	4.3	0.170	2.8	0.059
17.0	0.110	17.0	0.100	5.7	0.220	4.3	0.085
22.6	0.145	22.6	0.160	7.1	0.255	5.7	0.340
28.3	0.205	26.9	0.210	8.5	0.260	7.1	0.255
32.5	0.240	29.7	0.255	11.3	0.270	8.5	0.345
34.0	0.210	32.5	0.285	12.7	0.295	11.3	0.340
36.8	0.155	36.8	0.170	15.5	0.295	14.1	0.340
59.5	0.077	44.5	0.085	18.4	0.295	19.8	0.340

Data for Curve 9 (continued).

E_{wf}= 35 V.		E_{wf}= 40 V.		E_{wf}= 35 V		E_{wf}= 40 V.	
E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w
19.8	0.303	33.9	0.313	51.0	0.160	62.3	0.170
22.6	0.290	39.6	0.295	56.6	0.135	68.0	0.155
33.9	0.260	48.8	0.255	62.3	0.100	73.5	0.135
39.6	0.213	51.0	0.205	68.0	0.095	79.3	0.120
45.8	0.170	56.6	0.195				

Data for Curve 9 (continued).

E_{wf}= 45 V.		E_{wf}= 55 V.		E_{wf}= 60 V.		E_{wf}= 78.0	
E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w
0	0.085	0	0.085	0	0.550	0	0.550
1.4	0.068	1.4	0.600	1.4	0.560	1.4	0.565
2.8	0.510	2.8	0.600	2.8	0.560	2.8	0.560
4.2	0.500	4.2	0.560	4.2	0.560	4.2	0.565
5.7	0.510	5.7	0.600	8.5	0.560	5.7	0.565
8.5	0.510	11.3	0.600	11.3	0.550	7.1	0.565
9.9	0.510	16.9	0.575	14.2	0.545	8.5	0.565
14.1	0.475	21.2	0.561	19.6	0.535	14.2	0.593
17.0	0.475	28.3	0.410	25.5	0.535	16.9	0.593
19.8	0.375	34.0	0.405	31.1	0.535	21.2	0.585
22.6	0.365	39.6	0.390	39.6	0.535	28.3	0.585.
25.4	0.345	45.3	0.380	47.2	0.420	34.0	0.585
28.3	0.340	51.0	0.340	53.8	0.405	39.6	0.517
31.1	0.340	56.5	0.315	59.4	0.380	45.3	0.577

Data for Curve 9 (continued)

E_{wf}= 45 V.		E_{wf}= 55 V.		E_{wf}= 60 V.		E_{wf}= 78 V.	
E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w	E_{gf}	I_w
33.9	0.340	62.2	0.255	65.1	0.340	51.5	0.565
39.6	0.305	68.0	0.235	70.8	0.255	62.3	0.565
45.8	0.295	73.6	0.220	77.8	0.255	68.0	0.510
51.0	0.260	79.3	0.205	85.0	0.235	77.8	0.370
56.6	0.220	85.0	0.185	99.0	0.205	85.0	0.365
62.3	0.193	99.0	0.165	113.0	0.170	102.0	0.280
68.0	0.170	113.0	0.135	130.0	0.145	119.0	0.230
73.3	0.155	141.5	0.100			170.0	0.135

Data for Curve 10 (lamp 3).

Showing The Relation between I_w and E_{gf}.

with Different Constant E_{wf}.

I_f= .4 amp.= Const.

	E_{wf}= 17	E_{wf}= 25	E_{wf}= 35	E_{wf}= 45	E_{wf}= 60	E_{wf}= 83
E_{gf}	I_w	I_w	I_w	I_w	I_w	I_w
0.0	0.042	0.155	0.653	0.770	0.635	0.635
5.7	0.076	0.170	0.610	0.693	0.617	0.625
11.3	0.138	0.235	0.423	0.685	0.610	0.625
16.9	0.170	0.295	0.405	0.677	0.610	0.617
22.6	0.185	0.345	0.390	0.668	0.610	0.610
28.3	0.238	0.255	0.380	0.668	0.600	0.600
33.9	0.135	0.205	0.340	0.645	0.600	0.600
39.5	0.093	0.170	0.287	0.470	0.594	0.600

Data for Curve 10 (continued).

E_{gf}	$E_{wf}=17$ I_w	$E_{wf}=25$ I_w	$E_{wf}=35$ I_w	$E_{wf}=45$ I_w	$E_{wf}=60$ I_w	$E_{wf}=83$ I_w
45.2	0.068	0.155	o.255	0.405	0.597	0.600
50.8	0.051	0.120	0.235	0.340	0.594	0.600
56.6	0.042	0.093	0.205	0.287	0.594	0.600
62.2	0.034	0.085	0.185	0.235	0.398	0.600
67.8	0.026	0.077	0.170	0.235	0.355	0.593
73.5	0.056	0.077	0.165	0.220	0.305	0.593
79.2	0.017	0.077	0.153	0.205	0.280	0.593
84.8	0.017	0.077	0.145	0.185	0.263	0.425
90.5	0.017	0.068	0.135	0.180	0.255	0.368
96.0	0.017	0.059	0.135	0.170	0.235	0.337
101.0	0.017	0.051	0.130	0.160	0.228	0.330
107.0	0.017	0.042	0.120	0.160	0.214	0.305
113.0	0.017	0.034	0.120	0.160	0.205	0.280
124.0	0.017	0.025	0.110	0.160	0.185	0.263

Data for Curve 11 (lamp 4).

Showing the Relation between I_w and E_{gf}

with Different Constant E_{wf}

I_f= .4 amp.= Const.

E_{gf}	$E_{wf}=17$ I_w	$E_{wf}= 25$ I_w	$E_{wf}= 35$ I_w	$E_{wf}=39$ I_w	$E_{wf}=45$ I_w	$E_{wf}=48$ I_w
0	0	0,008	0,042	o.o5o	o.55o	o.995
5.7	.008	o.025	0.095	0.092	0.560	1.055

Data for Curve 11 (continued)

E_{gf}	$E_{wf}=17$ I_w	$E_{wf}=25$ I_w	$E_{wf}=35$ I_w	$E_{wf}=39$ I_w	$E_{wf}=45$ I_w	$E_{wf}=48$ I_w
11.4	0.034	0.051	0.150	0.510	0.575	1.055
17.1	0.059	0.076	0.185	0.450	0.575	1.005
22.8	0.076	0.100	0.220	0.500	0.575	0.930
28.6	0.100	0.150	0.270	0.450	0.575	0.910
34.3	0.126	0.195	0.345	0.370	0.570	0.745
40.0	0.145	0.145	0.250	0.320	0.430	0.610
45.7	0.100	0.100	0.195	0.280	0.340	0.510
51.6	0.085	0.085	0.170	0.230	0.310	0.440
57.2	0.085	0.085	0.146	0.235	0.270	0.390
62.8	0.076	0.076	0.135	0.195	0.250	0.365
68.5	0.059	0.067	0.128	0.180	0.235	0.320
74.3	0.059	0.063	0.120	0.170	0.210	0.290
80.0	0.055	0.055	0.095	0.160	0.195	0.280
85.6	0.051	0.051	0.090	0.155	0.170	0.255
91.4	0.042	0.042	0.085	0.135	0.170	0.235
97.1	0.038	0.025	0.085	0.135	0.165	0.225
102.7	0.034	0.021	0.095	0.125	0.155	0.210
108.0	0.025	0.017	0.085	0.120	0.146	0.195
114.2	0.025	0.017	0.085	0.120	0.135	0.185
120.0	0.025	0.017	0.080	0.100	0.125	0.180
131.3	0.017	0.017	0.076	0.095	0.135	0.170
137.0	0.013	0.015	0.063	0.100	0.135	0.150

Data for Curve 11 (continued)

	$E_{wf}=35$	$E_{wf}=45$		$E_{wf}=35$	$E_{wf}=45$
E_{gf}	I_w	I_w	E_{gf}	I_w	I_w
142.5	0.051	0.128	182.0	0.029	0.085
148.0	0.042	0.125	188.0	0.025	0.083
154.0	0.042	0.110	193.5	0.025	0.085
159.5	0.042	0.110	199.5	0.025	0.085
165.0	0.038	0.100	205.5	0.025	0.085
171.0	0.034	0.095	211.0		0.085
177.0	0.034	0.095			

Data for Curve 12.

Showing The Different Characteristics

of Different Audions.

$E_{gf}=0.$ $I_f=.4$ Amp.

	Lamp 1	Lamp2	Lamp 3		Lamp 4
E_{wf}	I_w	I_w	I_w	E_{wf}	I_w
17.0	0.017	0.025	0.042	17	0.059
22.0	0.042	0.051	0.067	21	0.094
26.0	0.051	0.120	0.093	25	0.130
30.0	0.085	0.150	0.152	29	0.170
35.0	0.110	0.228	0.210	30	0.185
39.0	0.125	0.337	0.295	31	0.195
43.0	0.175	0.510	0.760	32	0.228
47.5	0.212	2.120		34	0.270

Data for Curve 12 (continued)

Lamp 4.

E_{wf}	35	36	37	38	39
I_w	0.305	0.345	0.355	0.370	0.415

Data for Curve 13.

Showing The Different Characteristics

of Different Audions.

I_f=.45 Amp. E_{gf}= 0.

	Lamp 1	Lamp 4		Lamp 1	Lamp 4.
E_{wf}	I_w	I_w	E_{wf}	I_w	I_w
17.5	0.034	0.051	34.5	0.152	0.295
21.5	0.051	0.067	39.5	0.225	0.450
26.0	0.085	0.120	43.5	0.295	0.625
30.0	0.125	0.195	47.4	0.380	3.130

Data for Curve 14.

Showing the Different Characteristics.

of Different Audions

I_f= .4 Amp. E_{gf}= 5.32 Volts.

	Lamp 3.	Lamp 4.
E_{wf}	I_w	Iw
18.0	0.067	0.026
22.0	0.072	0.042
26.0	0.093	0.067
30.5	0.152	0.085
35.0	0.210	0.930
40.0	0.256	

Data for Curve 15 (Lamp 4)

Comparing The Effect of Variation

of E_{wf} on I_w between Different Values of I_f

$E_{gf} = 0.$

E_{wf}	$I_f = .4$ Amp. I_w	$I_f = .45$ Amp. I_w	$I_f = .50$ I_w
17.0	0.034	0.034	0.120
22.0	0.042	0.051	0.135
26.0	0.051	0.085	0.185
30.0	0.085	0.125	0.225
35.0	0.110	0.152	0.305
39.0	0.125	0.225	0.398
43.0	0.175	0.295	0.541
47.5	0.212	0.380	0.720

Data for Durve 16 (Lamp 3)

Showing The Effect of Variation of I_f on I_w.

E_{wf}= 70= Const.

E_{gf}= 0		E_{gf}=22.6		E_{gf}= 45.3	
I_f	I_w	I_f	I_w	I_f	I_w
0.333	0.034	0.357	0.034	0.353	0.043
0.357	0.067	0.366	0.060	0.363	0.060
0.375	0.135	0.374	0.085	0.310	0.085
0.384	0.210	0.378	0.170	0.376	0.130
0.390	0.320	0.383	0.255	0.383	0.185
0.400	0.535	0.390	0.340	0.390	0.245
0.413	0.945	0.397	0.465	0.393	0.295
0.424	1.550	0.400	0.515	0.397	0.435
		0.403	0.640	0.400	0.545
		0.406	0.725	0.403	0.625
		0.410	0.865	0.407	0.805
		0.413	1.155	0.410	0.950
		0.416	1.270	0.413	1.075
		0.420	1.480	0.470	1.250
		0.427	1.700		

Curve 17 (Lamp 3)

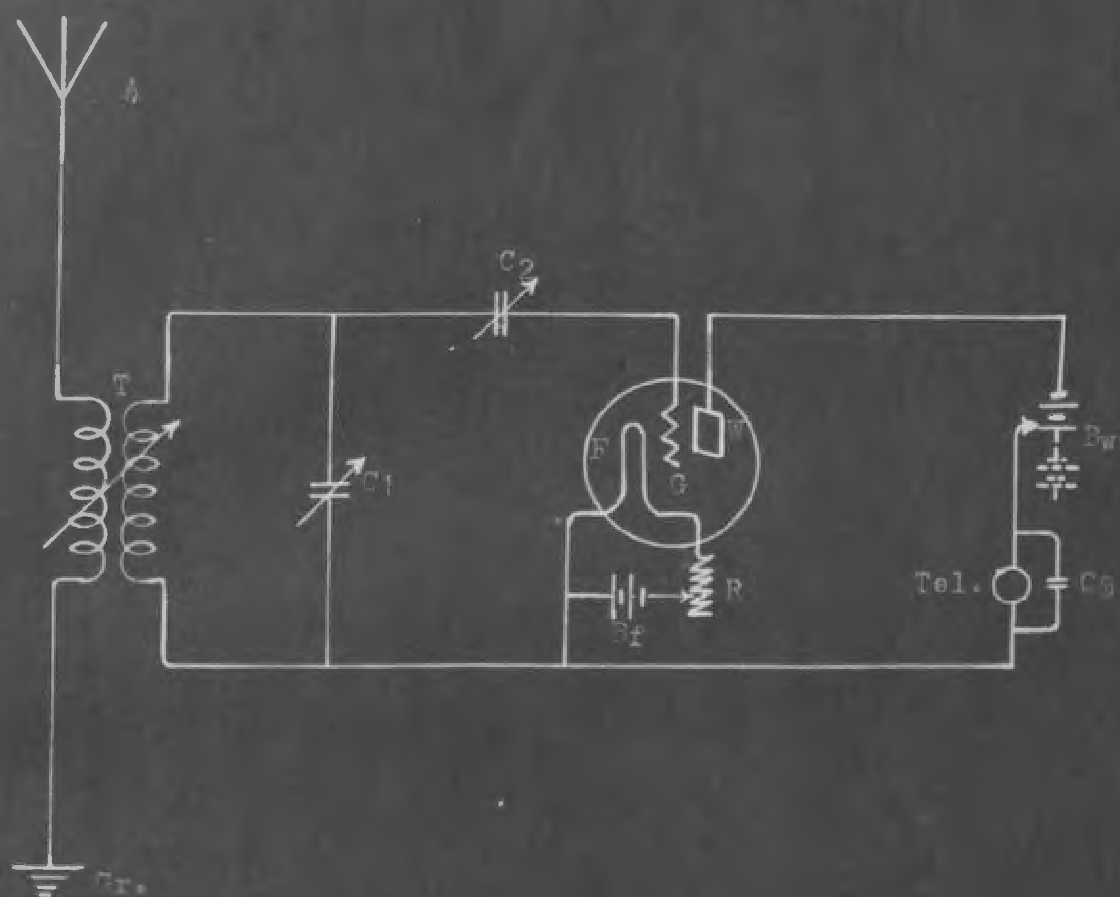
Showing The Effect of Variation of I_f on I_w

E_{wf}= 54 Volts.

E_{gf}= 0		E_{gf}= 45.3		E_{gf}= 45.3	
I_f	I_w	I_f	I_w	I_f	I_w
0.450	5.100	0.357	0.051	0.397	0.340
0.437	3.100	0.363	0.085	0.400	0.415
0.420	1.500	0.370	0.093	0.403	0.475
0.404	0.750	0.377	0.120	0.407	0.585
0.386	0.340	0.385	0.185	0.410	0.775
0.370	0.084	0.390	0.255	0.413	1.095
0.353	0.036	0.393	0.305	0.416	1.285
0.336	0				

Diagram 1.

Connection of Audion as A Wireless Detector.



Where A, an antenna; T, receiving transformer;

C_1, C_2 and C_3, condensers; R, resistance;

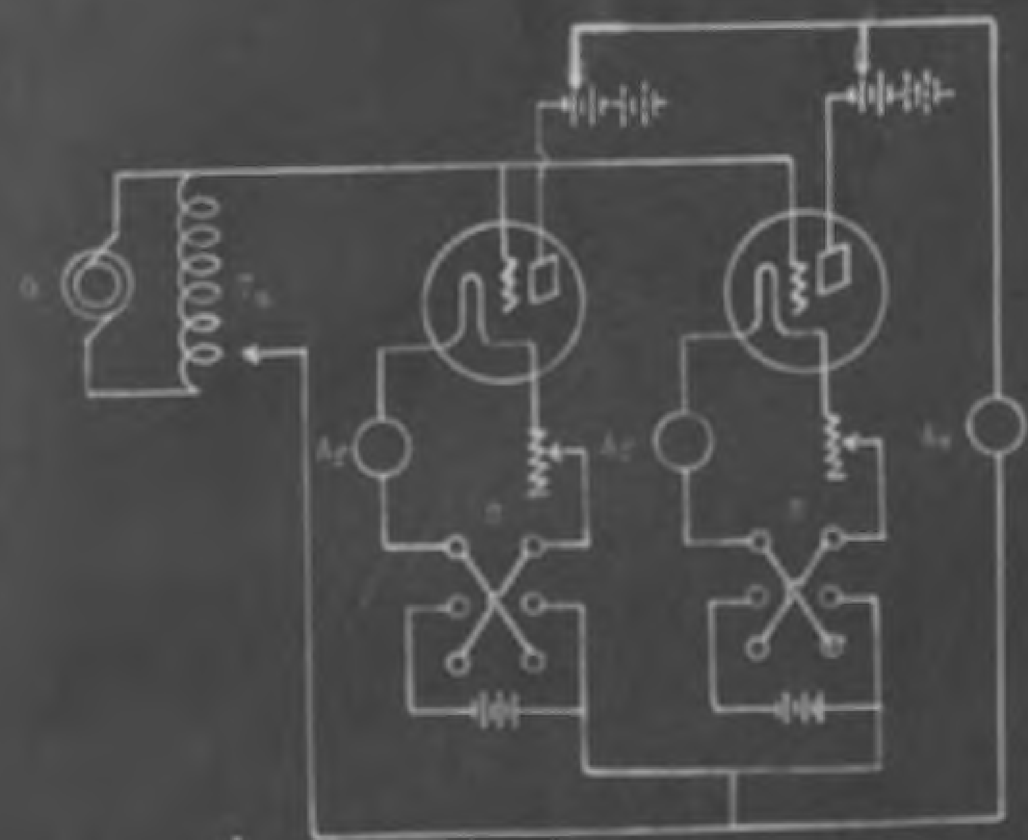
W, G and F, wing, grid and filament of Audion;

B_w and B_f, wing and filament batteries;

Tel, telephone receiver; Gr, ground.

Diagram 2.

Two Audions Connected in Parallel.



G is a 60 cycles, 120 volts, a.c. generator;

T_a, autotransformer; S, double throw switch;

A_f, ammeter for measuring filament current;

A_w, milliammeter for measuring wing current.

Diagram 3.

Connection of Audions for Oscillogram

Four Lamps in Parallel.

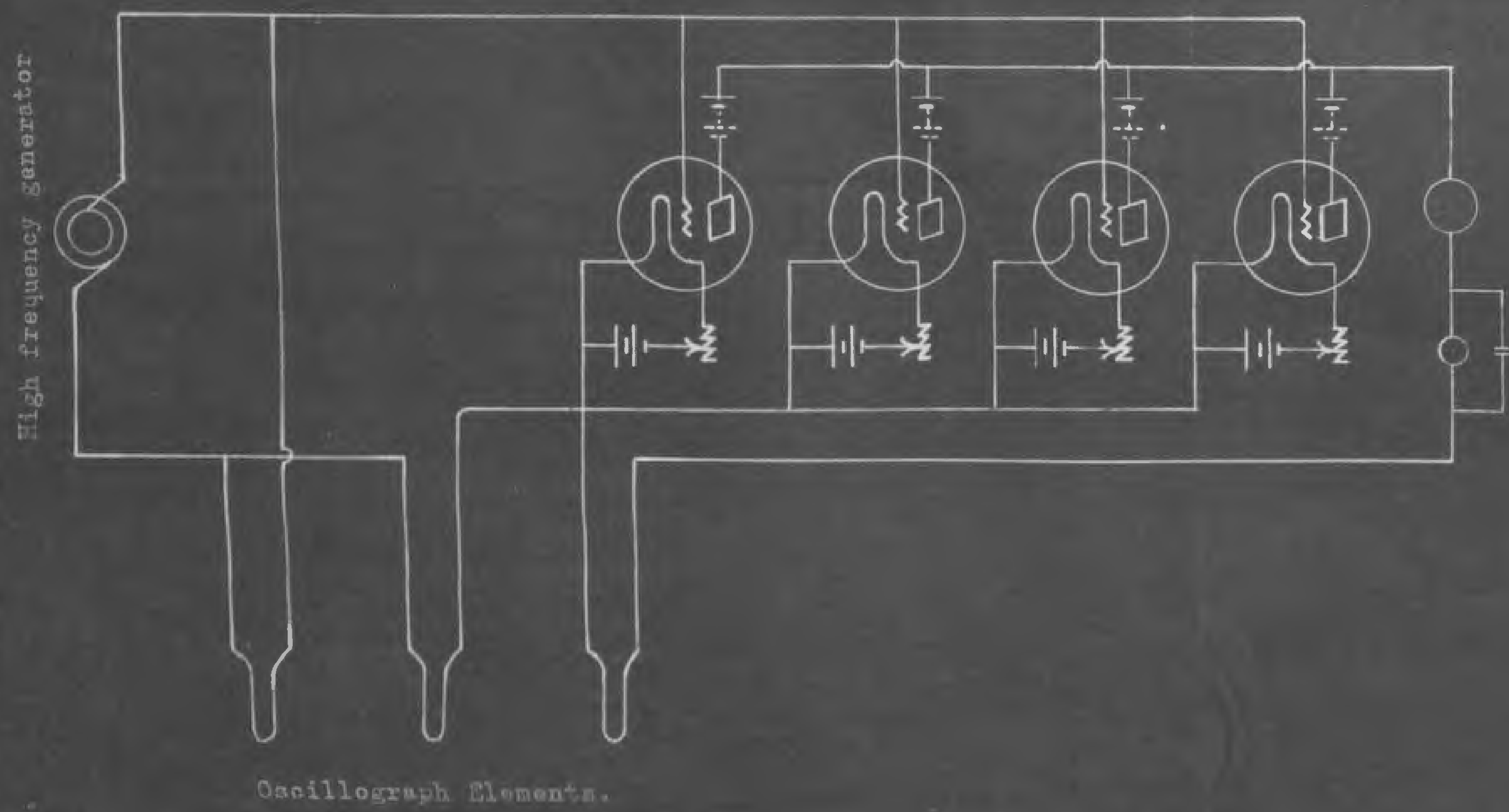
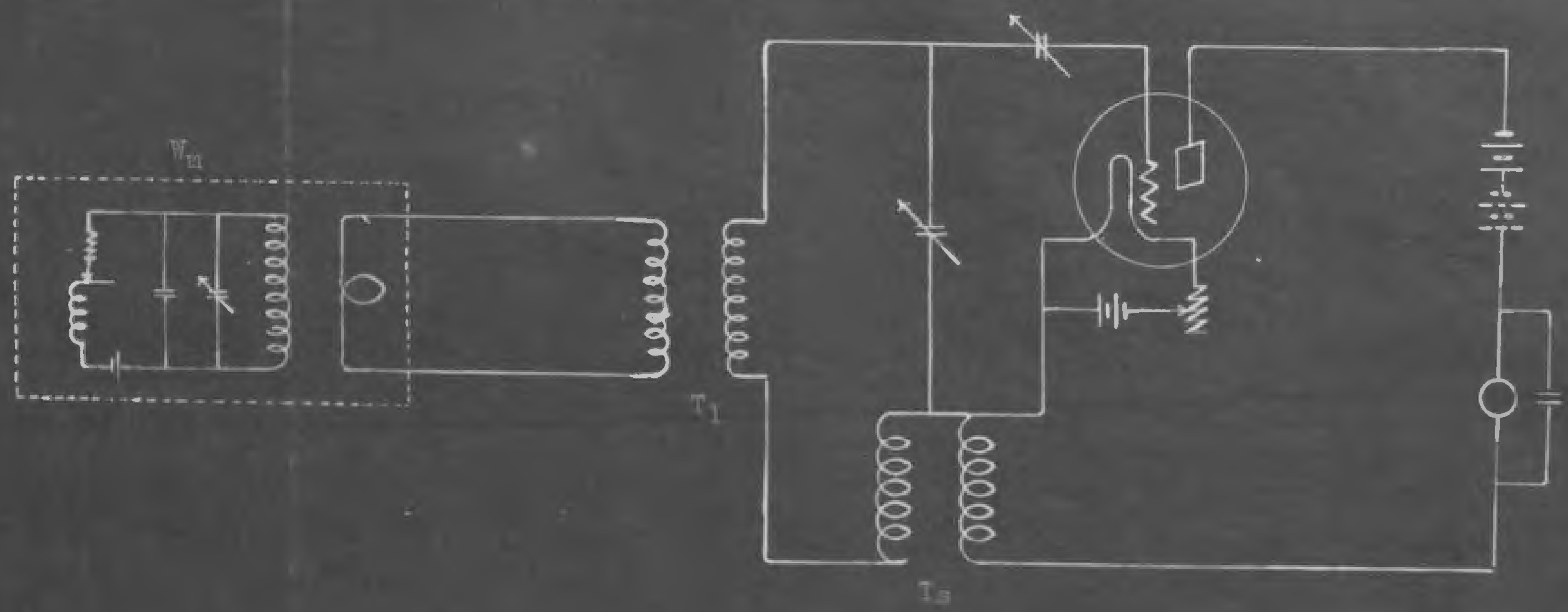


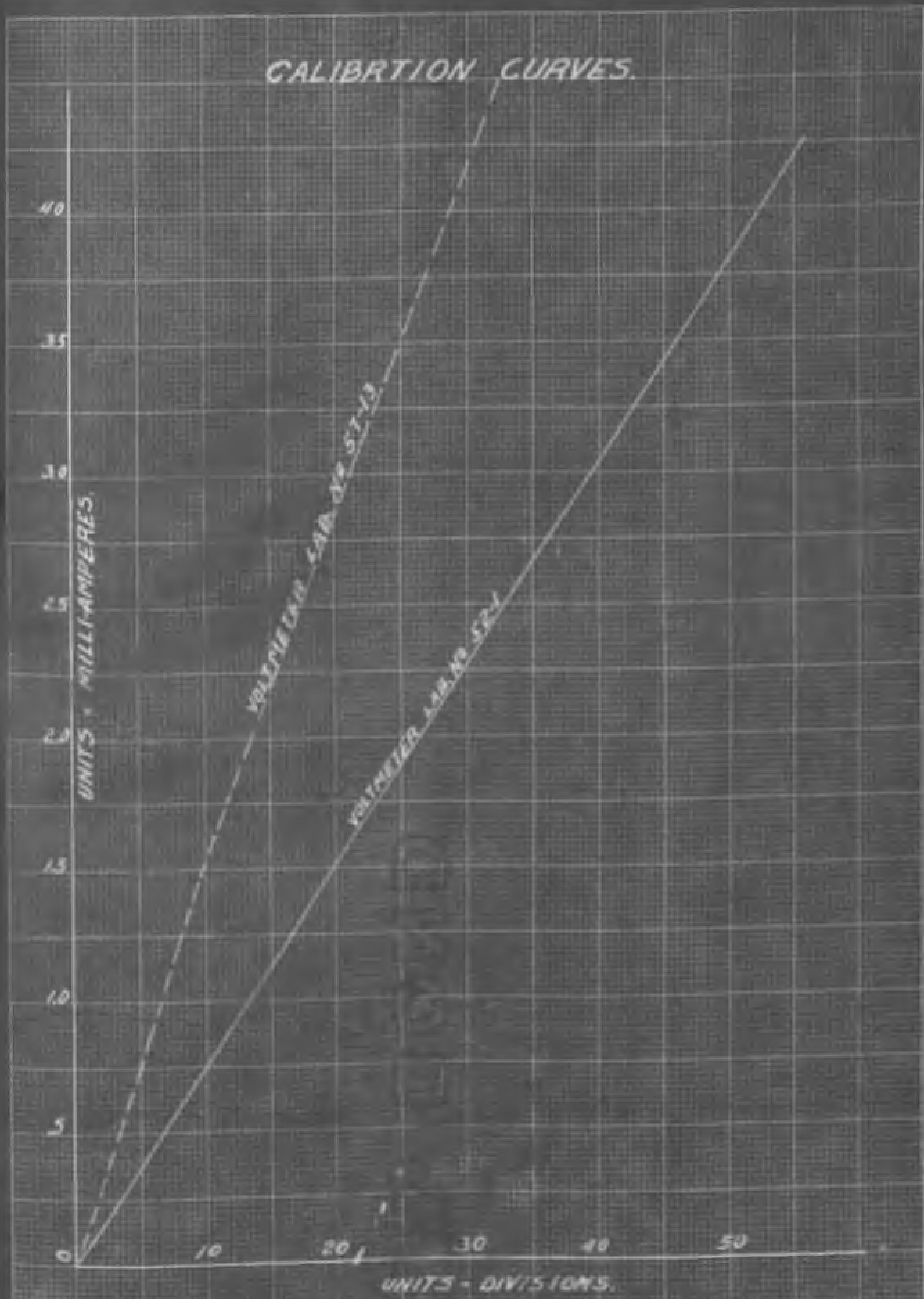
Diagram 4.

Connection of Audion as High Frequency Generator.

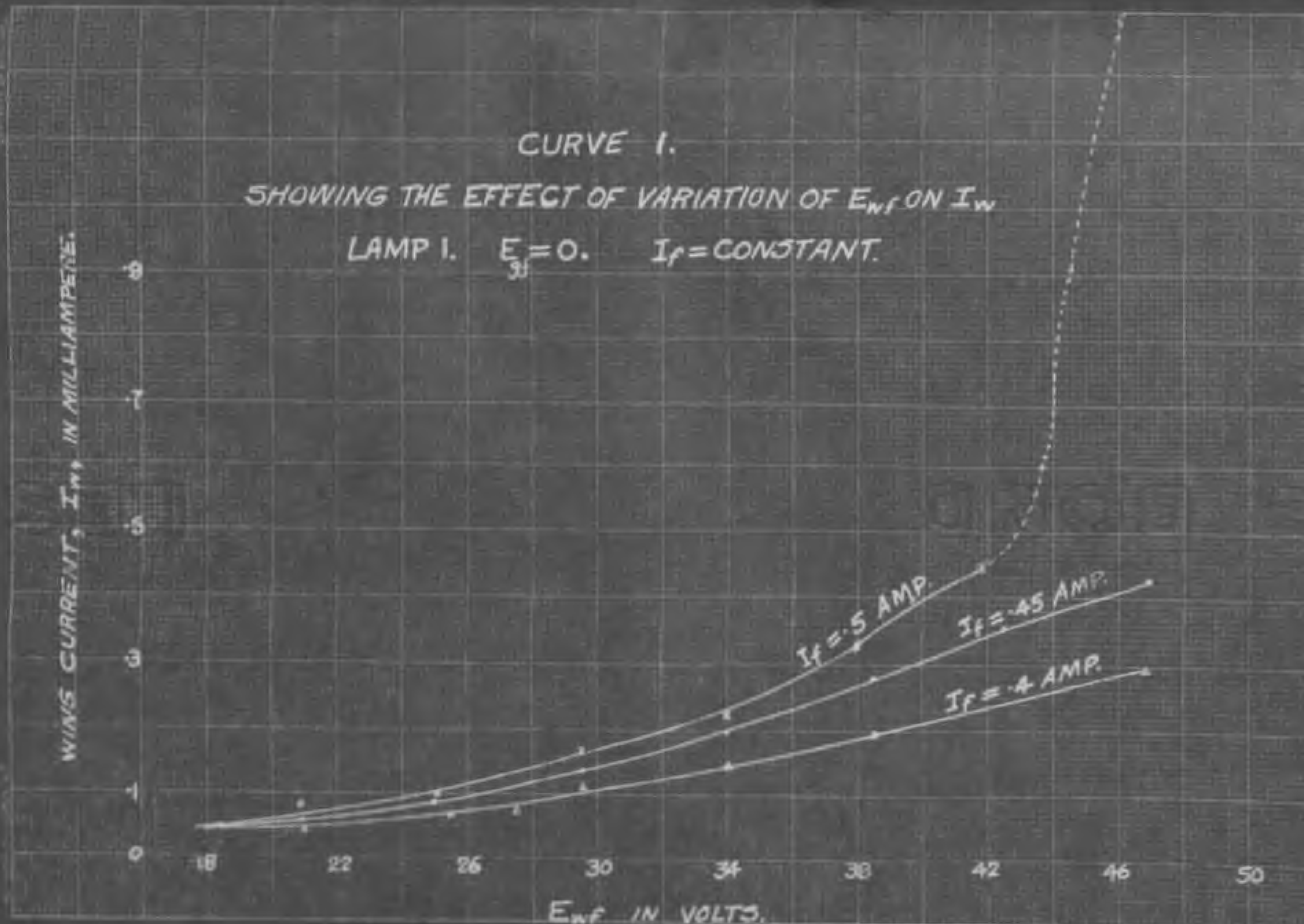


W_m is a wavemeter used for tunning only;

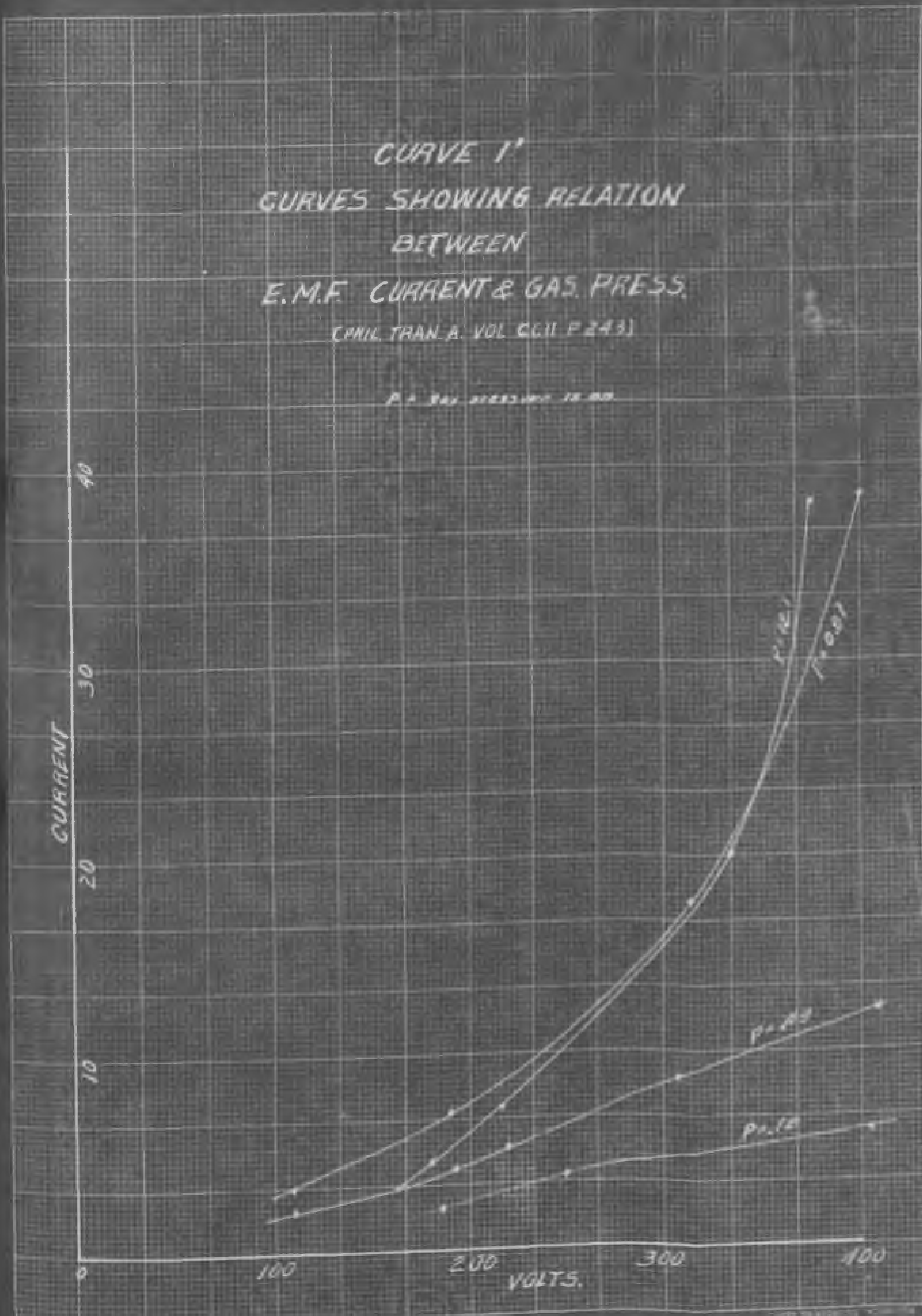
T_1, long tuner; T_s, short tuner.



CALIBRTION CURVES.
UNITS - MILLIAMPERES.
UNITS - DIVISIONS.
VOLTMETER LAB. NO. ST-13
VOLTMETER LAB. NO. ST-1
0
10
20
30
40
50
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0



CURVE I.
SHOWING THE EFFECT OF VARIATION OF E_{wf} ON I_w
LAMP I. $E_{gf}=0$. I_f = CONSTANT.
I_f = ·5 AMP.
I_f = ·45 AMP.
I_f = ·4 AMP.
WINS CURRENT, I_w, IN MILLIAMPERE.
·8
·7
·5
·3
·1
0
18
22
26
30
34
38
42
46
50
E_{wf} IN VOLTS.

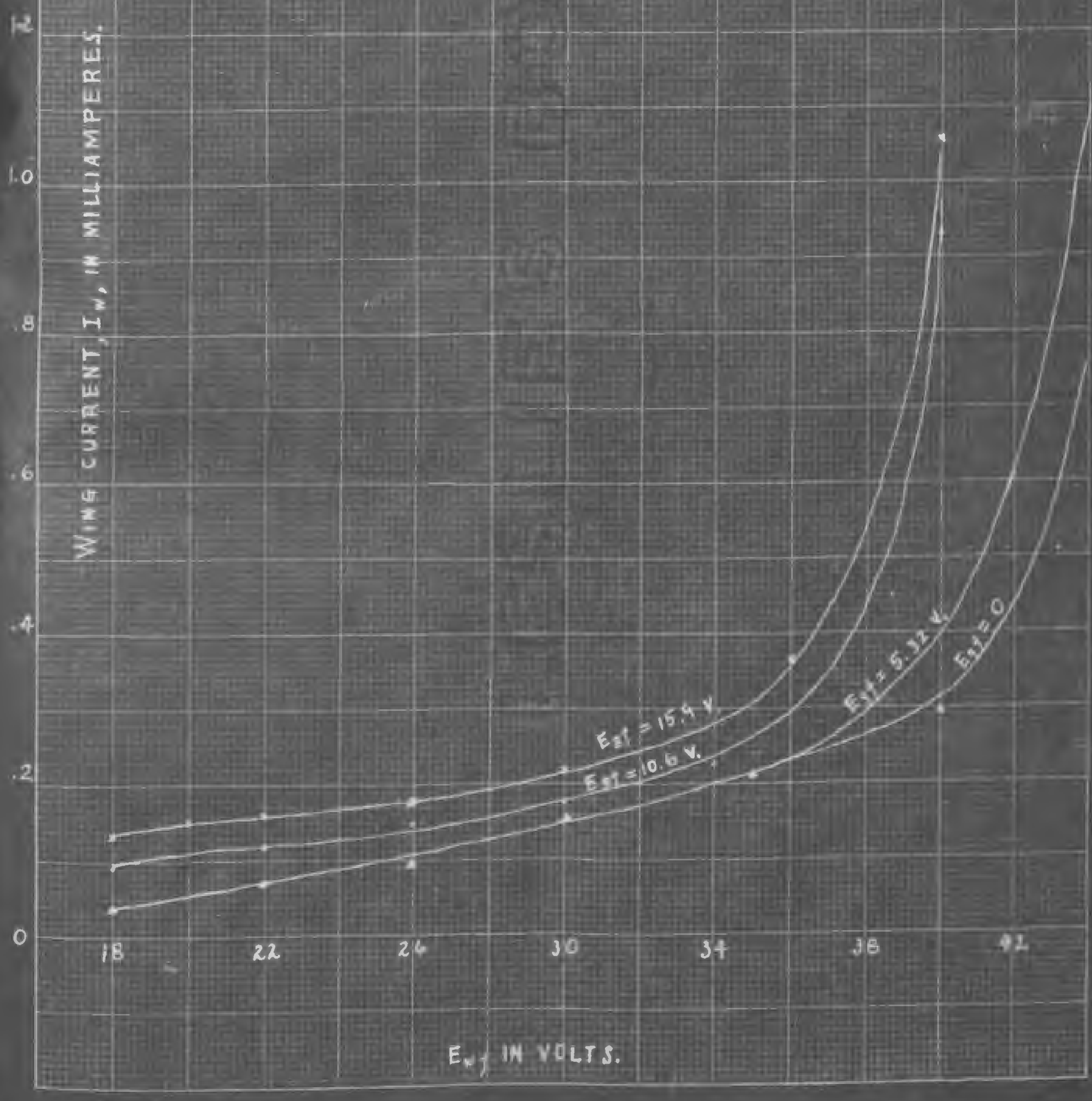


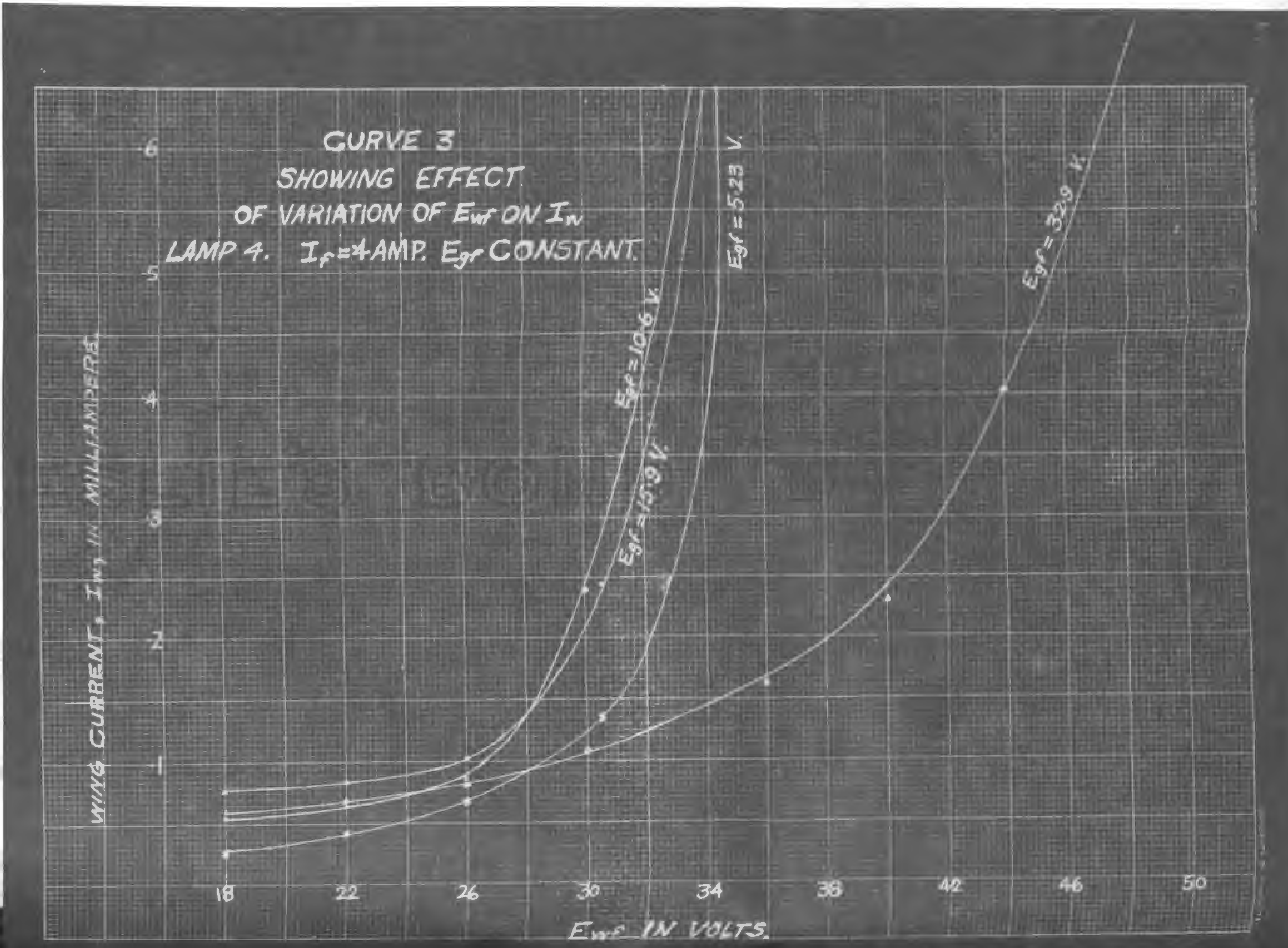
CURVE I'
CURVES SHOWING RELATION
BETWEEN
E.M.F. CURRENT & GAS. PRESS.
(PHIL. TRAN. A. VOL. CCII P 243)
CURRENT
0
10
20
30
40
100
200
300
400
VOLTS.

CURVE 2.

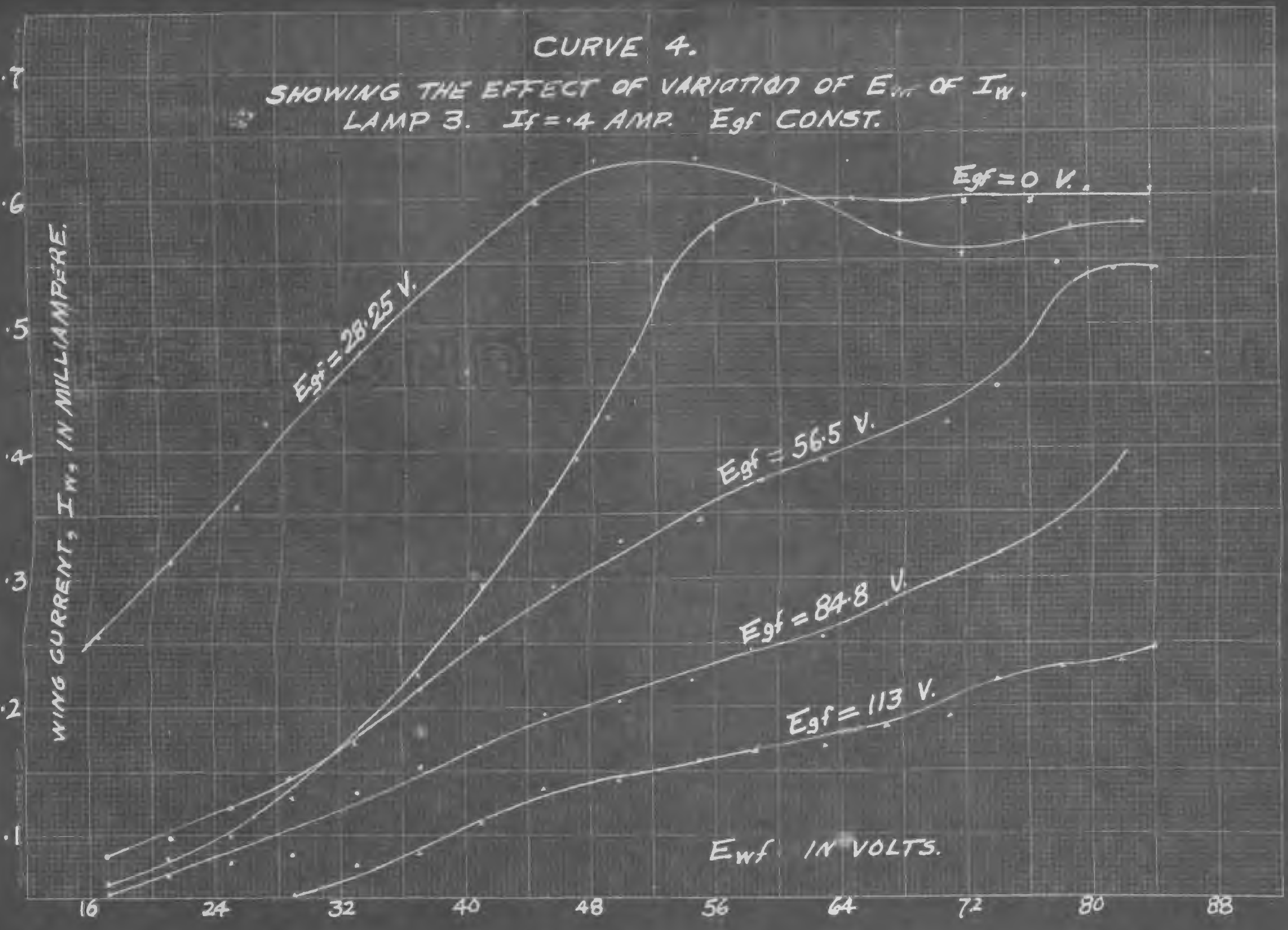
SHOWING THE EFFECT OF VARIATION OF E_{wf} ON I_w

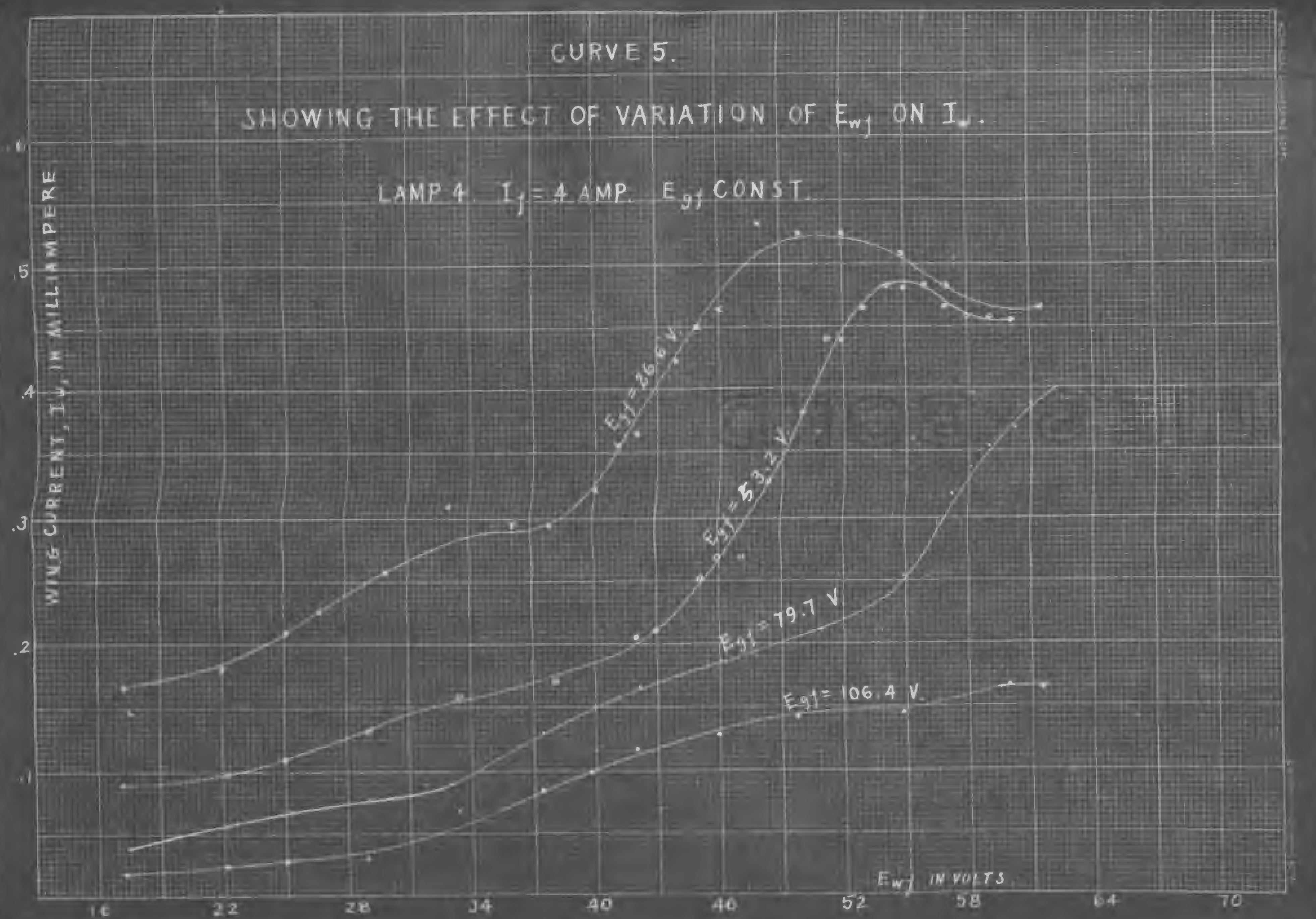
LAMP 4. I_f = .4 AMP. E_{gf} = CONST.

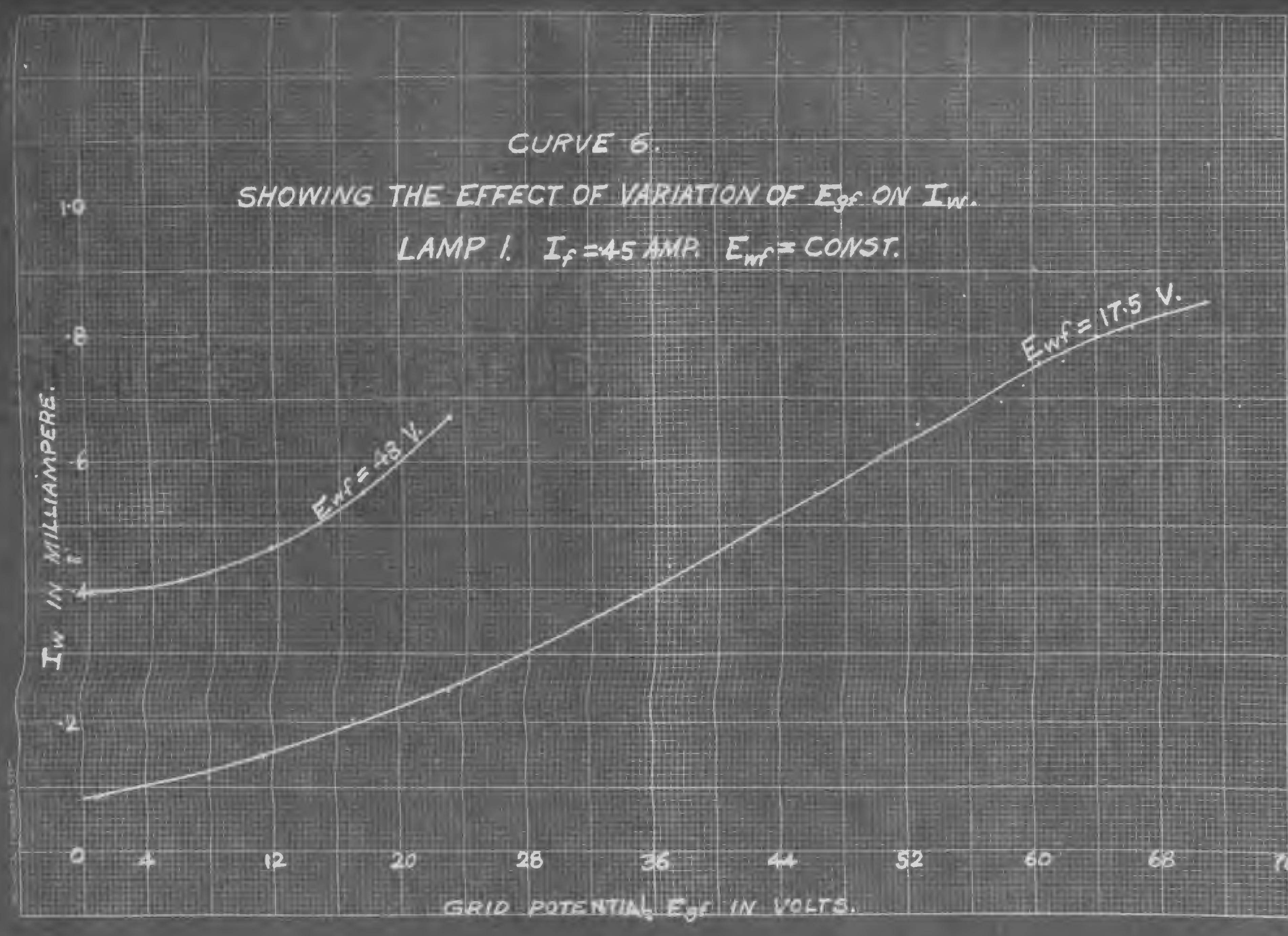


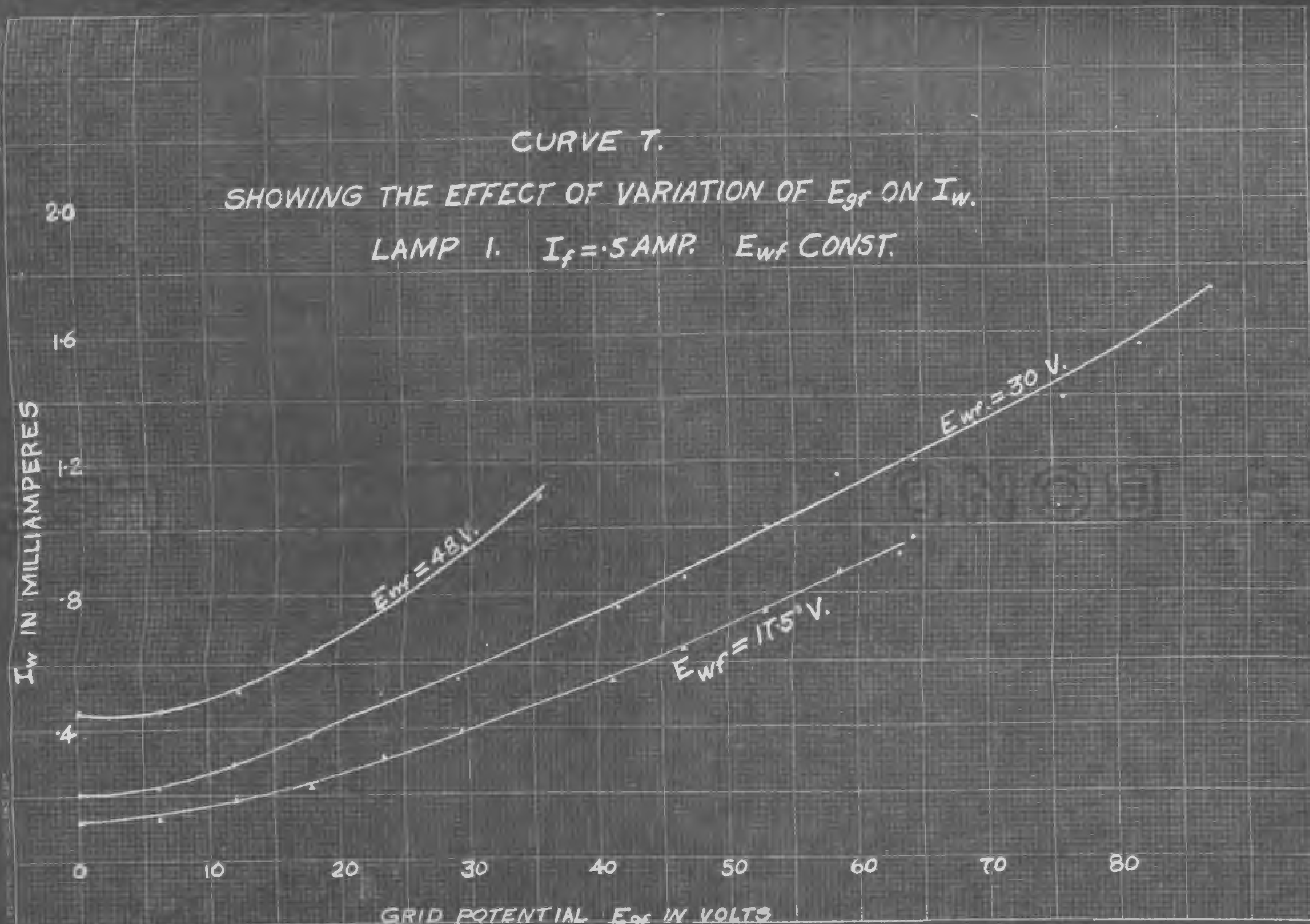


CURVE 3
SHOWING EFFECT
OF VARIATION OF E_{wf} ON I_w
LAMP 4. I_f=4 AMP. E_{gr} CONSTANT.
WING CURRENT, I_w, IN MILLIAMPERE.
E_{wf} IN VOLTS.
E_{gf}=10.6 V.
E_{gf}=15.9 V.
E_{gf}=5.23 V.
E_{gf}=32.9 V.
1
2
3
4
5
6
18
22
26
30
34
38
42
46
50

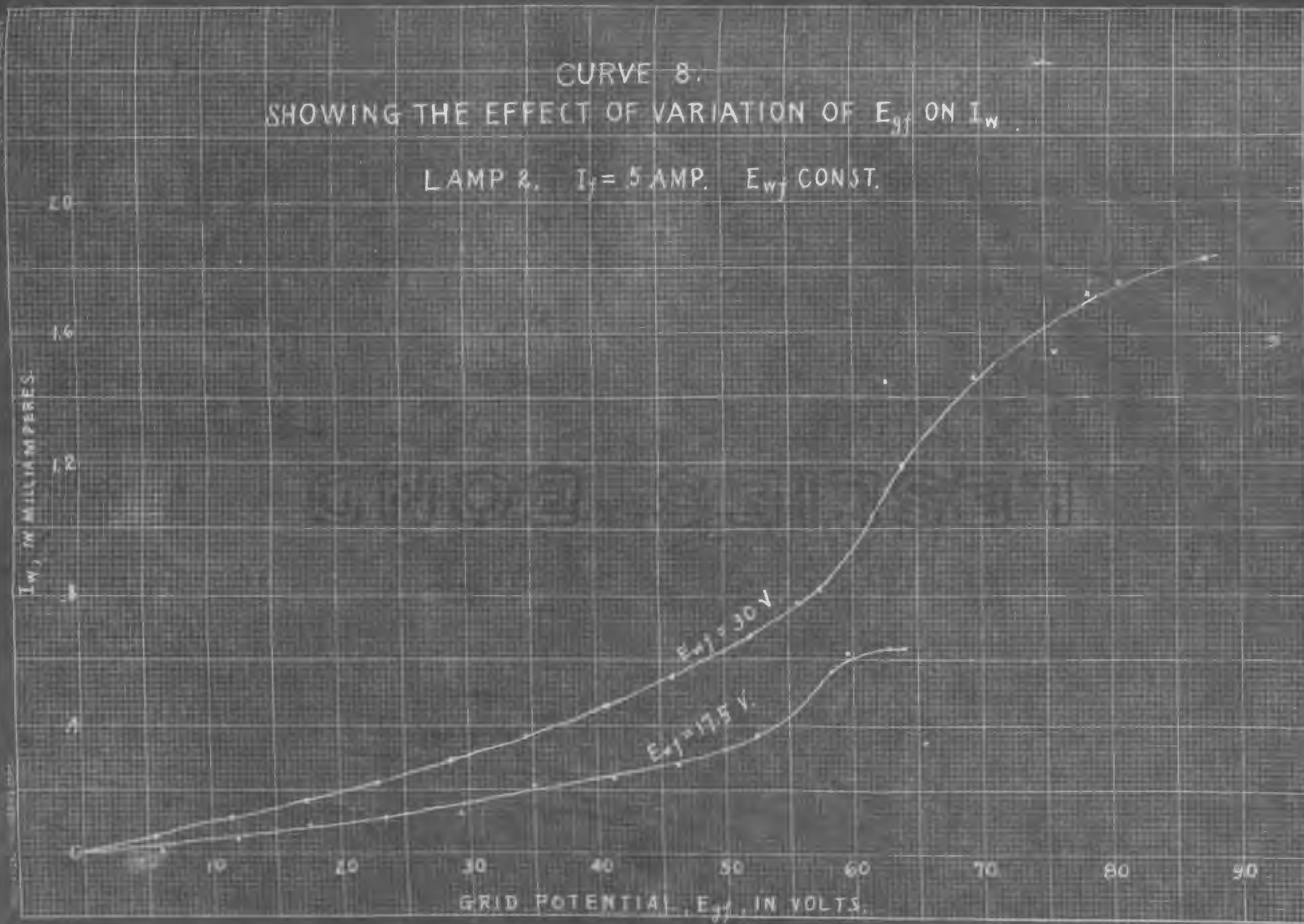

CURVE 4.
SHOWING THE EFFECT OF VARIATION OF E_{wf} OF I_w.
LAMP 3. I_f = ·4 AMP. E_{gf} CONST.
E_{gf} = 0 V.
E_{gf} = 28·25 V.
E_{gf} = 56·5 V.
E_{gf} = 84·8 V.
E_{gf} = 113 V.
WING CURRENT, I_w, IN MILLIAMPERE.
E_{wf} IN VOLTS.
·1
·2
·3
·4
·5
·6
·7
16
24
32
40
48
56
64
72
80
88

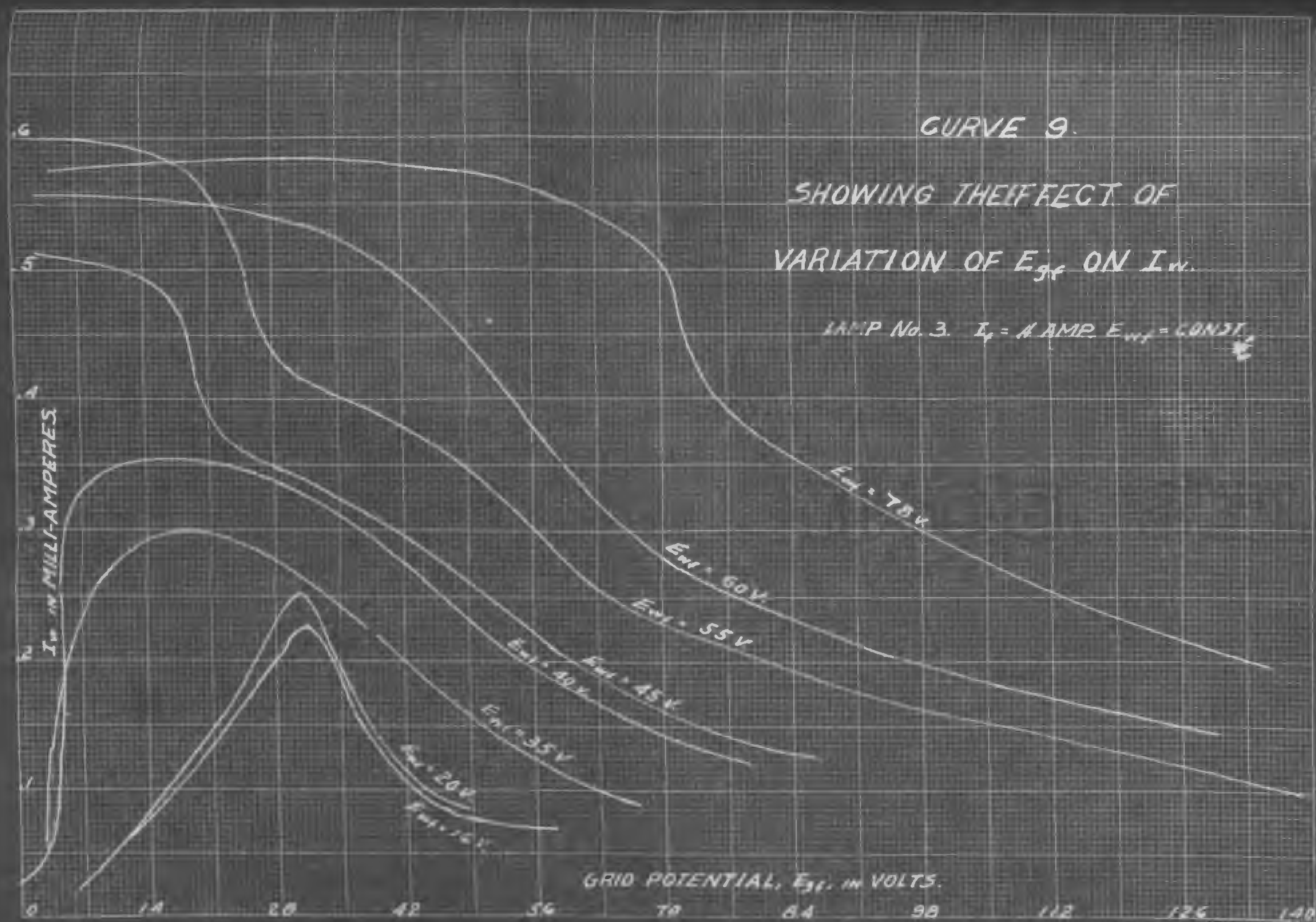

CURVE 5.
SHOWING THE EFFECT OF VARIATION OF E_{wf} ON I_w.
LAMP 4. I_f = 4 AMP. E_{gf} CONST.
E_{gf} = 26.6 V.
E_{gf} = 53.2 V.
E_{gf} = 79.7 V.
E_{gf} = 106.4 V.
WING CURRENT, I_w, IN MILLIAMPERE
.6
.5
.4
.3
.2
.1
E_{wf} IN VOLTS
16
22
28
34
40
46
52
58
64
70

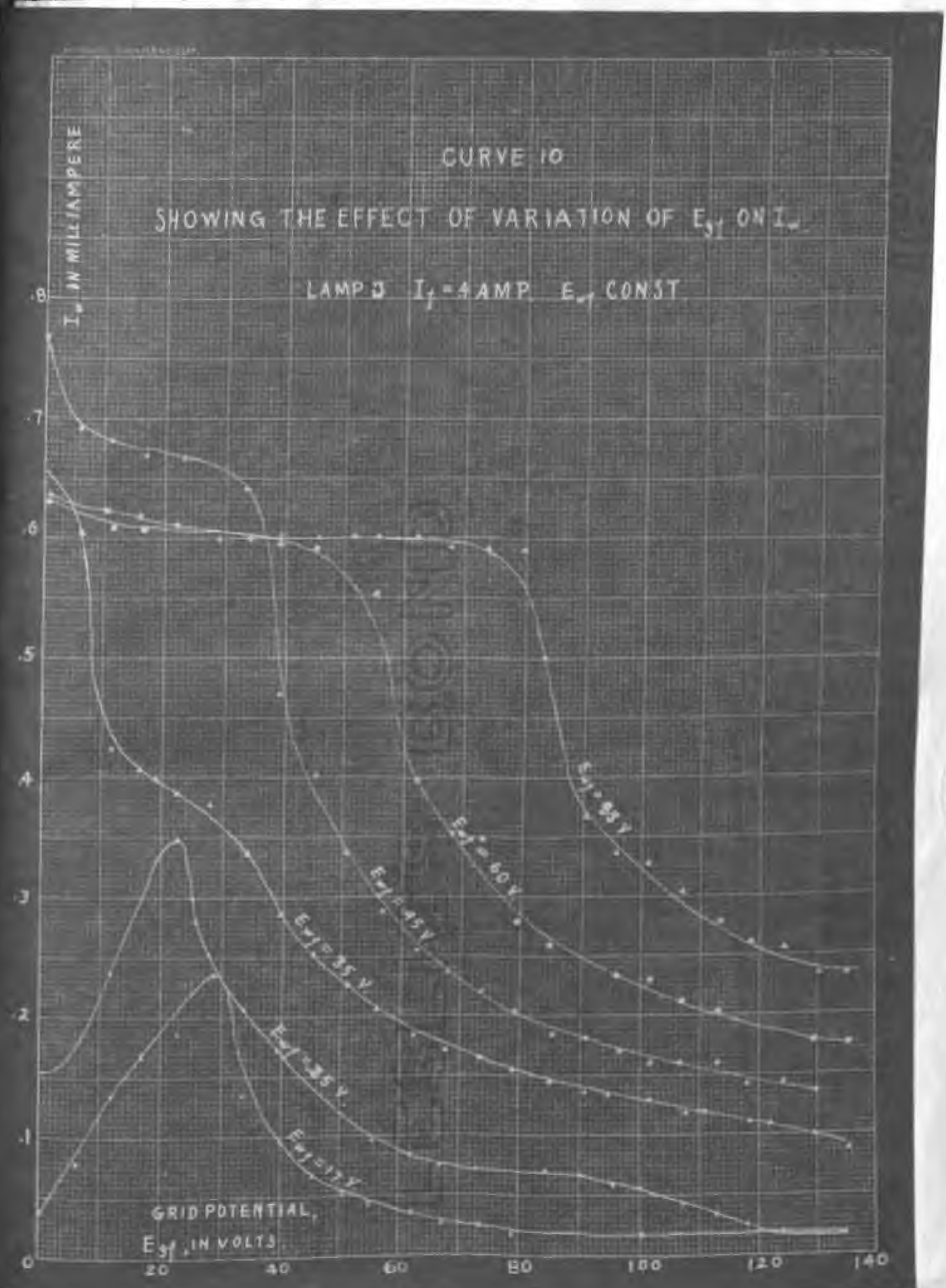

CURVE 6.
SHOWING THE EFFECT OF VARIATION OF E_{gf} ON I_w.
LAMP 1. I_f = ·45 AMP. E_{wf} = CONST.
E_{wf} = 17·5 V.
E_{wf} = 48 V.
I_w IN MILLIAMPERE.
1·0
·8
·6
·4
·2
0
4
12
20
28
36
44
52
60
68
76
GRID POTENTIAL E_{gf} IN VOLTS.



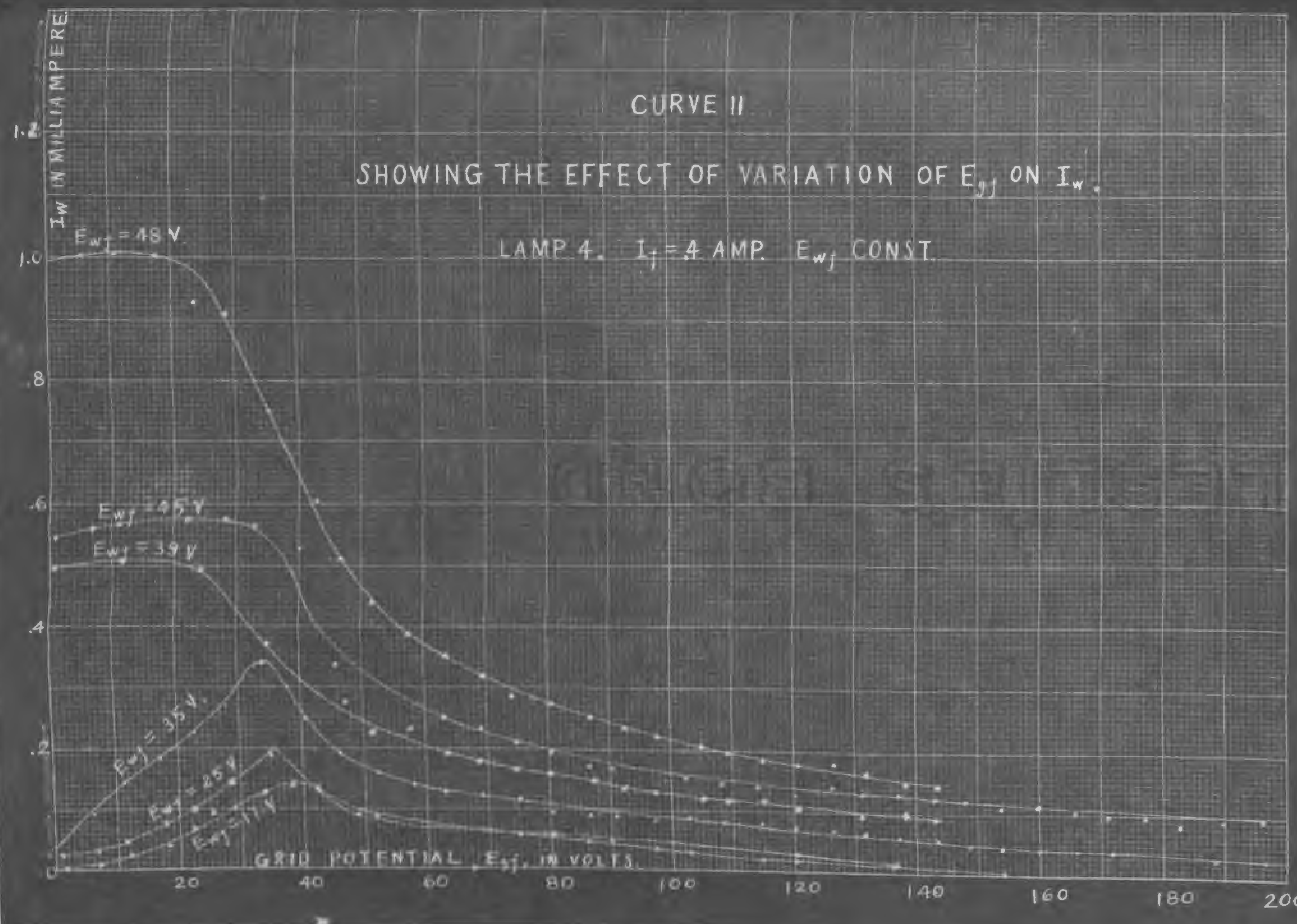
CURVE 7.
SHOWING THE EFFECT OF VARIATION OF E_{gf} ON I_w.
LAMP 1. $I_f = \cdot 5$ AMP. E_{wf} CONST.
$E_{wf} = 48$ V.
$E_{wf} = 30$ V.
$E_{wf} = 17\cdot 5$ V.
2·0
1·6
1·2
·8
·4
I_w IN MILLIAMPERES
0
10
20
30
40
50
60
70
80
GRID POTENTIAL E_{gf} IN VOLTS

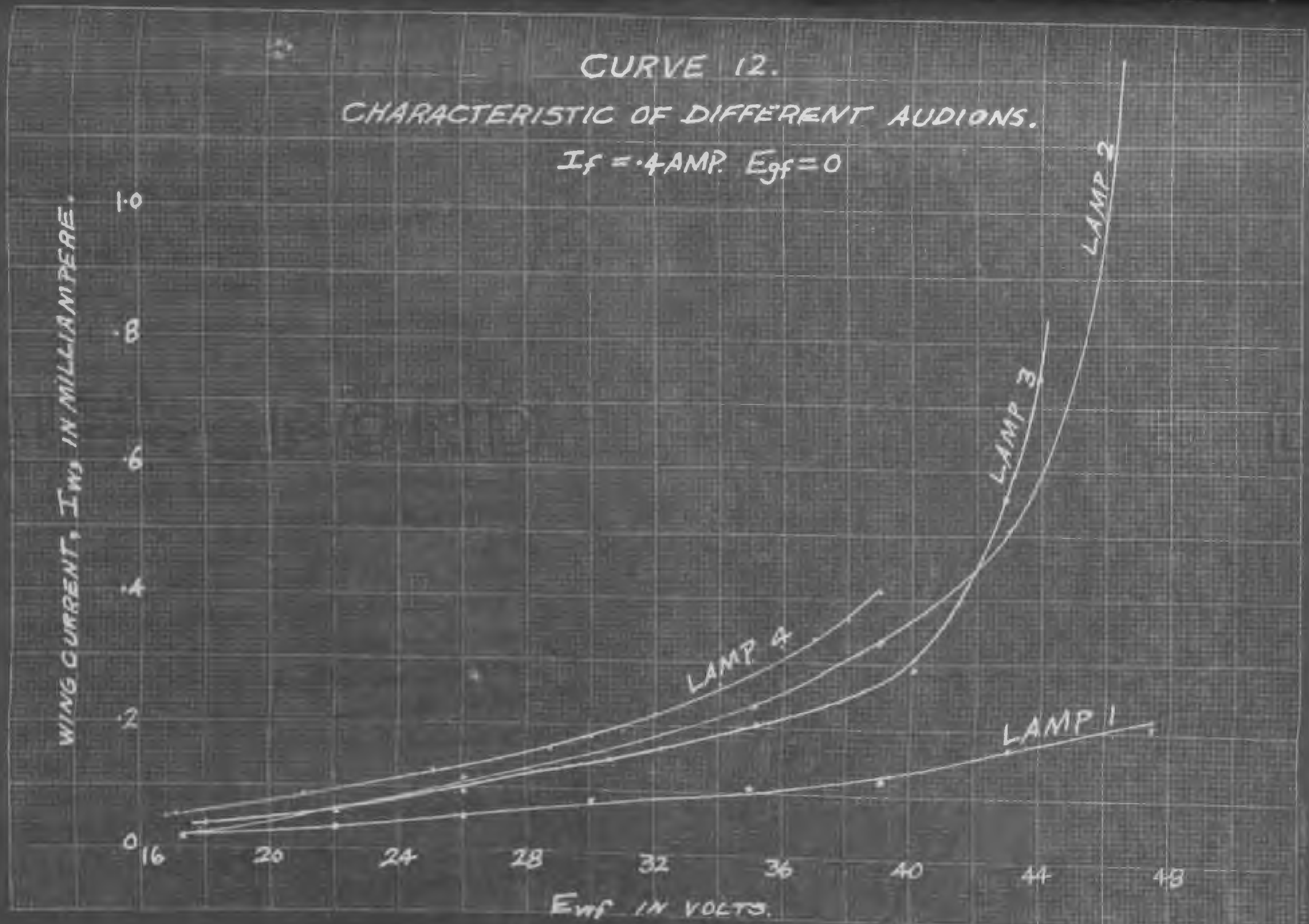

CURVE 8.
SHOWING THE EFFECT OF VARIATION OF E_{gf} ON I_w.
LAMP 2. I_f = .5 AMP. E_{wf} CONST.
I_w, IN MILLIAMPERES.
2.0
1.6
1.2
.8
.4
10
20
30
40
50
60
70
80
90
GRID POTENTIAL, E_{gf}, IN VOLTS.
E_{wf} = 30 V
E_{wf} = 17.5 V.


CURVE 9.
SHOWING THE EFFECT OF
VARIATION OF E_{gf} ON I_w.
LAMP No. 3. I_f = 4 AMP. E_{wf} = CONST.
E_{wf} = 75 V.
E_{wf} = 60 V.
E_{wf} = 55 V
E_{wf} = 45 V.
E_{wf} = 40 V.
E_{wf} = 35 V
E_{wf} = 20 V.
I_w IN MILLI-AMPERES.
GRID POTENTIAL, E_{gf}, IN VOLTS.
0
14
28
42
56
70
84
98
112
126
140
1
2
3
4
5
6

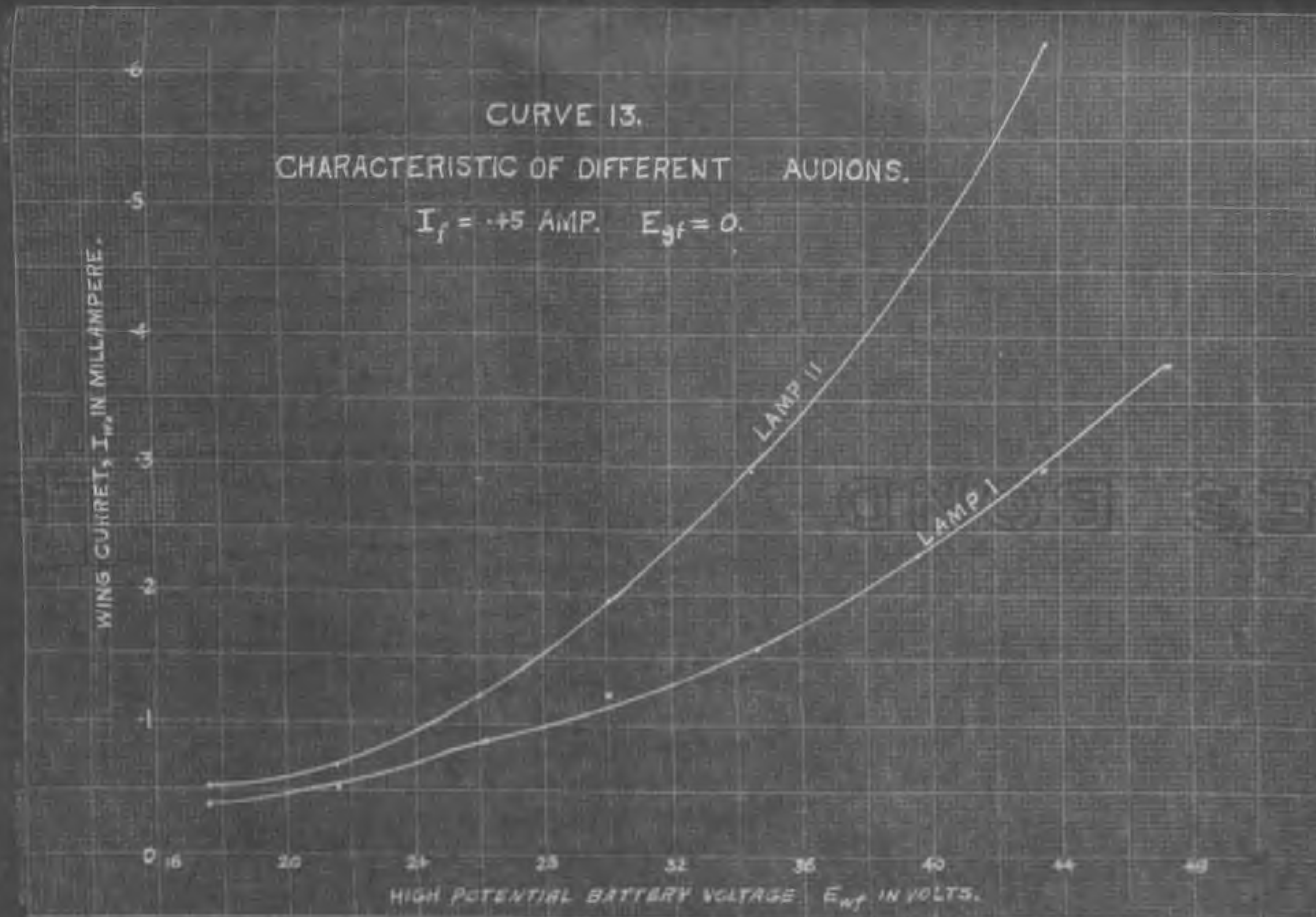


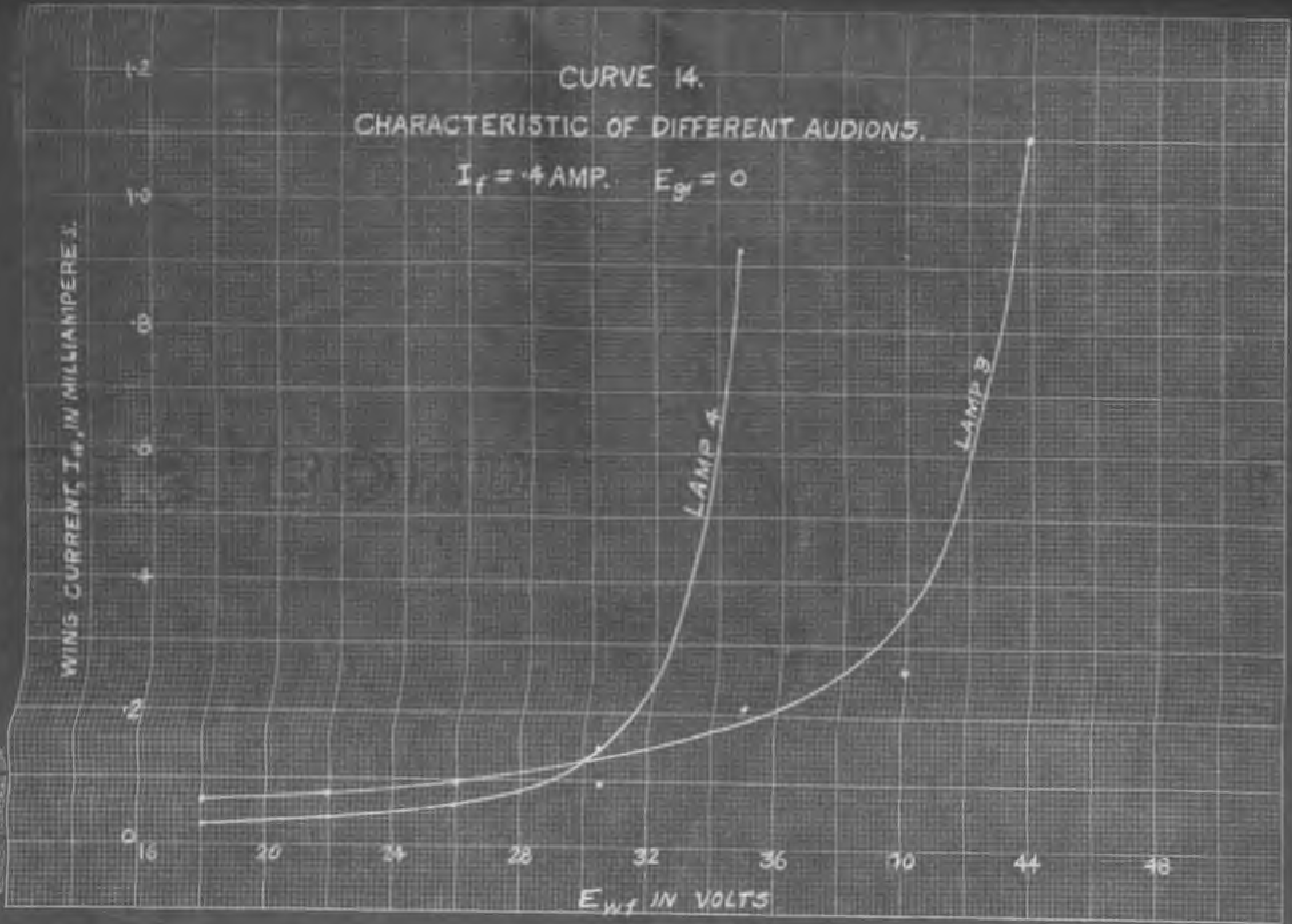
CURVE 10
SHOWING THE EFFECT OF VARIATION OF E_{gf} ON I_w
LAMP J I_f = 4 AMP. E_{wf} CONST.
I_w IN MILLIAMPERE
.8
.7
.6
.5
.4
.3
.2
.1
0
20
40
60
80
100
120
140
GRID POTENTIAL,
E_{gf}, IN VOLTS

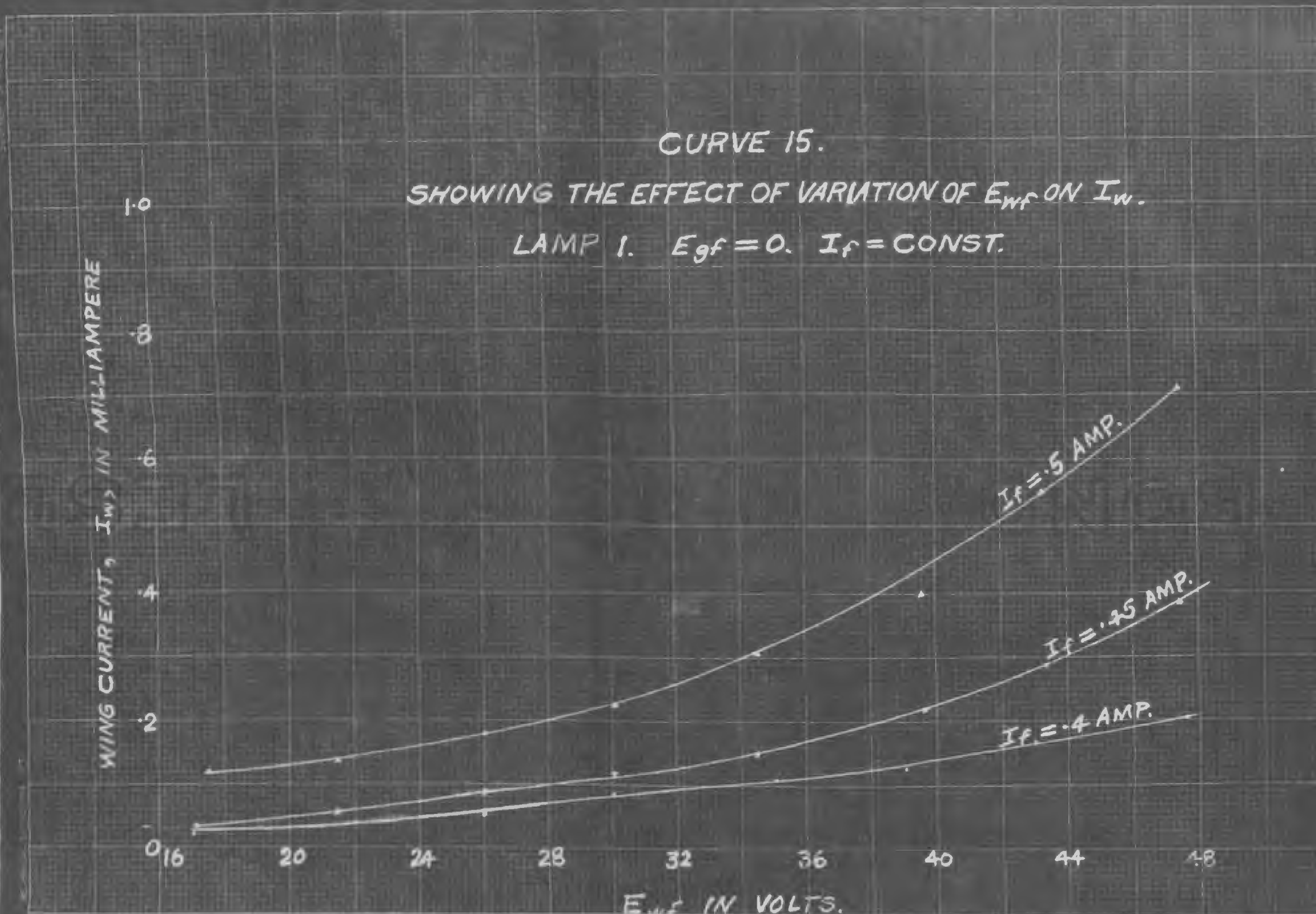

CURVE II
SHOWING THE EFFECT OF VARIATION OF E_{gf} ON I_w.
LAMP 4. I_f = .4 AMP. E_{wf} CONST.
I_W IN MILLIAMPERE
1.2
1.0
.8
.6
.4
.2
0
E_{wf} = 48 V
E_{wf} = 45 V
E_{wf} = 39 V
E_{wf} = 35 V.
E_{wf} = 25 V
E_{wf} = 17 V
GRID POTENTIAL, E_{gf}, IN VOLTS.
20
40
60
80
100
120
140
160
180
200

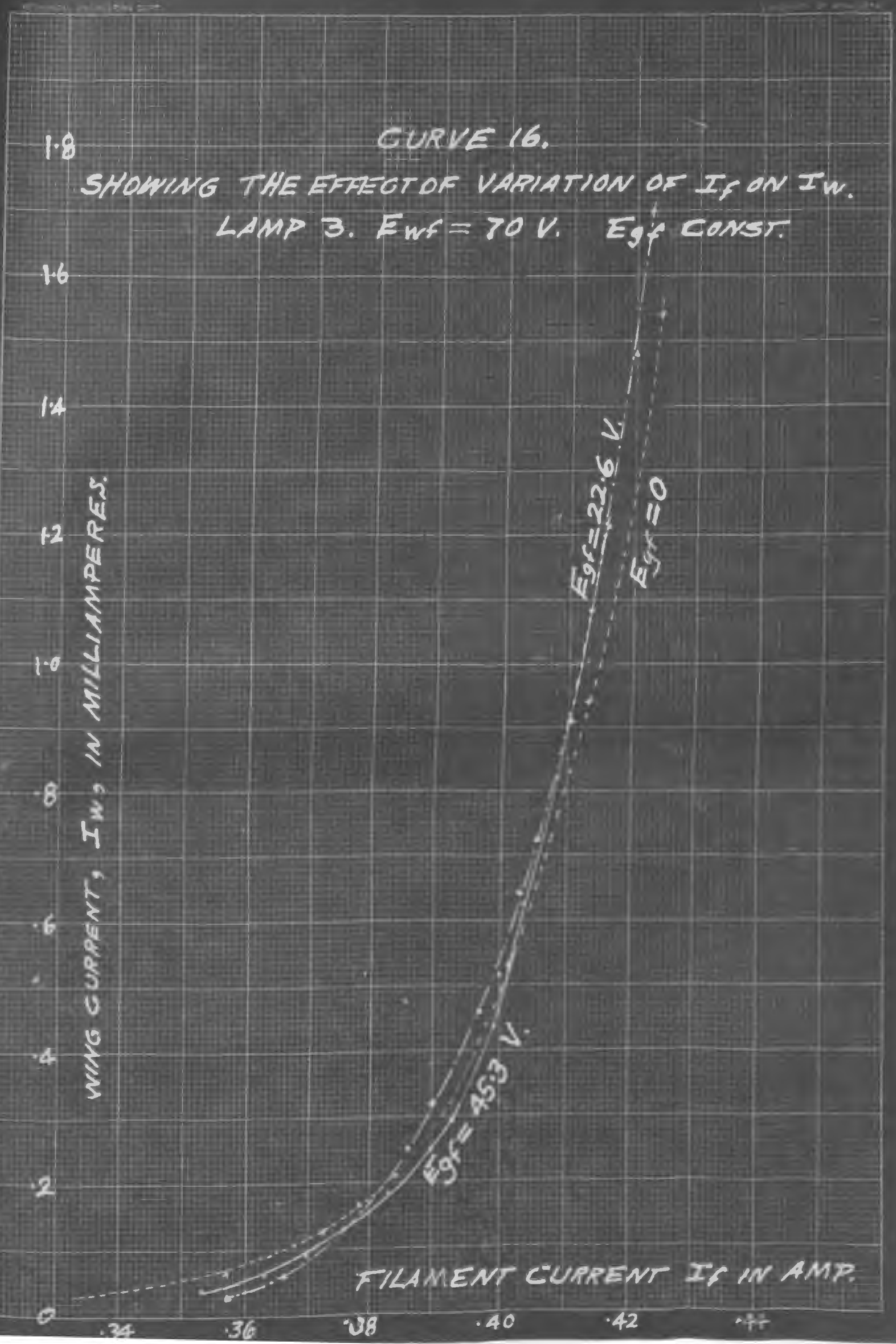


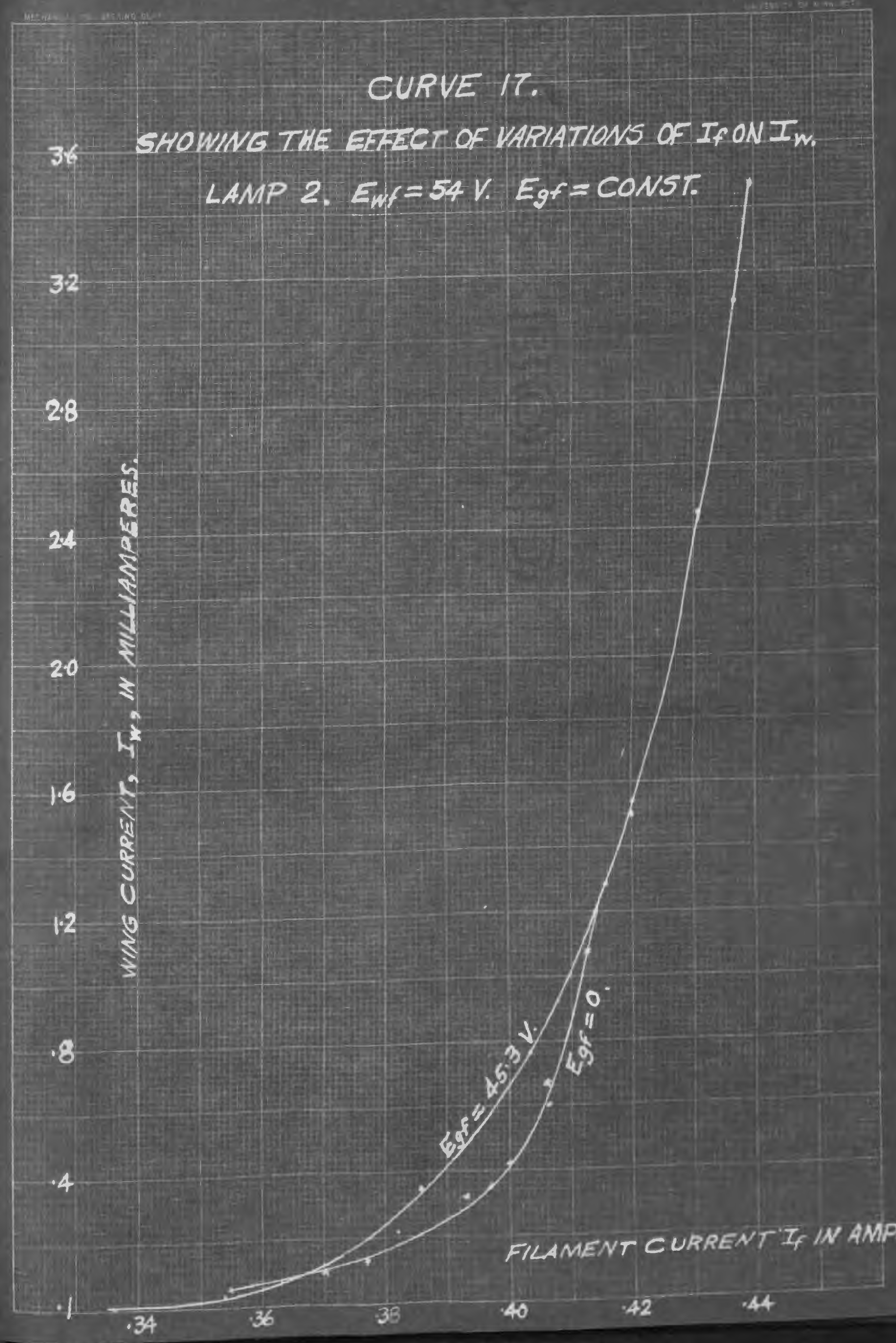
CURVE 12.
CHARACTERISTIC OF DIFFERENT AUDIONS.
If = ·4 AMP. Egf = 0
WING CURRENT, Iw, IN MILLIAMPERE.
1·0
·8
·6
·4
·2
0
16
20
24
28
32
36
40
44
48
Ewf IN VOLTS.
LAMP 1
LAMP 2
LAMP 3
LAMP 4


CURVE 13.
CHARACTERISTIC OF DIFFERENT AUDIONS.
I_f = ·45 AMP. E_{gf} = 0.
LAMP II
LAMP I
WING CURRET, I_w, IN MILLAMPERE.
HIGH POTENTIAL BATTERY VOLTAGE E_{wf} IN VOLTS.
0
1
2
3
4
5
6
16
20
24
28
32
36
40
44
48


CURVE 14.
CHARACTERISTIC OF DIFFERENT AUDIONS.
I_f = ·4 AMP. E_{gf} = 0
LAMP 4
LAMP 3
WING CURRENT, I_w, IN MILLIAMPERES.
1·2
1·0
·8
·6
·4
·2
0
16
20
24
28
32
36
40
44
48
E_{wf} IN VOLTS


CURVE 15.
SHOWING THE EFFECT OF VARIATION OF E_{wf} ON I_w.
LAMP 1. $E_{gf} = 0$. I_f = CONST.
WING CURRENT, I_w, IN MILLIAMPERE
1.0
·8
·6
·4
·2
0
16
20
24
28
32
36
40
44
48
E_{wf} IN VOLTS.
I_f = ·5 AMP.
I_f = ·45 AMP.
I_f = ·4 AMP.


CURVE 16.
SHOWING THE EFFECT OF VARIATION OF If ON Iw.
LAMP 3. Ewf = 70 V. Egf CONST.
WING CURRENT, Iw, IN MILLIAMPERES.
FILAMENT CURRENT If IN AMP.
Egf = 22.6 V.
Egf = 0
Egf = 45.3 V.
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
.34
.36
.38
.40
.42

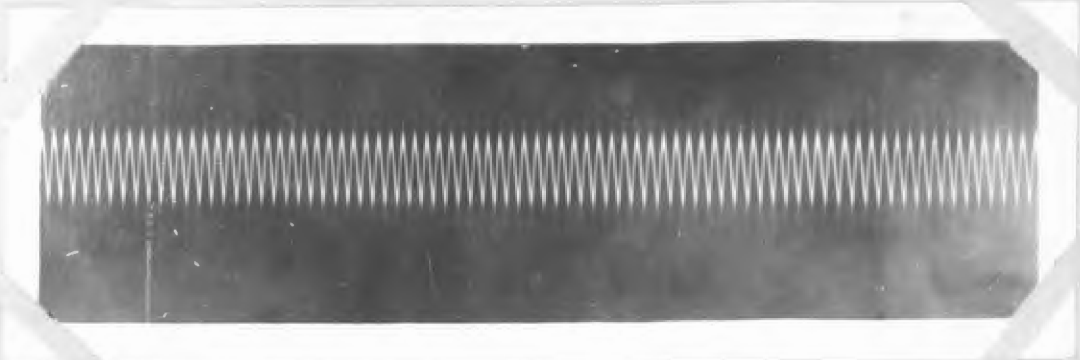


CURVE 17.
SHOWING THE EFFECT OF VARIATIONS OF If ON Iw.
LAMP 2. Ewf = 54 V. Egf = CONST.
WING CURRENT, Iw, IN MILLIAMPERES.
FILAMENT CURRENT If IN AMP.
Egf = 45.3 V.
Egf = 0.
3.6
3.2
2.8
2.4
2.0
1.6
1.2
.8
.4
.1
.34
.36
.38
.40
.42
.44

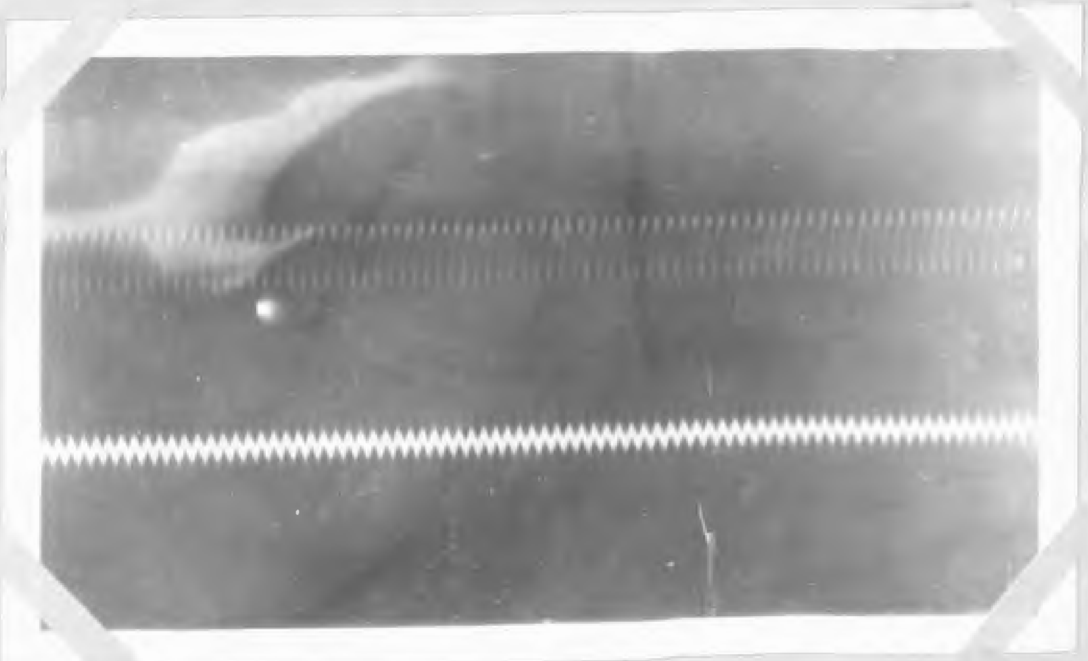
Curve 18.

Showing the Magnitude of Grid Potential and Current

Four Lamps in Parallel.



Grid Potential

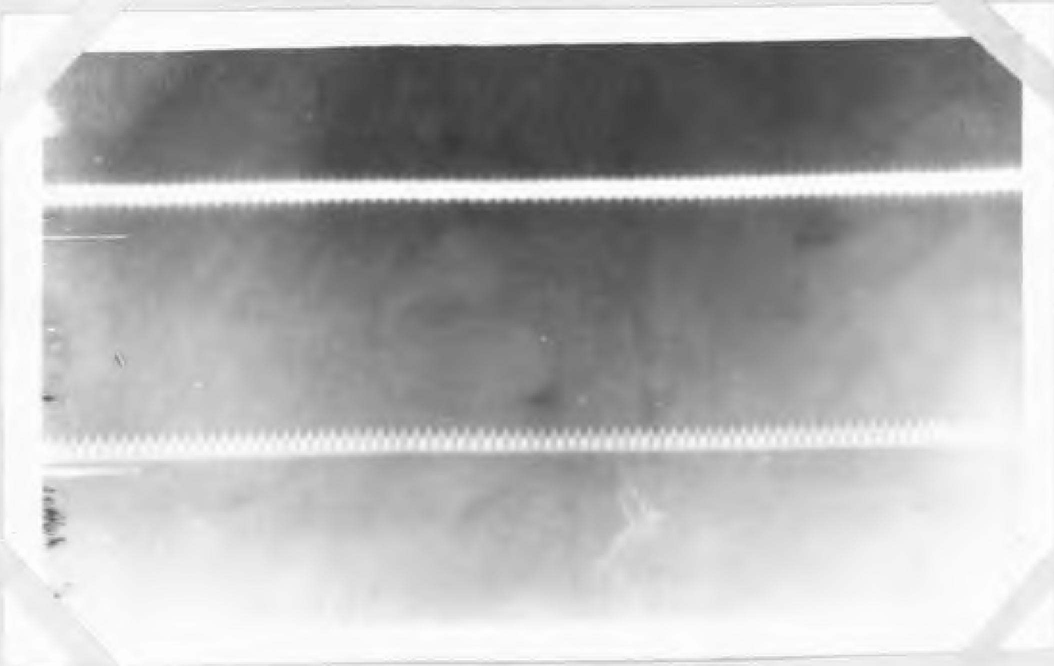


Grid Potential and Current.

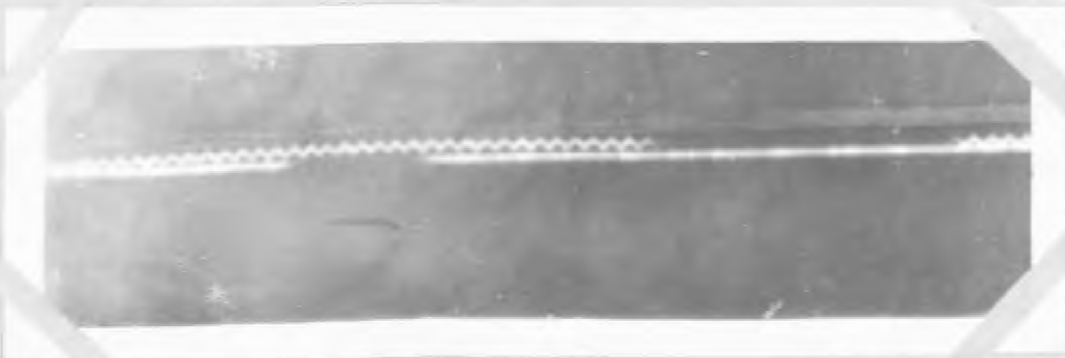
Curve 19

Showing the Magnitude of Wing and Grid Current.

Four Lamps in Parallel.



Wing and Grid Current



Wing Current

with Respect to Ground Line.