AN ELECTRONIC DEVICE FOR AUTOMATICALLY EXPOSING A SPECTROGRAPHIC PLATE

A Thesis Submitted To The

GRADUATE COMMITTEE

By

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Chairman of Graduate Committee

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INTRODUCTION

In recent years the spectrograph has developed from a small table-model optical instrument with little resolving power to a massive structure occupying a space of some 20 feet by 10 feet and having a resolving power of approximately 2.6 angstroms per millimeter for the instrument constructed at this institution. (Diagram 7) The necessity for some device whereby duplicate exposures of the photographic plates might be obtained arises in qualitative and especially in quantitative analysis. The device is required to be able to "integrate" light energy falling upon the plate over a period of time during which the light energy is continually being varied due to the change in arc conditions itself and to the change in the position of the image of the arc upon the slit.

There is always the chance for the arc to fail causing a serious loss of time while the arc is reestablished and refocused upon the slit. In quantitative analysis such a device would indicate the proper exposure of the photographic plate and aid in providing consistant end points for the consumption of the sample. These variations or errors can not be judged by the operator and therefore stresses the importance of some type of automatic control of the exposure time to insure duplication of results.

Types of Photosensitive Devices

The photoelectric cell is the most common photosensitive device for measurements of incident light energy. Other devices include the thermocouple or thermopile and the photographic plate whose sensitivity

depends upon a chemical reaction due to light energy falling on its surface.

Photoelectric cells may be divided into three classes:

(1) Photovoltaic

(2) Photoconductive

(3) Photoemissive

The photovoltaic cell is commonly known as the Weston type cell and produces an e.m.f. when light energy falls thereon. The Weston cell is characterized by its low impedance, linearity and simplicity.

The photoconductive cells become more conductive to electricity when light energy falls upon them due to a decrease in their characteristic resistance. The selenium cell is a typical example of this type and is not dependable.

The photoemissive cell consists of a photosensitive material placed usually in a low pressure enclosure and ejects photoelectrons from its surface when struck by light energy. This type of cell can be subdivided into three classes:

(1) The vacuum cell

(2) The gas cell

(3) The secondary emission electron multiplier cell.

Materials used as cathodes of vacuum and gas cells are metals of low work function sensitive to light rays. Examples are sodium, caesium, lithium, potassium, rubidium and barium. These metals are characterized by; one, their threshold frequency, that is the frequency below which no photo-

electric emission will take place; two, their low surface work function.

The threshold frequency is given by:

$$\nu = \frac{\frac{1}{2}mV^2 - p}{h}$$

ν = frequency

h = Planck's constant

V = velocity of light

m = mass of the electron

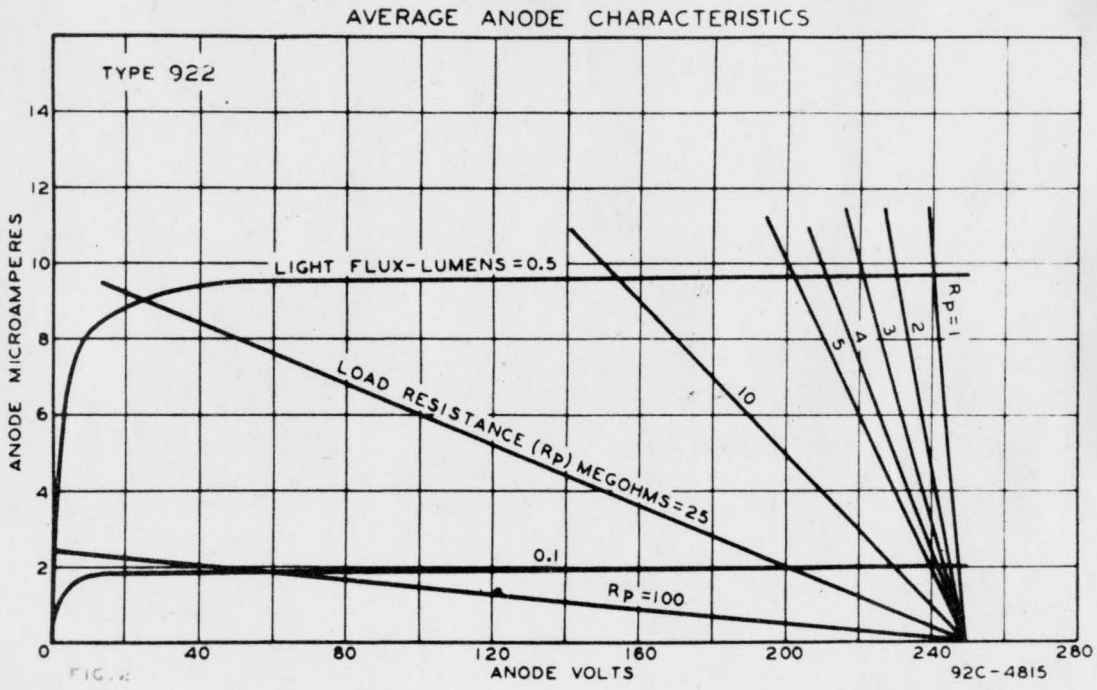
p = work function of the photo-electric surface

The following table gives the work function and threshold wave lengths of important elements:

Table I Photoelectric Constants

Atomic No.	Metal	Work function	Threshold Wave Length
3	Li	2.28 volts	5400 A
11	Na	2.46	5000 A
19	K	2.27	5500 A
20	Ca		3700 A
37	Rb	2.17	5700 A
55	Cs	1.90	6600 A
56	Ba		5400 A

In graph I the characteristics of a typical vacuum cell is given. These characteristics apply to both the ordinary vacuum cell and the secondary emission photoelectric multiplier for its cathode and


AVERAGE ANODE CHARACTERISTICS
TYPE 922
ANODE MICROAMPERES
ANODE VOLTS
LIGHT FLUX-LUMENS = 0.5
LOAD RESISTANCE (Rp) MEGOHMS = 25
0.1
Rp = 100
10
5
4
3
2
Rp = 1
0
2
4
6
8
10
12
14
40
80
120
160
200
240
280
92C-4815

GRAPH 1

first anode. The vacuum cell and the secondary emission multiplies have constant sensitivities over large ranges of anode to cathode potentials. Their sensitivities are linear with respect to intensity of illumination. They are further characterized by a wide operating range of anode to cathode potentials.

The gas cell consists of a simple vacuum cell structure containing a rare gas at low pressure. Typical gases are neon, argon or nitrogen. The gas acts to amplify the photoelectric currents by collision of electrons with atoms of the gas producing ions.

The negative ions produced add to the photoelectric current and proceed to the anode while the positive ions are neutralized at the cathode. The newly produced negative ions may also strike other atoms and ionize them in their path to the anode, thus a large amplification can be obtained. This amplification is limited to approximately 10 by the geometry of the tube and ionization potential of the gas therein. The amplification also decreases for decreased light intensities. The potential between the anode and cathode is limited by the ionization potential of the gas contained therein. The polorization potential is usually less than 90 volts and varies with the intensity of incident light energy. The photoelectric current is not linear with illumination or anode to cathode potential. Its sensitivity approaches that of a vacuum cell for intensities below 0.1 lumen.

The secondary emission multiplier is simply a vacuum phototube which makes use of secondary emission of the first anode and each successive anode to amplify the photoelectric current.

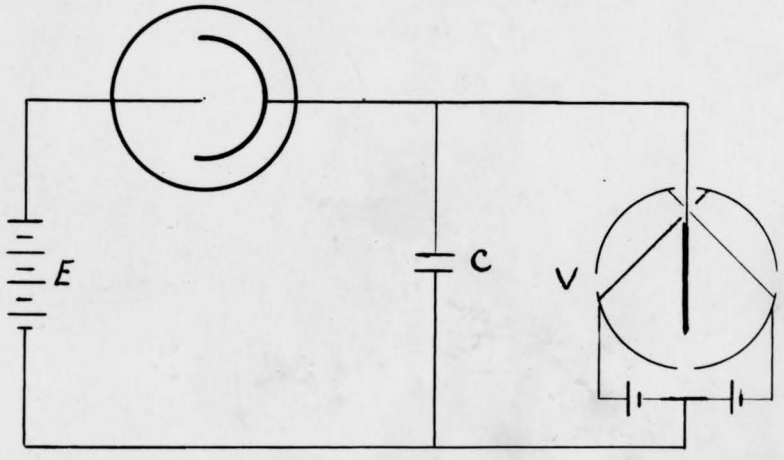
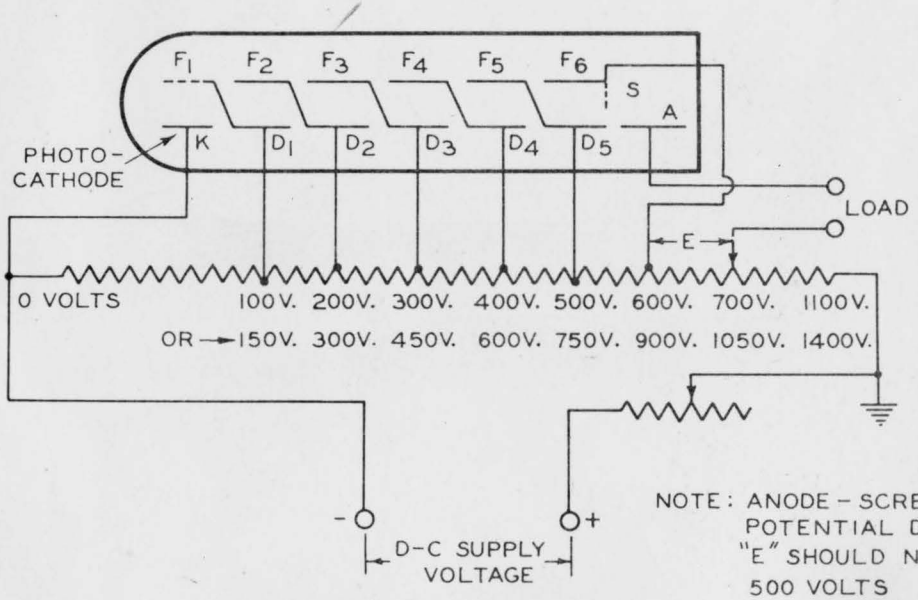


DIAGRAM 1.

C-7004

SCHEMATIC WIRING DIAGRAM
WITH TYPICAL OPERATING VOLTAGES



NOTE: ANODE - SCREEN
POTENTIAL DIFFERENCE
"E" SHOULD NOT EXCEED
500 VOLTS

DIAGRAM 2.

The arrangement of such a tube is shown in diagram 2 taken from application sheets of R. C. A. The focusing of the beam of electrons throughout the tube is accomplished by both an electrostatic field and an electromagnetic field produced at right angles to each other. This produces a cycloidol path of electrons proceeding down to the collector anode. The secondary emissive surfaces are prepared in the same manner as the photo-sensitive surface.

The following table gives the relative sensitivity of outstanding photocells:

Table II.

Relative Sensitivities of Photoelectric Cells

Type	Sensitivity micro-amperes per lumen
Vacuum cell	14
Gas cell	50
One stage secondary emission multiplier	150
Five stage " " "	10,200
Nine stage " " "	200,000

The relation between the charge produced on a condenser by light falling on a cell at the central image and the darkening of the photographic plate.

In diagram (1) there is illustrated a simple circuit for a light integrating device. The photocell charges the condenser C whose potential is measured by electrometer (V).

Assuming that the photoelectric cell is a linear device then for a constant source of light energy the photoelectric current will be constant for various potentials applied to the cell as long as (E) exceeds the saturation potential.

Let Q = the charge on the condenser

B = the blackening on the photographic plate

I = intensity of illumination

L = time

i = photoelectric current

Then $Q = CV$

$$V = \frac{1}{C}\int i\,dt$$

$$Q = C \times \frac{1}{C}\int i\,dt$$

$$Q = \int i\,dt$$

But for a particular cell at any instant $i = R_1 I$

$$Q = \int R_1 I\,dt$$

$$B = R_2 \int I\,dt$$

R_1, R_2 = constants of integration

But $B = I\,t^p$ for constant light intensity where p is a constant characteristic of the photographic surface.

$$\frac{B}{Q} = \frac{R_2 \int I\,dt}{R_1 \int I\,dt}$$

$$B = \frac{R_2}{R_1} Q = I t^p$$

Thus the blackening is proportional to the charge upon the condenser. This charge can be measured in terms of the potential on the condenser using an electrometer as shown in diagram (1).

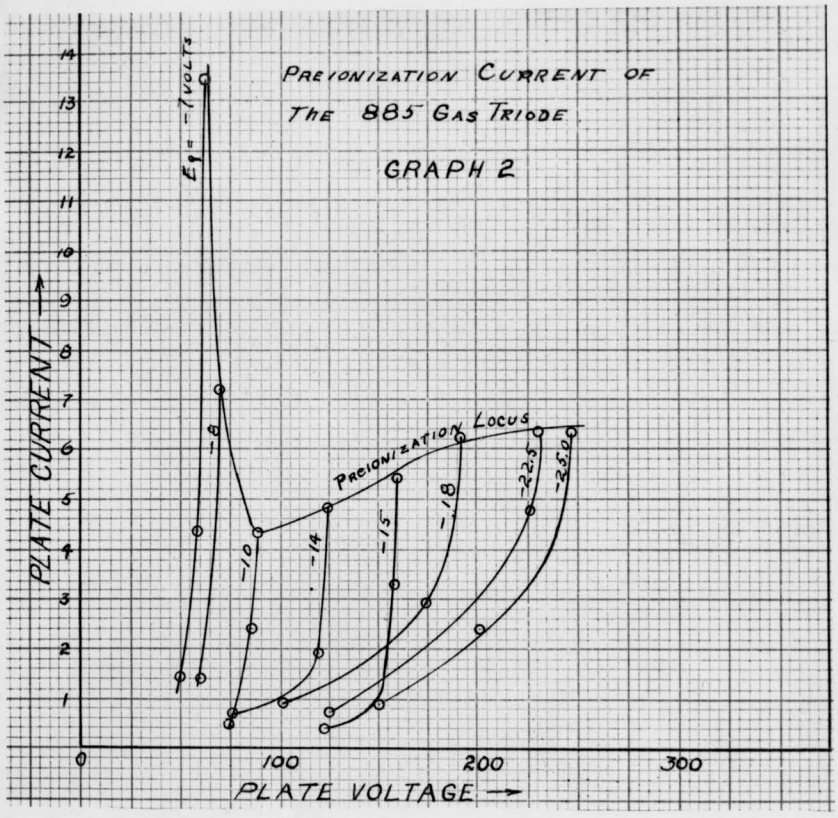
It is also noted that B is independent of the time involved for $B = \frac{R_2}{R_1} Q$ and gives a direct quantitative measure of the quantity of light energy fallen on the cell and is a function of the light energy which has fallen on the plate. If the cell is placed at the central image of the spectrograph the relation between the energy falling upon the plate of the photocell is probably very nearly the same as that falling upon the photographic plate itself.

In Diagram 7 the light falling upon the cell is always some fraction of that falling upon the plate,

thus,

$$B = A \frac{R_2}{R_1} Q$$ where A is the sector fraction

In the above derivation all errors such as leakage and non-linear response of the phototube have been neglected. Errors due to surface leakage can be reduced to a minimum by using material of high resistivity for all mountings and by adopting a photocell constructed with a top-cap cathode placing the cathode insulated by the glass bulb of the phototube from the anode. Electrostatic interference can be eliminated by shielding the cell and grounding the shield.


PREIONIZATION CURRENT OF
THE 885 GAS TRIODE
GRAPH 2
PLATE CURRENT →
PLATE VOLTAGE →
Eg = -1 VOLTS
-8
-10
-14
-15
-18
-22.5
-25.0
PREIONIZATION LOCUS
0
100
200
300
1
2
3
4
5
6
7
8
9
10
11
12
13
14

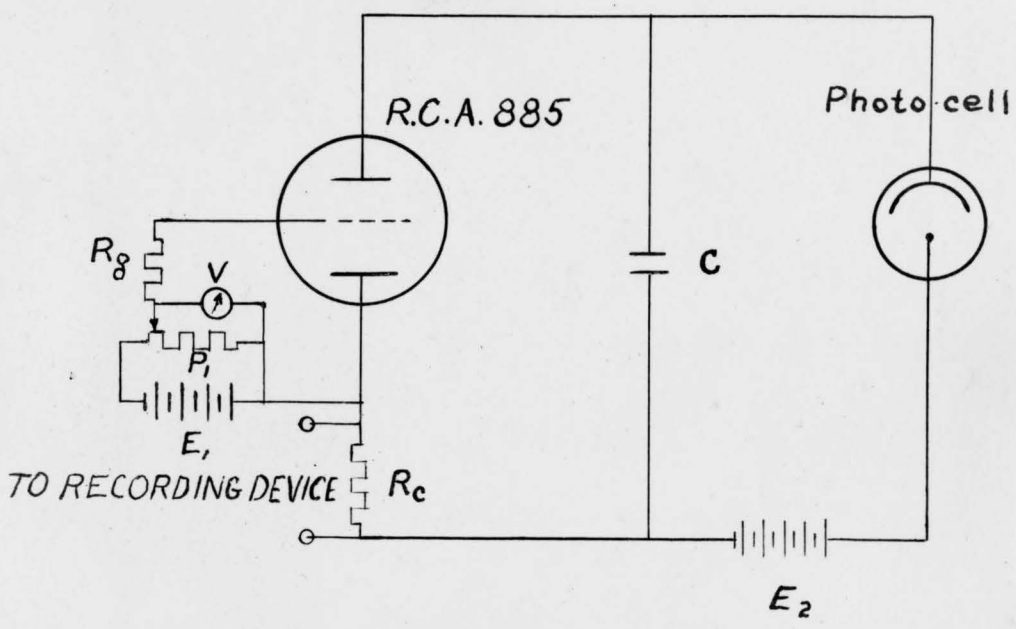


DIAGRAM 3

Application of the Gas Triode to Automatic Exposure

In the development of the final apparatus several schemes were tried. The first scheme consisted of amplifying the rectified alternating voltage developed by the photocell when illuminated and this in turn operating a watthour meter as the integrating device. This method though worked with success for illumination of slow intensity variations would not work for illumination of rapid variations due to the large moment of inertia of the watthour meter disc.

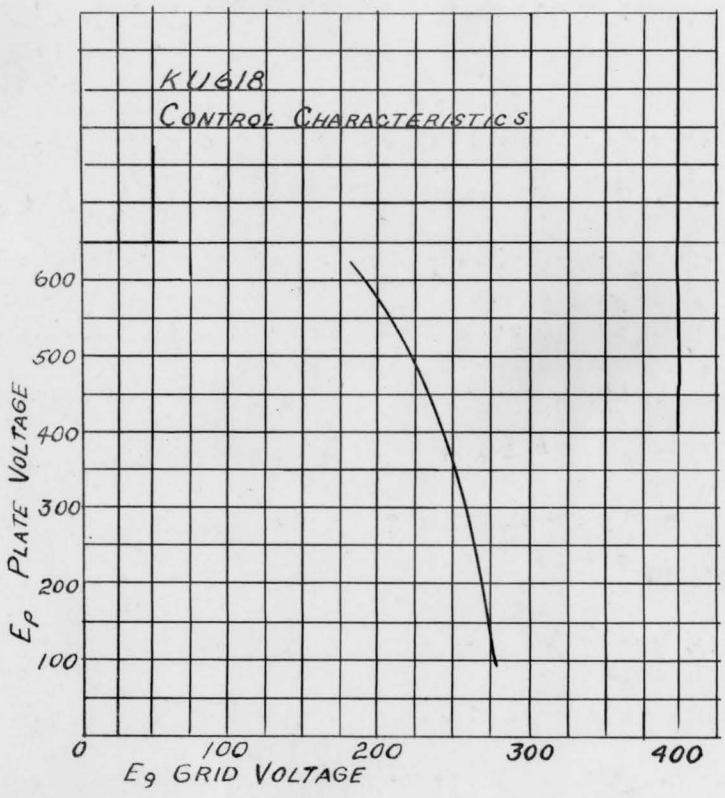
Attention was again turned to the integrating properties of the condenser given in the above derivation. If the charge on a condenser could be measured and at some predetermined value of charge the condenser be discharged and again allowed to charge, a repetition of this process could be used as an integrating method. If the process could be repeated frequently enough the light energy could be considered integrated by increments.

The grid-plate discharge properties of the gas triode uniquely fulfills these requirements. It not only will determine the point at which some predetermined charge has been reached but also acts as the discharge mechanism. A typical curve giving the characteristics of a gas triode is shown in graph (3) for the Westinghouse cold cathode grid glow gas triode # RU618.

Characteristics for an R.C.A. 885 hot cathode gas triode obtained from experimental data is given in graph (2).

The R.C.A. 885 is noted for its lower control grid-plate ratio and was tried in several different circuits. In diagram 3 is shown one of the first methods. In this circuit the cell charges the condenser to some potential at which the gas triode becomes conducting and discharges the condenser. By

GRAPH 3


KU618
CONTROL CHARACTERISTICS
600
500
400
300
200
100
E_p PLATE VOLTAGE
0
100
200
300
400
E_g GRID VOLTAGE

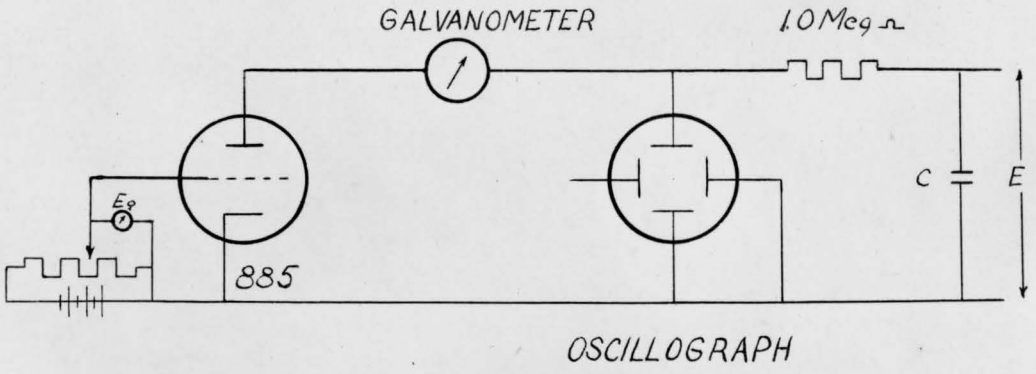


DIAGRAM 4.

counting the number of discharges the light energy can be considered integrated. The potential at which discharge occurs can be controlled by the applied grid voltage (V). Experimentally it was found that this arrangement would not work for small amounts of light, probably due to leakage in the 885 prior to breakdown. In an effort to find how this leakage varied the data and curve shown in graph (2) was obtained by the circuit shown in diagram 4.

The following table gives the data obtained for the preionization locus for an 885 gas triode.

Table II.

Data Jan. 5, 1940

Graph II

Preionization Currents of the 885 Gas Triode

Eg	Ep	Ip x 10^{-7}	Eg	Ep	Ip x 10^{-7}	Eg	Ep	Ip x 10^{-7}
-25.0	150	0.965	-15.0	120	0.483	-10.0	75	0.483
	200	2.41		150	0.960		85	2.40
	225	3.37		155	1.93		87	4.35
	240	4.35		157	3.37		88	ionizes
	245	6.3		157	4.83			
	246	ionizes		158	ionizes	-8.0	65	1.45
							70	7.20
-22.5	150	0.72	-14.0	75	0.72		71	ionizes
	200	1.93		100	0.96			
	225	4.83		120	1.93	-7.0	60	4.35
	230	6.3		122	2.9		61	8.68
	231	ionizes		123	4.83		62	13.5
				124	ionizes		64	ionizes

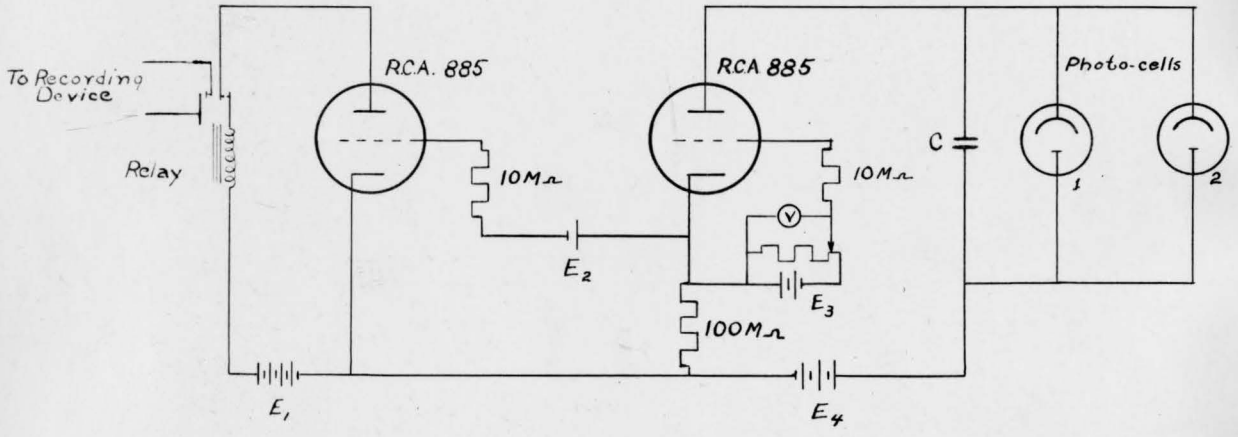

To Recording Device
Relay
R.C.A. 885
RCA 885
Photo-cells
C
10M Ω
10M Ω
100M Ω
E1
E2
E3
E4
V
1
2

DIAGRAM 5

Eg	Ep	Ip x 10^{-7}	Eg	Ep	Ip x 10^{-7}	Eg	Ep	Ip x 10^{-7}
-18.0	100	0.97	-12.0	100	0.96	-5	35	1.45
	150	1.83		105	2.40		40	7.2
	175	2.90		106	4.83		41	21.7
	185	4.35		107	ionizes		42	ionizes
	186	6.3						
	188	ionizes						

As the plate voltage was increased readings were taken of the plate current indicated by the galvanometer. This was continued until breakdown of the gas occurs at which point the plate voltage was noted from the deflection of the oscillograph beam. The breakdown is noted by oscillations of the gas triode producing a sawtooth wave form on the screen of the oscillograph. This method allows a very sensitive galvanometer tc be inserted in the plate circuit being protected by the high resistance of one million ohms. The oscillograph acts as a no current voltmeter whose voltage is given by the deflection of the cathode ray beam. Readings were taken for various values of grid potentials and graph 2 shows the grid-plate relation as well as the preionization locus. The characteristic of the tube takes on three definite and different types as will be noted by inspection of the curves. The preionization currents reach a minimum at a grid voltage of ten volts.

The method shown in diagram 3 of course failed due to the large preionization currents of the 885. These currents were far greater than the photoelectric currents and therefore the 885 tube would not fire for very small photoelectric currents produced by small amounts of illumination.

In diagram 5 is shown a modified circuit arrangement similar to that shown in diagram 3. In this circuit cell number one receives the light to be

integrated. Immediately as the circuit is placed into operation the 885 charges the condenser to some value and then the cell acts as the discharge device. Upon discharge to some value the 885 again charges the condenser to the same predetermined voltage. In this arrangement it was found that there was a constant leakage through the 885 and was of the same order of magnitude as the currents experienced for small order of illumination values. This leakage was due either to internal leakage in the gas or to leakage in the base of the tube support, or both.

An effort to overcome this was tried by using a second photo-cell, cell number two, in diagram 5. A constant discharge current was maintained by a small amount of light falling upon cell number two producing a current equal to that tending to charge the condenser by the 885. This scheme seemed to work with greater success than that shown in diagram 3 but did not prove to be sensitive enough in actual practice.

A study of gas triodes gave rise to the use of a cold cathode gas triode KU 618 which has a positive grid control potential. Characteristics are given in graph III.

In diagram 6 the photoelectric cell and cold cathode grid glow tube are mounted together giving a compact arrangement and minimum capacitance in the circuit. The capacitance in the circuit is the distributed capacitance of the tubes themselves. The cell is connected such that the charging current due to illumination drives the control grid positive. Breakdown occurs at approximately 400 volts positive with respect to the cathode.

During breakdown the tube becomes conducting and relay (3) causes the step by step indicating device to move releasing the tube from a conducting state by breaking the plate circuit and restoring the tube to a nonconducting

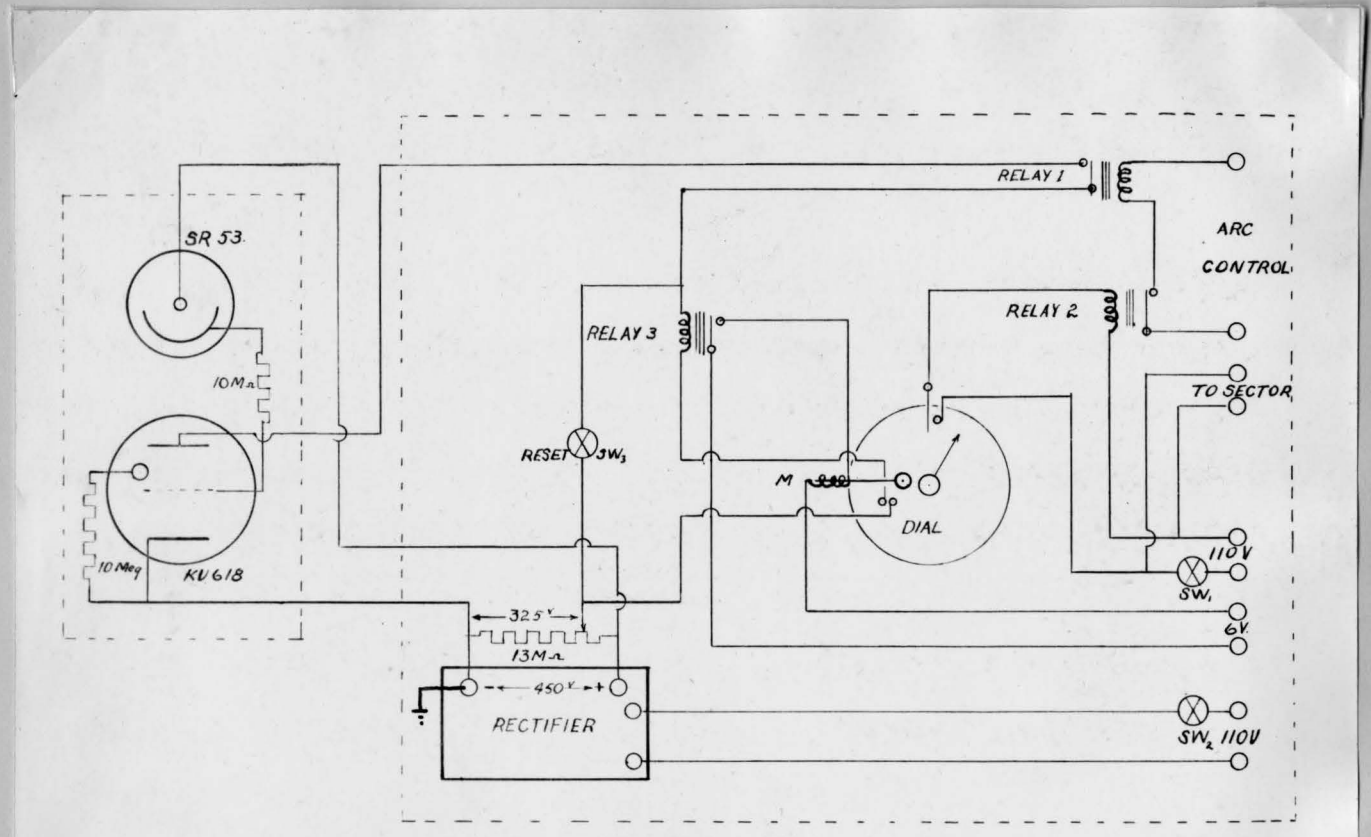

SR 53
10 Meg
10 Meg
KV 618
RELAY 1
ARC
CONTROL
RELAY 2
RELAY 3
TO SECTOR
RESET
SW3
M
DIAL
110 V
SW1
6V.
325 V
13 M Ω
450 V
RECTIFIER
SW2 110V

DIAGRAM 6

state. During breakdown the discharge in the tube also discharges the charge on the distributed capacitance of the circuit and the operation is ready to be repeated. Small increments of the light energy can thus be obtained in this manner.

In actual use the light coming through the slit is reflected upon the cell by an aluminum sector rotating about 1200 R.P.M. The schematic arrangement for the apparatus is shown in diagram 7.

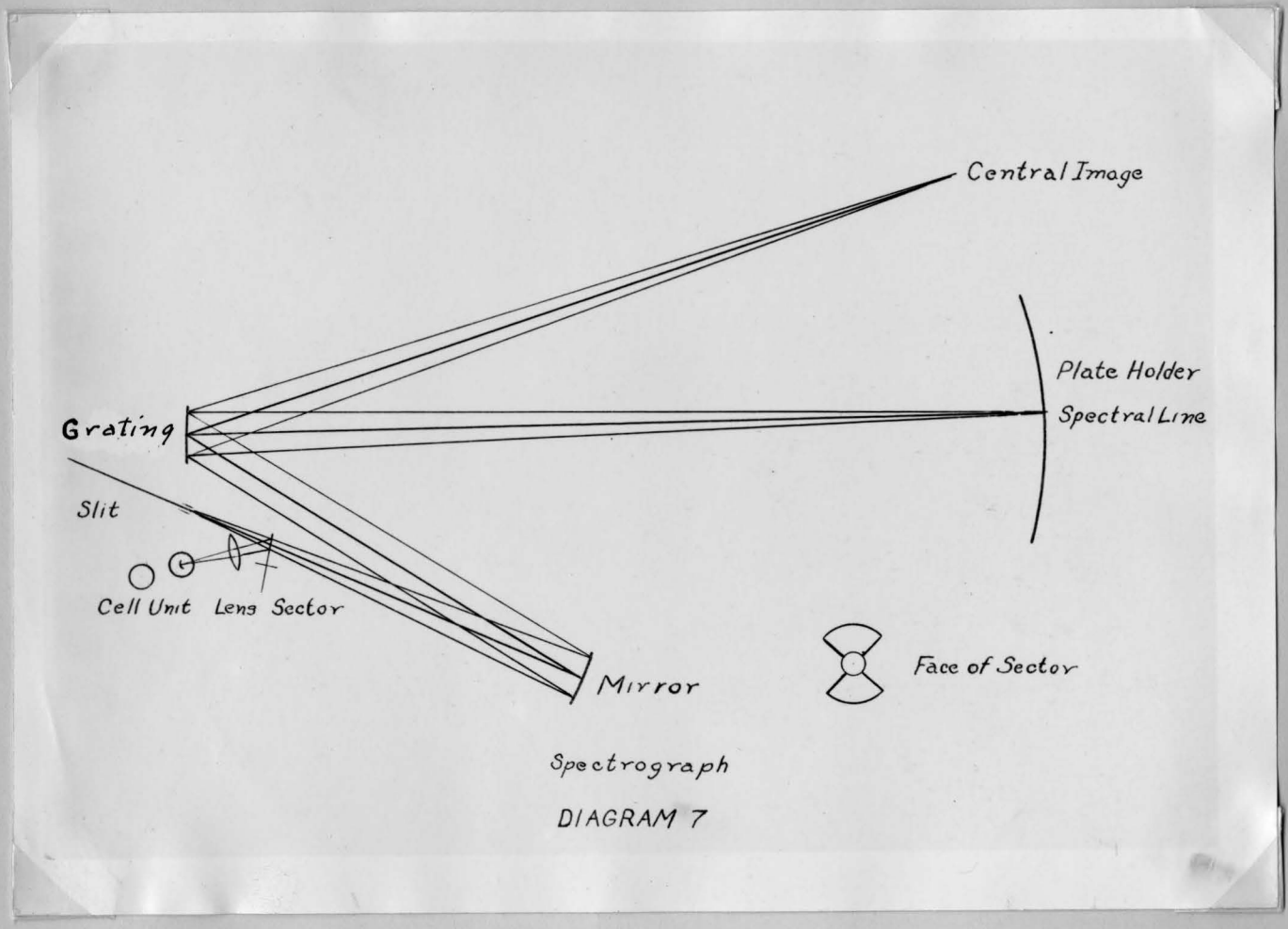
The sector is set so that some definite fraction of the incident energy falls upon the cell; the remainder of the light goes to the grating.

Since it is necessary to prolong the exposure of the spectrogram until all of the sample has been consumed in the arc, use can then be made of this excess light to operate the integrating device. By rotating the sector at a speed of 1200 R.P.M. a very good cross section of the light falling upon the cell and photographic plate is obtained.

Relay (1) cuts on the integrating device when the arc is made. Relay (2) cuts off the arc when the proper exposure has been accomplished. Direct current is obtained by a full wave rectifier. The apparatus is divided into two units, one containing the photo-cell and discharge tube, the other containing the control panel.

In operation the dial is set to the number corresponding to a particular length of exposure depending upon the sector opening and type of material being photographed.

Plate I shows a spectrogram of copper made using the exposure meter or automatic timer. It will be noted that one spectrogram is over three



Spectrograph

DIAGRAM 7

Current Amps
Time in Sec
5.6 253.1
5.6 155.7
5.6 88.0
5.7 82.0
5.7 105.0
2961
3010
3017
3021
3022
3036
3073
3116
3273
3247
3440
3478
3500
3503

PLATE I

times as long in actual exposure time as the shortest exposure. The lines are of uniform density for all five (5) spectrograms. Deliberate attempt to cause the arc to vary erratically was employed in the 253 second exposure. Measurements of the density of these lines by the Densitometer give readings which are practically the same and within experimental error. Note the uniformity of such lines as 3012, 3021, 3116 and 3503 for each spectrogram.

The following table gives the data for the exposure of plate I.

Spectrogram Plate I. Table III

Sample Copper May 16, 1940

Decker	Time sec.	Current amps.	Remarks
(1)	253.1	5.6	Very erratic arc conditions
(2)	155.7	5.6	Erratic arc conditions
(3)	88.0	5.6	Normal arc conditions
(4)	82.0	5.7	Slightly erratic arc conditions
(5)	105.0	5.7	Normal arc conditions

Sector 1/8 Slit 2 equivalent distance .0069 cms.

The following table gives the density of the lines determined by the Densitometer.

Table IV. May 21, 1940 Copper Spectrogram

Wave length	Time sec.	S_1	S_2	S_1-S_2	Average
3116	253.1	12.1	31.0	18.9	
	155.7	12.9	31.5	18.6	
	88.0	14.2	31.6	17.4	
	82.0	13.5	31.4	17.9	
	105.0	16.4	32.0	15.6	17.7

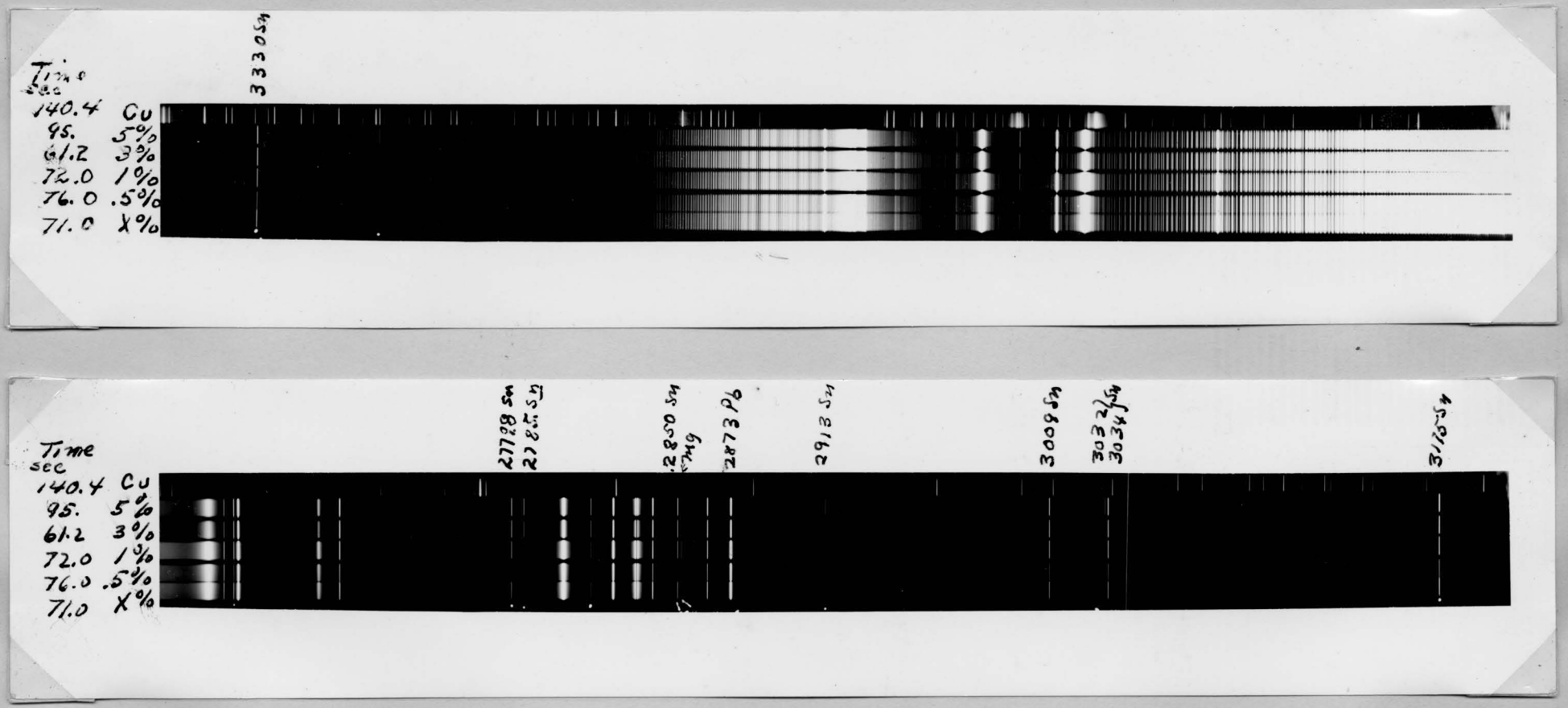

Time
sec
140.4 Cu
95. 5%
61.2 3%
72.0 1%
76.0 .5%
71.0 X%
3330 Sn
Time
sec
140.4 Cu
95. 5%
61.2 3%
72.0 1%
76.0 .5%
71.0 X%
2772.8 Sn
2828.5 Sn
2850 Sn
Mg
2873 Pb
2913 Sn
3009 Sn
3032.1 Sn
3034 Sn
3170 Sn

PLATE II

Table IV. Continued May 21, 1940 Copper Spectrogram

Wave length	Time sec.	S_1	S_2	S_1-S_2	Average
3021	253.1	19.4	30.9	11.5	
	155.7	21.0	31.1	10.1	
	88.0	20.1	31.0	10.9	
	82.0	20.0	30.9	10.9	
	105.0	21.8	30.5	8.7	10.6

In plate (2) is shown a quantitative analysis of tin using an internal standard of lead exposed by this device. Results give the unknown to be a 0.93% sample. The sample actually was a 1.0% sample. By noticing such lines as 2779, 2785 and 3300 tin lines one could easily estimate the percentage of tin in the sample.

The following table gives the data obtained from plate 2.

Date May 16, 1940

Table V Spectrogram Plate II

Decker	Time sec.	Current amps.	Sample	Dial Indicator
(1)	140.5	5.6	Copper	10
(2)	95.0	9.0	5% tin	20
(3)	61.2	10.0	3% tin	20
(4)	72.2	8.5	1% tin	20
(5)	76.0	8.5	0.5% tin	20
(6)	71.0	8.5	x% tin	20

Sector 1/8 Slit 2 equivalent distance 0.0069 cms.

Table V. continued

Data for Graph IV. Readings from plate 2

	S_0	S_1	S_2	S_1-S_0	S_2-S_0	$\frac{S_1-S_0}{S_2-S_0}$	D	%Sn	Log 10 x %Sn
2785	2.5	28.3	15.7	25.8	13.2	1.95	0.290	x	
		26.7	24.7	24.2	22.2	1.09	0.037	0.5	0.697
		26.5	12.5	24.0	10.0	2.40	0.379	1	1.000
		26.1	7.6	23.6	5.1	4.63	0.665	3	1.477
		25.5	4.7	23.0	2.2	10.45	1.019	5	1.699

% Tin from graph 0.93

Using a decker having slots arranged so that portions of the incident illumination can be allowed to pass through the slit, determination of the sensitivity of the cell to increased illumination was made. The following data was obtained:

May 17, 1940 Table VI.

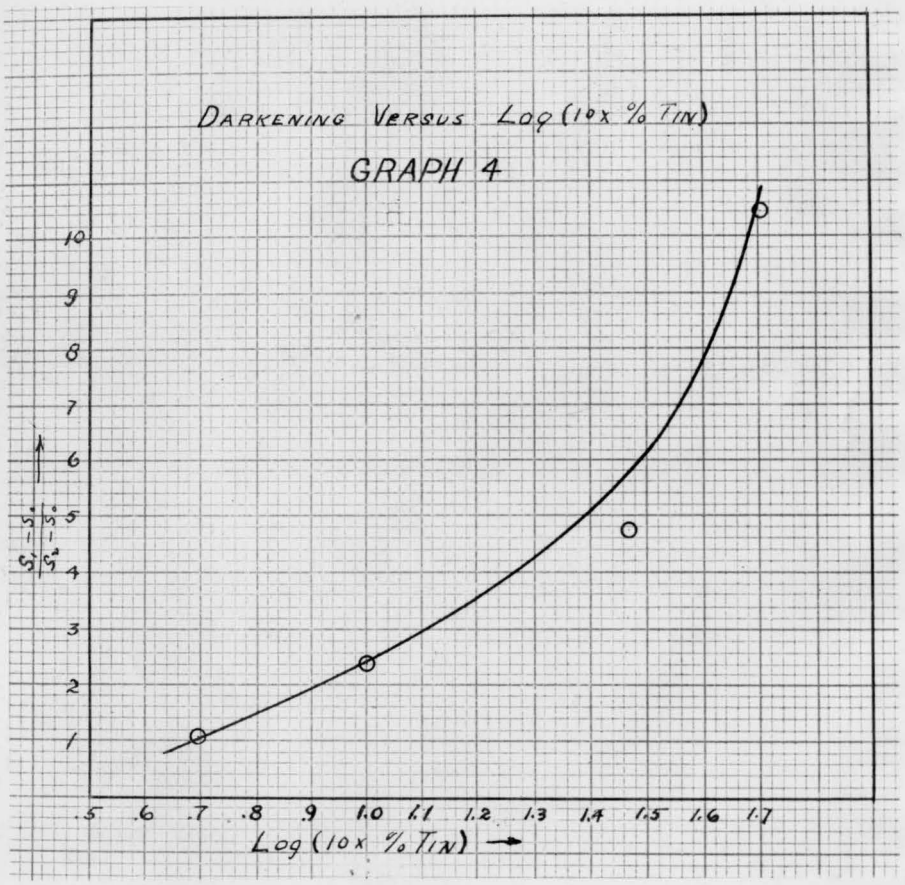
Determination of Sensitivity of cell to variation in illumination

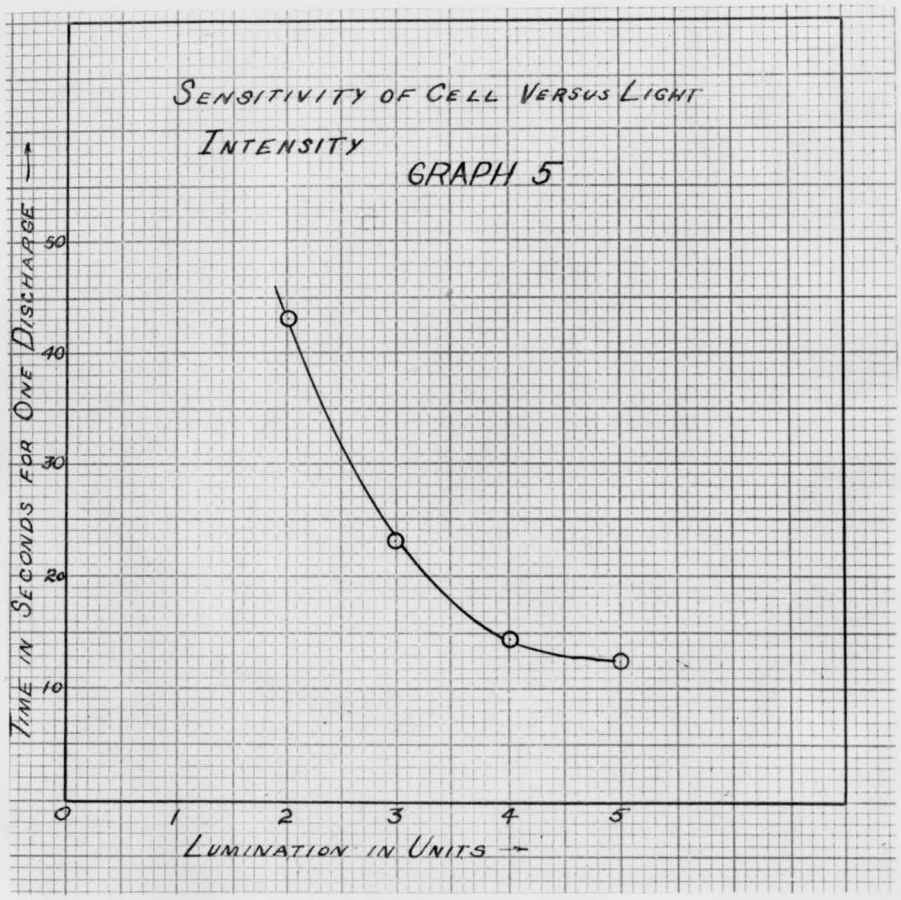
Graph V.

Sector 1/16

Size of Slit	2/5	3/5	4/5	5/5	Remarks
	41. sec.	21 sec.	14.5 sec.	11.8 sec	Cell is not linear
	38.8	23	14.0	11.0	to excessive changes
	44.2	22	14.6	11.0	in illumination
	43.0	20	14.9	10.8	
	43.0	24.8	13.5	12.0	
Average	42.0	22.2	14.3	11.3	

Time for one discharge of condenser.


DARKENING VERSUS LOG (10x % TIN)
GRAPH 4
10
9
8
7
6
5
4
3
2
1
.5 .6 .7 .8 .9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7
LOG (10x % TIN) →


SENSITIVITY OF CELL VERSUS LIGHT INTENSITY
GRAPH 5
TIME IN SECONDS FOR ONE DISCHARGE →
50
40
30
20
10
0
1
2
3
4
5
LUMINATION IN UNITS →

For small variations in intensity of illumination the response may be considered linear. The data above is represented by graph 5.

Further investigation was made as to the relative sensitivity of different portions of the cathode surface by exposing sections of the slit as given in the following data:

May 15, 1940 Table VII

Determination of Relative sensitivity of various portions of cell cathode surface.

Source 60 watt mazda lamp

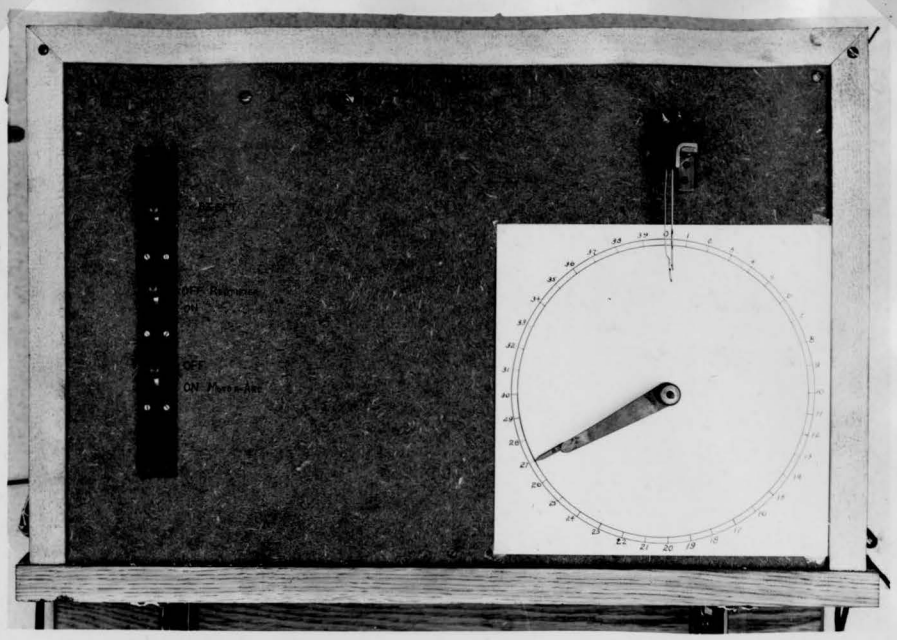
Time given for one discharge of condenser

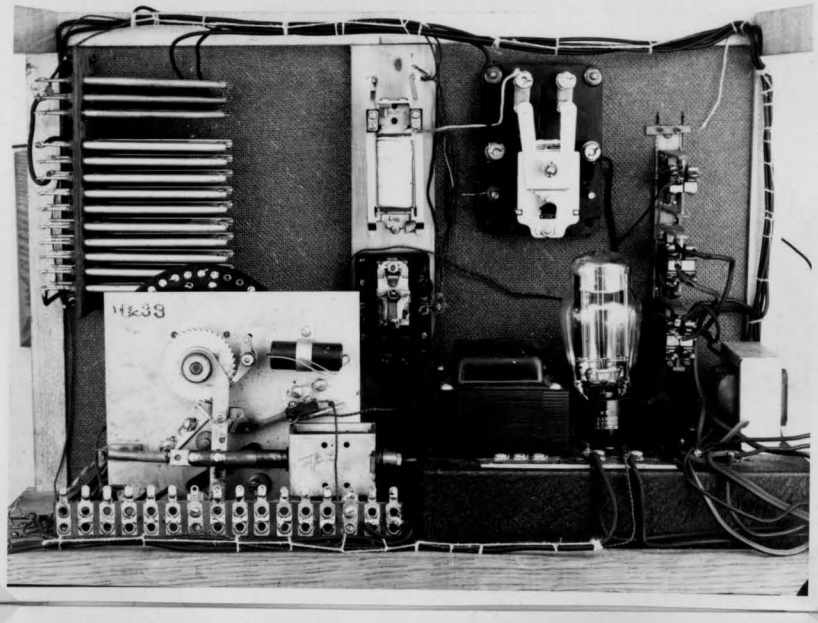
Section of slit

Top 1/5	Center 1/5	Bottom 1/5	Remarks
16 sec.	14.0	17.9	Results indicate that there
16.1	14.9	17.1	is a slight variation of the
16.2	14.8	18.9	sensitivity of the cathode
15.9	13.9	19.9	surface.
16.5	14.2	18.2	
Average 16.2	14.4	18.5	

These results indicate that the top and center of the slit portions of the image on the cell are more sensitive than the bottom portion of the slit image on the cathode surface.

In the operating the timer a cell polorization potential of 450 volts is used. From experimental data given below it was found that leakage at potentials above 500 volts was excessive and also the sensitivity of the cell





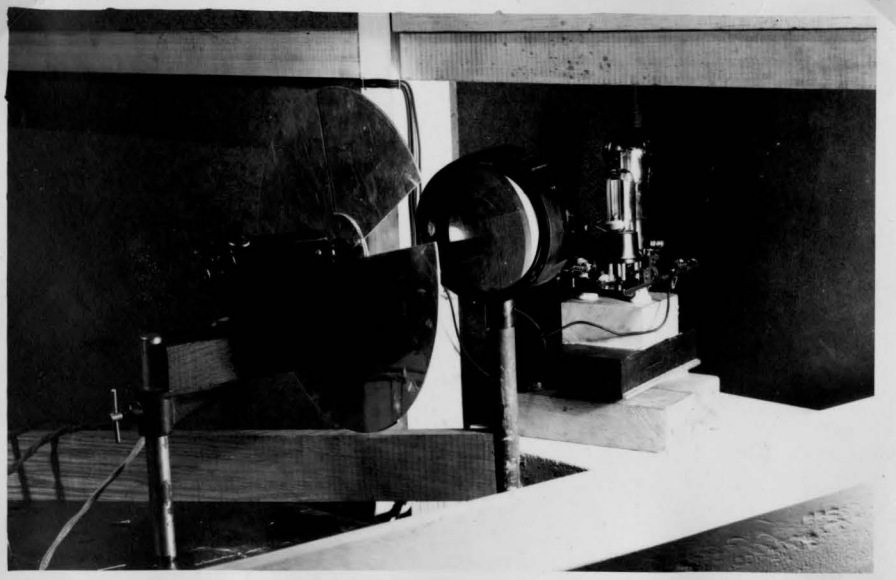


DIAGRAM 8

is independent of polorization voltage at potentials lower than 550 volts.

Data May 10, 1940 Table VII

Determination of Sensitivity Versus Cell Potential

Time for one charge of condenser sec.	Cell Potential Volts
27	400
27	450
27	500
26	550
23	600

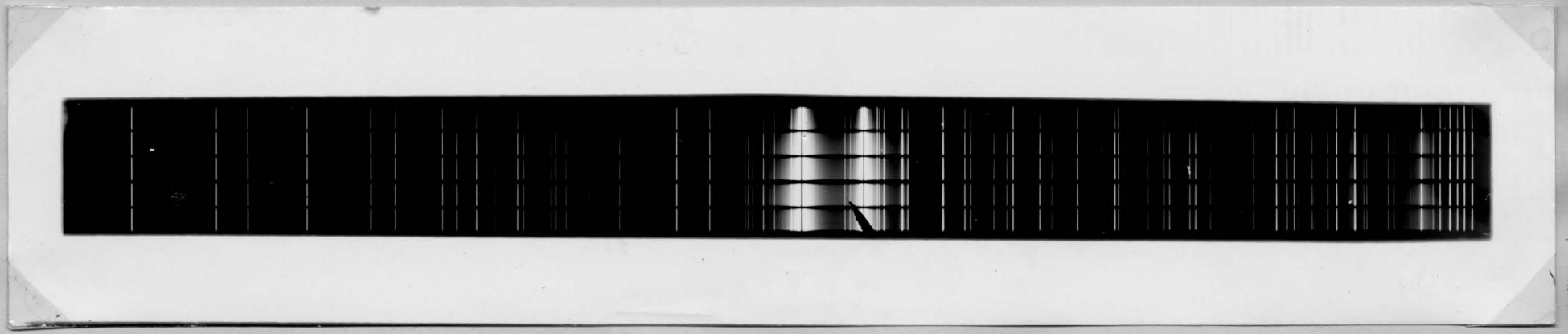
Source - 60 watt Mazda Lamp

Remarks: Sensitivity is independent of cell polorization voltage for potentials less than 550 volts.

Plate III shows five (5) spectrograms of copper made in the usual manner exposed by a stop watch for sixty seconds each and for a current of 6.4 amperes. The decided differences may be noted.

In figure 8 actual photographs of the apparatus are shown.

Fruitful experimentation should be expected in using the new and recently developed secondary emission multiplier photoelectric tube with this device in the future. The sensitivity should be increased in the order of over 10,000 for a nine stage multiplier tube.



Time For Each Exposure 60sec
Current 6.4 amps

PLATE III

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A C K N O W L E D G E M E N T

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