T6

Photo-electric Emission

by

Fadel George Antippa

American University of Beirut

A thesis presented to Professor Arthur Bacon in candidacy for the degree of Master of Arts.

March 1, 1933

Preface

The purpose of this thesis is to give a brief account of some of the work done on photoelectric emission.

Some of the experimental work done in connection with this thesis is based on a very recently published book on "Photoelectric Cells and their Applications.(1)"

Not all of the references listed in the bibliography were used in writing this thesis; the reason for including them is for future reference due to the fact that most of the material written on the subject and accounts of work done along that line are in the form of magazine articles and report papers.

---

(1) A discussion at a joint meeting of the Physical and Optical Societies, June 4 and 5, 1930.

Table of Contents

Photo Electric Emission

I Introduction

The visible region of the electromagnetic spectrum ranges between 3900 A.U. (violet) and 7600 A.U. (red). Waves that are shorter than these are the ultraviolet and those that are longer are the infra red. As we go down the spectrum we reach the X-rays, the gamma rays, and the cosmic rays. The wavelength w and the frequency f are connected by the relation,

$$c = wf$$

where c is the velocity of light and is approximately equal to three hundred thousand kilometers per second.

The term photoelectric action in its most general sense indicates all electrical effects due to the action of electromagnetic waves(1). Therefore photochemical action, fluorescence, phosphorescence, change of electrical resistance, the zeeman effect, dispersion, change in the e.m.f. of certain cells containing fluorescent substances as electrolytes(2), rotation of the plane of polarization in an electric field, and emission of electrons all come under the subject of photoelectric action. This thesis will treat photoelectric emission only.

---

(1) Stanley Allen, Photoelectricity, second edition, P 1

(2) Ritchmyer, Introduction to Modern Physics, P 136

In the year 1887(3)Hertz noticed that the discharge across a spark gap took place more easily when light was allowed to fall on the knobs than when the apparatus was in the dark. A little later, Ebert(4) showed that the above mentioned effect was at the kathode. In the year 1888, Halwacks(5) discovered that a negatively charged body loses its charge under the action of X-rays and that a neutral and insulated body would acquire a positive charge under the action of X-rays. In 1889, Elster and Geitel(6) showed that many of the electropositive elements showed photoelectric activity. Sodium and potassium exhibited the effect more strongly than others.

During the years following much work was done along that line, and the action was investigated in gases under various pressures, in high vacuum, and the effectsof temperature, intensity, frequency, plane of polarization, magnetic and electric fields upon the photoelectric action were studied.

---

(3) Stanley Allen, Photoelectricity, Second edition, P 2
(4) " " " " " "
(5) " " " " " "
(6) " " " " " P 3

II Early Investigations in the Field

The great German Physicist, Hertz, while working with the discharge of electricity between knobs, discovered a new phenomenon, mentioned on page 2, which after a short time proved to be the underlying principle of Photoelectric Emission. The discovery was this: when a discharge took place while the knobs were in the light, the spark produced was longer that when the knobs were enclosed in a dark chamber. After some experimentation, it was found that the source of light that contained a large proportion of ultraviolet rays had a greater effect on the length of the spark than the visible part of the spectrum. It was observed(1) that the action of the ultraviolet rays was more effective when they illuminated the negative knob than when they illuminated the positive one. However he could not decisively conclude that the rays had no effect on the positive knob.

Shortly after the discovery of Hertz, another remarkable effect of the action of light was discovered. A polished metal plate was charged negatively and then

---

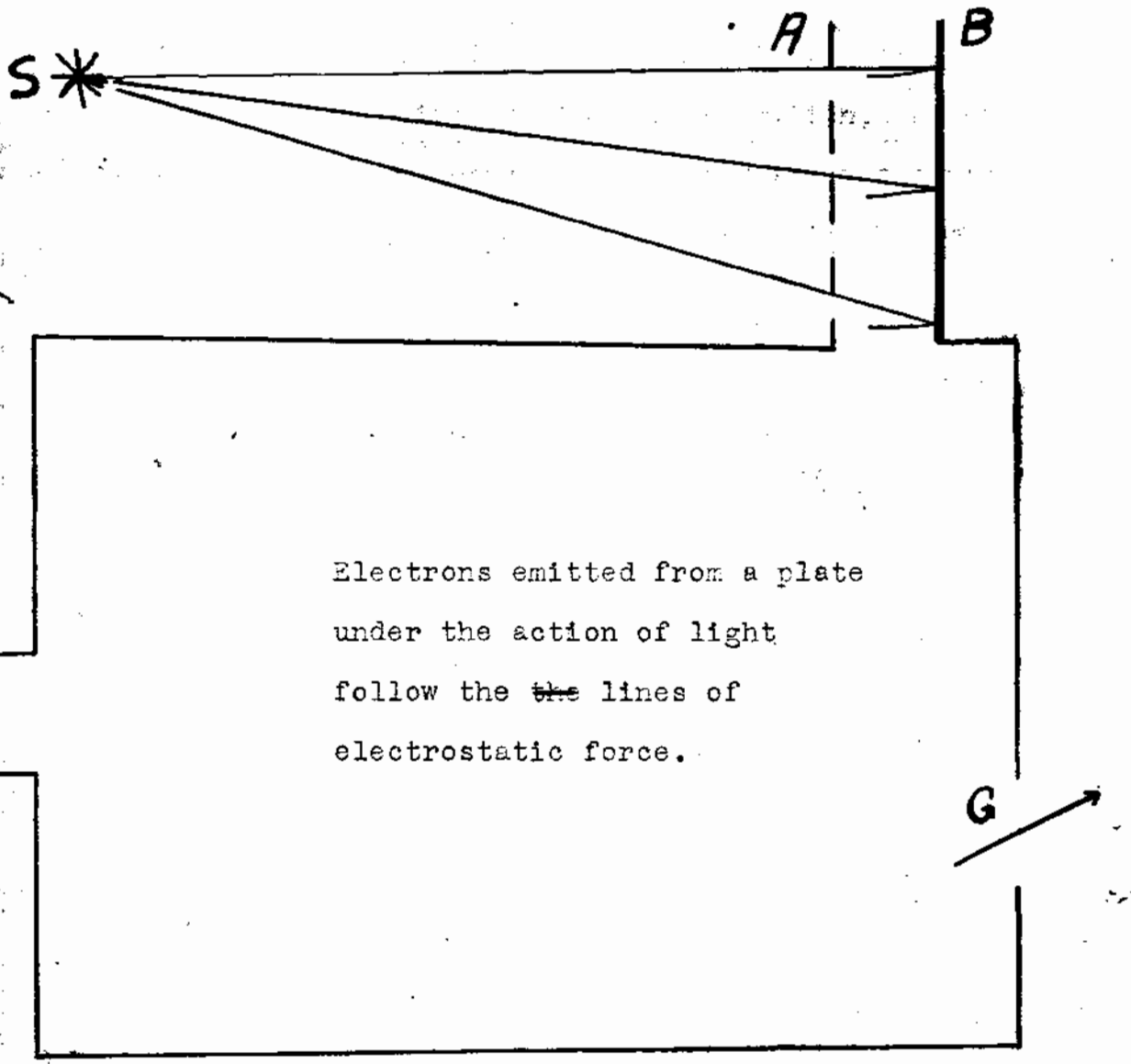
(1) An observation in Hertz's records

light that contained a large proportion of ultraviolet rays was allowed to fall on the plate. The electroscope that was connected to the plate collapsed showing that the plate was discharged. No effect of the light on the surrounding medium t he charged plate was detected and therefore it was concluded that light liberates electrons from a negatively charged body and these electrons follow the lines of electrostatic foree(2).

The foregoing simple effect due to light may be easily shown by the following arrangement:
light rich in ultraviolet rays is allowed to fall (Fig. 1) from the source S on to the perforated plate A and then on a polished plate(3) B that is connected to the negative terminal of the battery D through a galvanometer G. As soon as light falls on B , the galvanometer deflects.

---

(2) These two discoveries were made by Hallwacks
(3) Hallwacks found that zinc works well



Electrons emitted from a plate under the action of light follow the ~~the~~ lines of electrostatic force.

(Fig. I)

III Sources of Light Used in Experiments on Photoelectric Emission.

The source of light to be used in photoelectric work depends on the nature of the investigation, the duration of the experiment, the conditions under which the experiment is to be carried out, the constancy of the light, the wavelength and the intensity required.

A source that has been used for a long time andwhich is very commonly employed at the present time is the quartz mercury lamp. This lamp gives very constant illumination over long periods of time. Due to the fact that quartz has a great absorbing power on short waves, the shortest wavelength that this lamp could produce is about 1849 A.U.

If a shorter wavelength than that produced by the mercury lamp is desired, metallic arc lamps burning in vacuum are very often used because in addition to the short waves they produce, their intensity is great. The short wavelength of the arc is about 1435 A.U., the iron arc 1427 A.U., the copper arc 1925 A.U., and the carbon arc 584 A.U.(1).

---

(1)Experimental results by McLennan and Long

If the experiments to be carried cut require shorter wavelength than the ones cited above, metallic electrodes may be operated in very high vacuum, in which case carbon produces wavelengths that are as short as 360.5 A.U., zinc 317.5 A.U., iron 271.6 A.U., silver 260 A.U. and nickle 202 A.U.(2).

Another source of light that will give relatively short wavelength is the electric discharge through different gases. The shortwavelength limit of a discharge through hydrogen is 905 A.U. and that of helium is 510 A.U.(3).

In a very large number of investigations in photoelectric work, a monochromatic source of light is required. In that case a certain metal or gas may be excited to radiation either by heating to incandescence in the case of a solid or by an electric discharge in the case of a gas.

Light filters are coming into general use for producing monochromatic sources by filtering out or screening

---

(2) As found by Millikan and Sawyer
(3) Investigations carried out by Lyman

the wavelengths that are not needed. The advantages of using light filters are their simplicity, lack of adjustment and comparatively greater intensity.. The disadvantages are two: first, they are not sufficiently improved to be used in the ultraviolet region and second, they do not give an absolutely monochromatic light. In many instances solutions may be used to transmit certain wavelengths and absorb others. The selective absorbing power varies inversely with the concentration of the solution. Methyl alcohol has an absorbtion band at 2350 A.U.(4). Cobalt chloride dissolved in methyl alcohol trnsmits wavelengths between 2650 and 4600 A.U. for a two normal solution(5). Silver that is 0.00002 cms. thick transmits well wavelengths as short as 1140 A.U.(6). The compound benzol transmits wavelengths down to 1900 A.U.(7).

(4) By Hogenow
(5) By Kelly
(6) By Miss Laird
(7) By Lewis

IV Different Methods of Measuring Photoelectric Quantities

Before we start studying the different phases of the subject of photoelectric emission, we have to get acquainted with some of the more important methods that were and are still being used for quantitative measurements. The two quantities that are to be measured are the velocity and the number of electrons liberated.

One of the commonest methods for measuring the maximum velocity of the emitted electron is by measuring the applied positive potential that is necessary to draw the electron back and prevent it from leaving the plate. In figure 2 the positive side of the battery B is connected to the plate P_2 that is to be illuminated. If P_2 were negative and P_1 positive, electrons would pass to P_1 and the galvanometer G would register some current. But by varying the positive potential of P_2, we can know the velocity of the electrons trying to leave the plate P_2 under the action of the source S. Let V be the potential difference necessary to stop the electron that is trying to leave the plate P_2 with a velocity of v.

Then if m is the mass and e the charge of the electron we have,

$$\frac{1}{2} m v^2 = V e \quad (1)$$

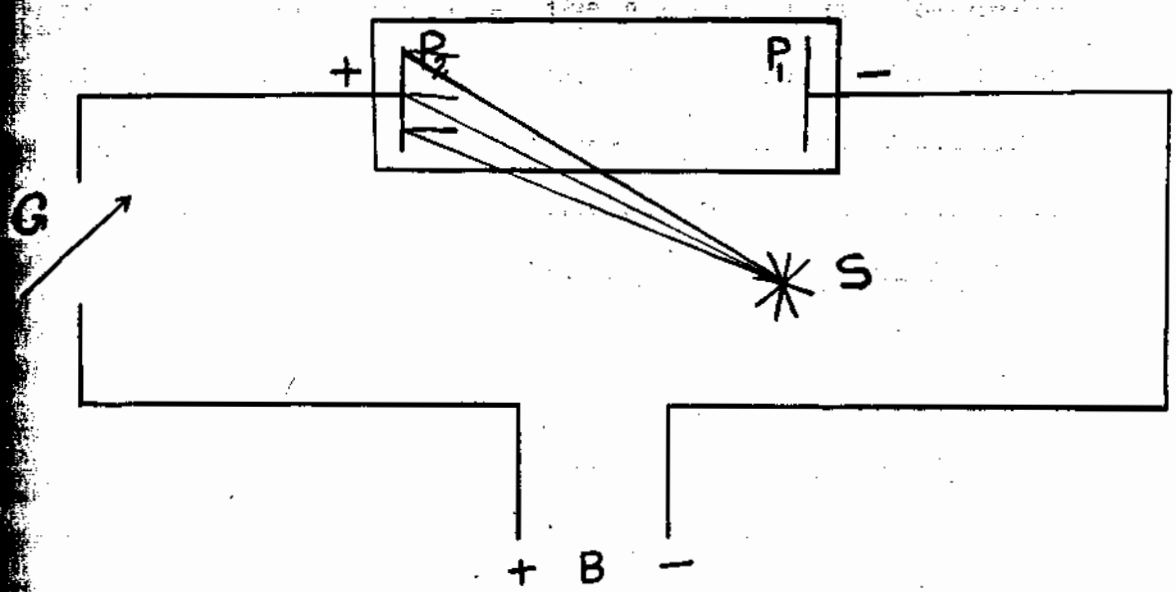
therefore $v = \sqrt{\frac{2Ve}{m}}$

let V be measured in volts and

$\frac{e}{m} = 1.761$ E.M.U.

then for one volt we get

v = 5.93 times 10^7 cms per sec.



(Fig. 2)

A certain definite positive potential should be applied to the illuminated plate to stop the electron from escaping.

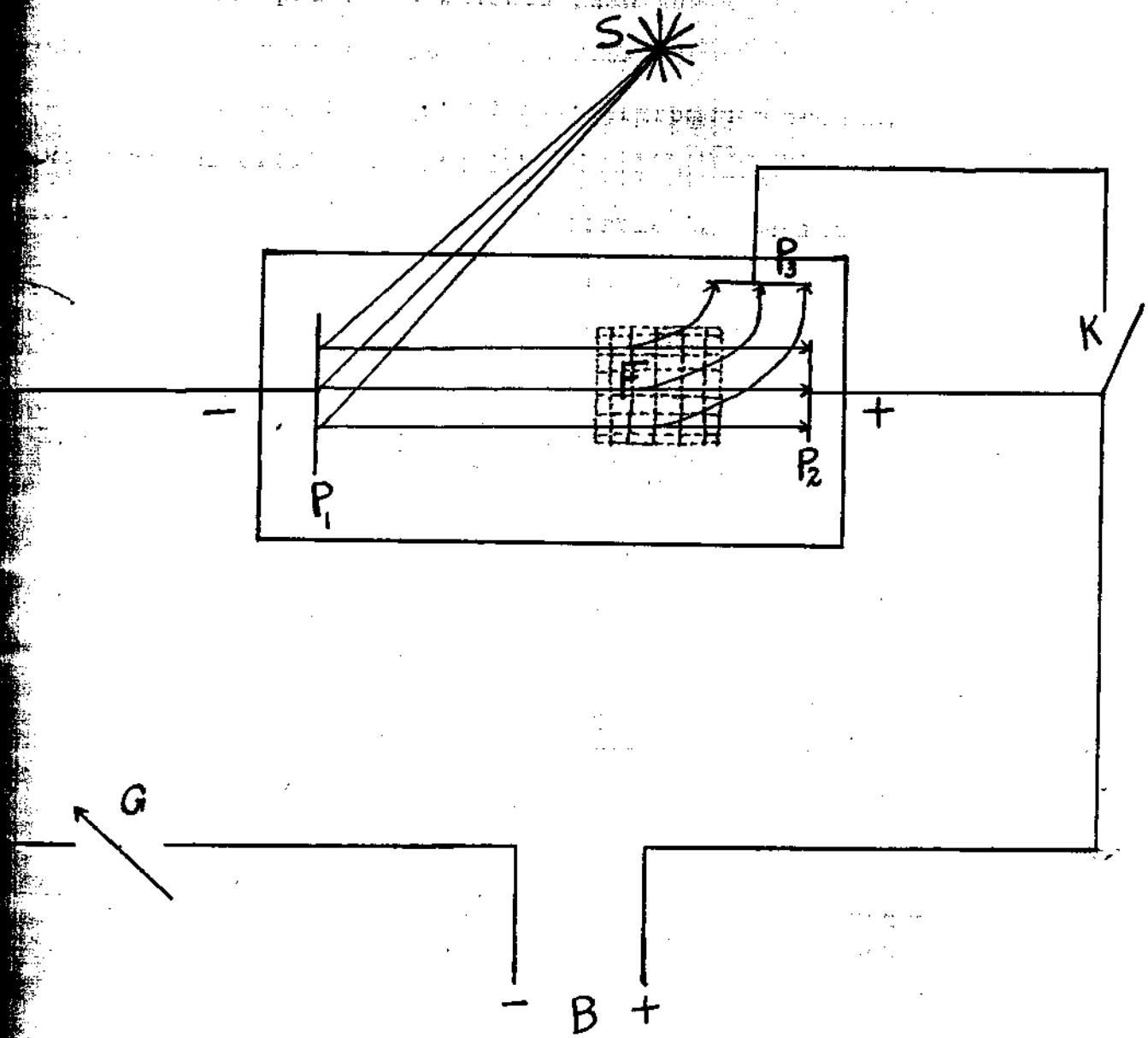
---

(1) Einstein's explanation of photoelectric emission

The second method that is commonly employed for measuring the velocity of the moving electron is by deflecting the electron by a strong magnetic field(2). In figure 3(3), the battery B keeps the plate P_1 negatively charged. The electrons emitted from P_1 due to the action of the source S move to the plate P_2 and the current is measured by the galvanometer G. If however a magnetic field F is established perpendicular to the direction of motion of the electrons, the electrons will be deflected, and by varying the strength of the field, the electrons may be made to reach plate P_3 and the galvanometer will not register any current untill the key K is closed. From the relative positions of plates P_2 and P_3 the velocity of the electrons may be determined because the radius of the arc described by the electrons is directly proportional to the first power of the velocity and inversly proportional to the strength of the magnetic field. Therefore the quantities to be measured are the strength of the field and the radius of the arc described by the electrons.

---

(2) The method is developped by Schuster and Lenard
(3) Arrangement due to Lenard



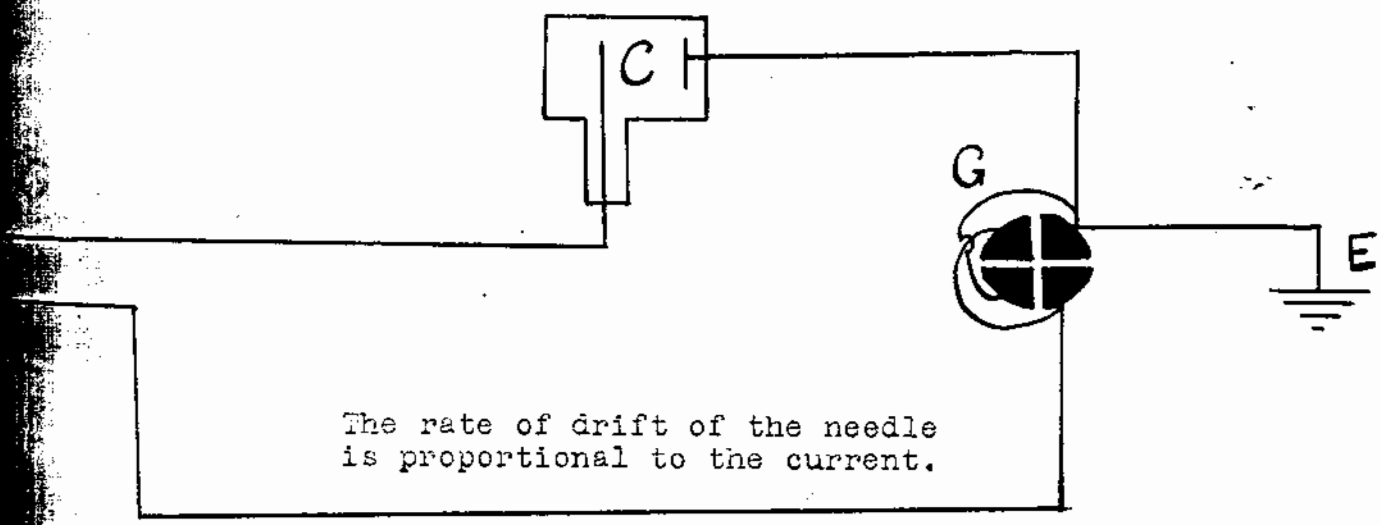
(Fig. 3)

The radius of the arc described by an electron moving in a magnetic field of known strength is a measure of its velocity.

The principal methods used for measuring the number of electrons emitted are five(4).

1. "by the rate of drift of an electrometer needle."
2. "by the ballistic method."
3. "by measuring the potential across the terminals of a high resistance in series with the cell."
4. "by balancing the photoelectric current against a current of known value."
5. "by a sensitive galvanometer."

Figure 4 represents the connections for using the first method. C is the photoelectric cell, B the battery, G the electrometer.

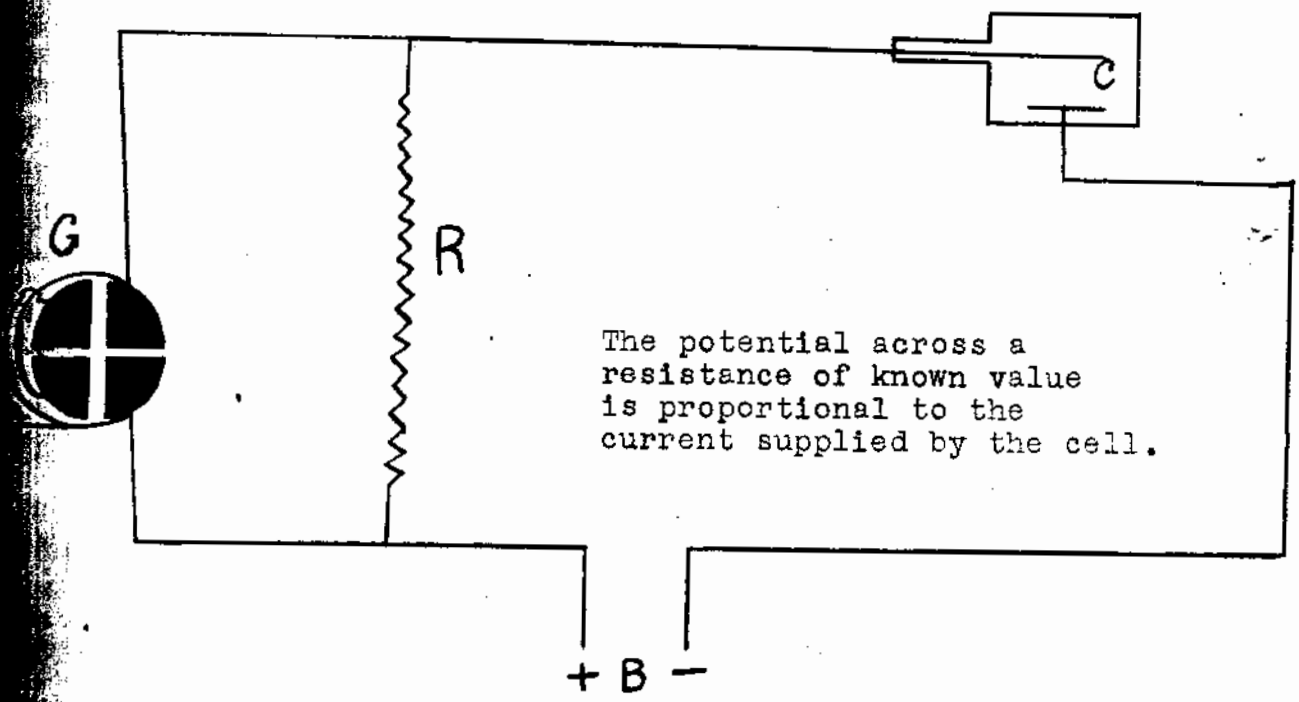


(Fig. 4)

(4) As classified by Allen.

The ballistic method consists in noting by the electrometer the charge acquired by the cell in a certain time during which the cell should be under the action of light. Then the drift of the needle is observed in the same time while the cell is not under the action of light. The difference between the two readings is the required quantity.

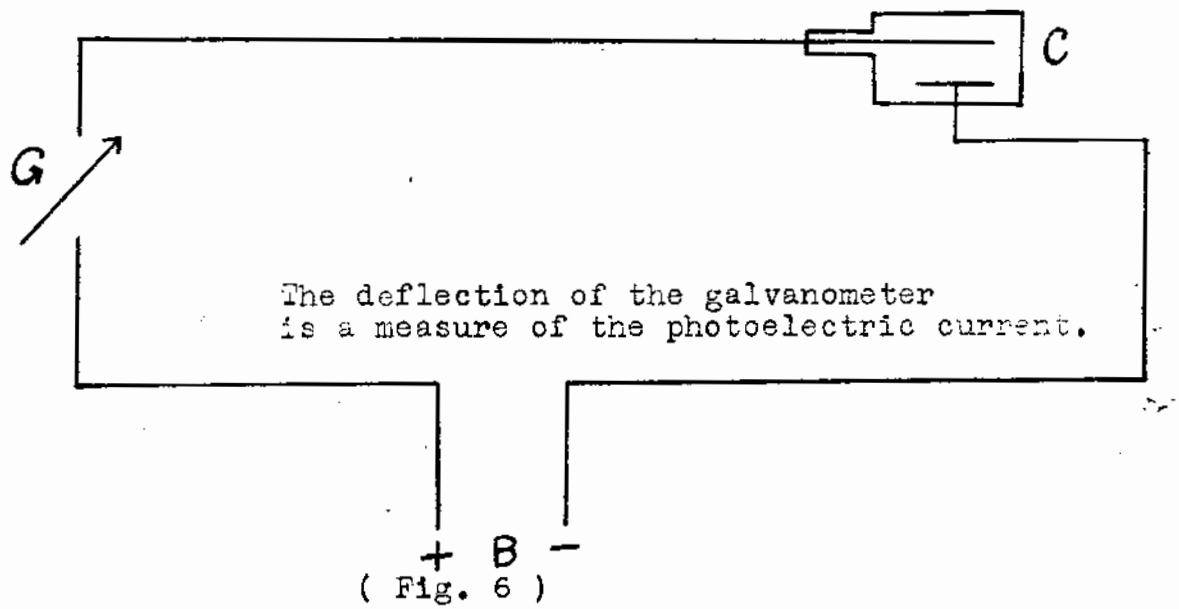
Figure 5 represents the connections for using the third method. C is the photoelectric cell, B the battery, R a high resistance of the order of 10^{11} ohms, G the quadrant electrometer.



(Fig. 5)

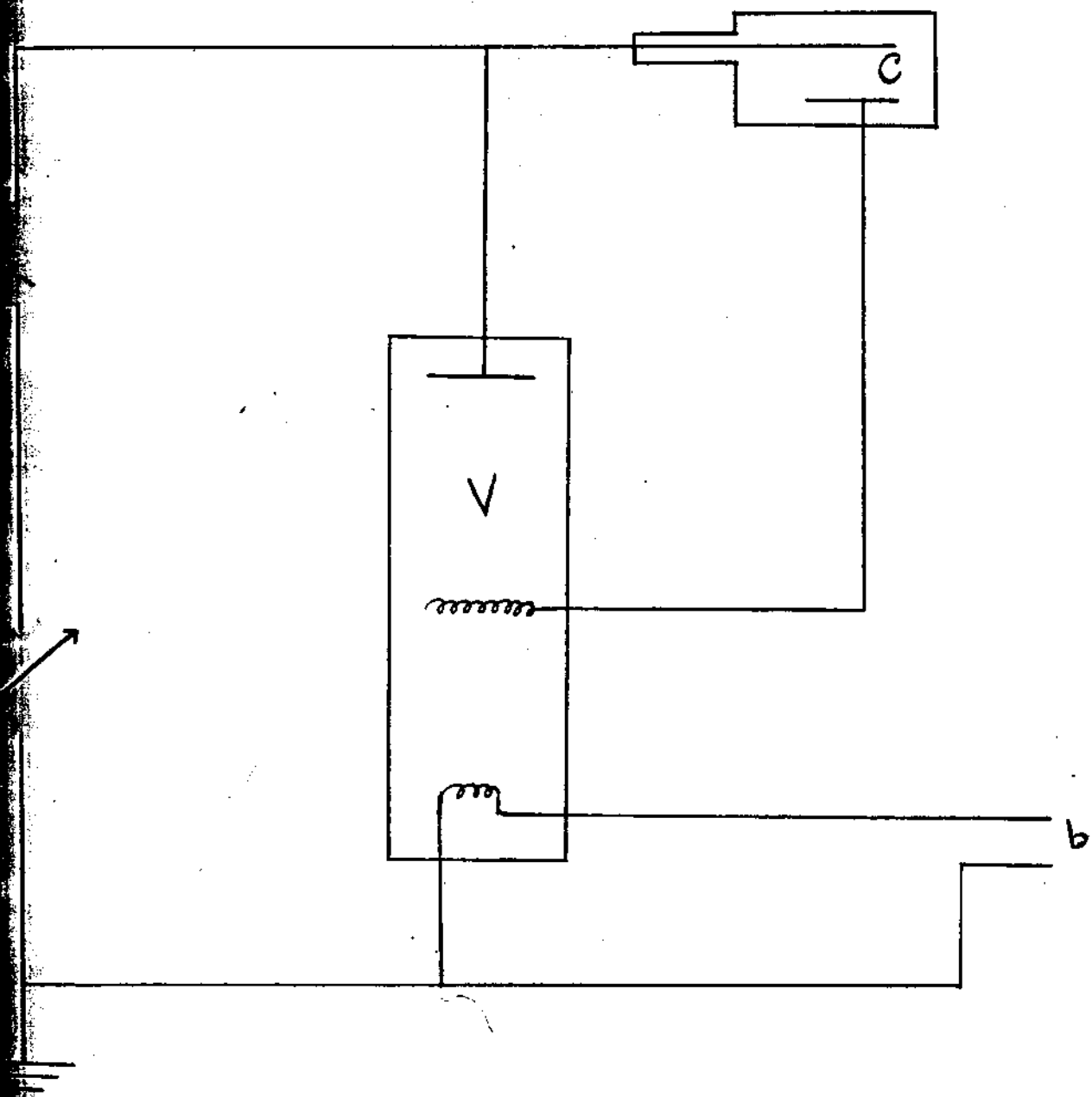
Method four consists in measuring the current generated by a photoelectric cell not directly but by comparison with a known current derived from a second standard photoelectric cell operating under certain definite conditions.

The fifth method consists in measuring the current by a sensitive galvanometer as shown in figure 6 in which C is the cell, B the battery, G the galvanometer.



(Fig. 6)

If the galvanometer is not sensitive enough to be deflected by the current generated by the cell, the current may be amplifyed as shown in figure 7 in which C is the cell, b a battery of 6 v, B a battery of about 100 v, G the galvanometer, V the amplifyer.



(Fig. 7)

The photoelectric current amplifyed could be read by a galvanometer that is not very sensitive.

V Emission of Electrons in High Vacuum.

Every bit of matter is composed of particles that are beyond the power of our present day microscopes. These minute particles are called molecules. Further, these molecules consist of still smaller particles that are called atoms. Every atom is an independent solar system consisting of small particles called electrons revolving about an attracting center consisting of particles that are about 2000 times as heavy as the electron. The particles in the center are called protons. Negative electricity consists of electrons and positive electricity of protons.

Different atoms consist of different numbers of electrons that should be eqaul to the protons and the greater the number of protons that the body contains the greater its mass will be.

The presence of these electrons is well proved by the fact that many of the theories of absorption, dispersion, scattering of light, the zeeman effect, the stark effect, and some theories of polarization of light are explained by assumihg their presence(1).

---

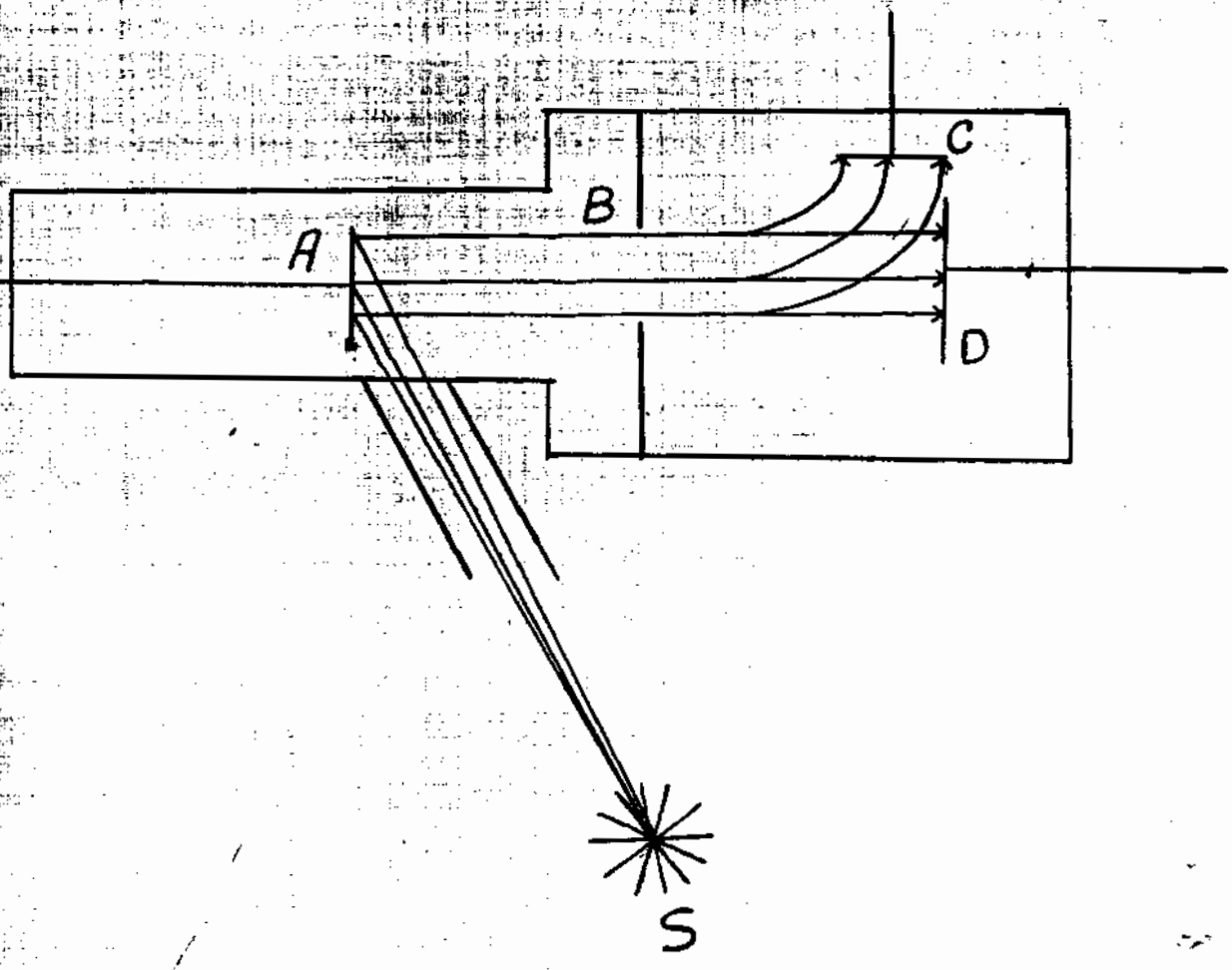
(1) These theories were explained by Johnston, Stoney, Helmholtz, Lorentz, Larmor, Thomson.

The presence of the electron is proved experimentally by kathode rays (2) which were found to produce a shadow if a screen is interposed, to produce heat on hitting a body, and to be deflected in a magnetic field. Many determinations were made of the mass and charge of the electron. The results obtained by different methods were in very close agreement.(3)

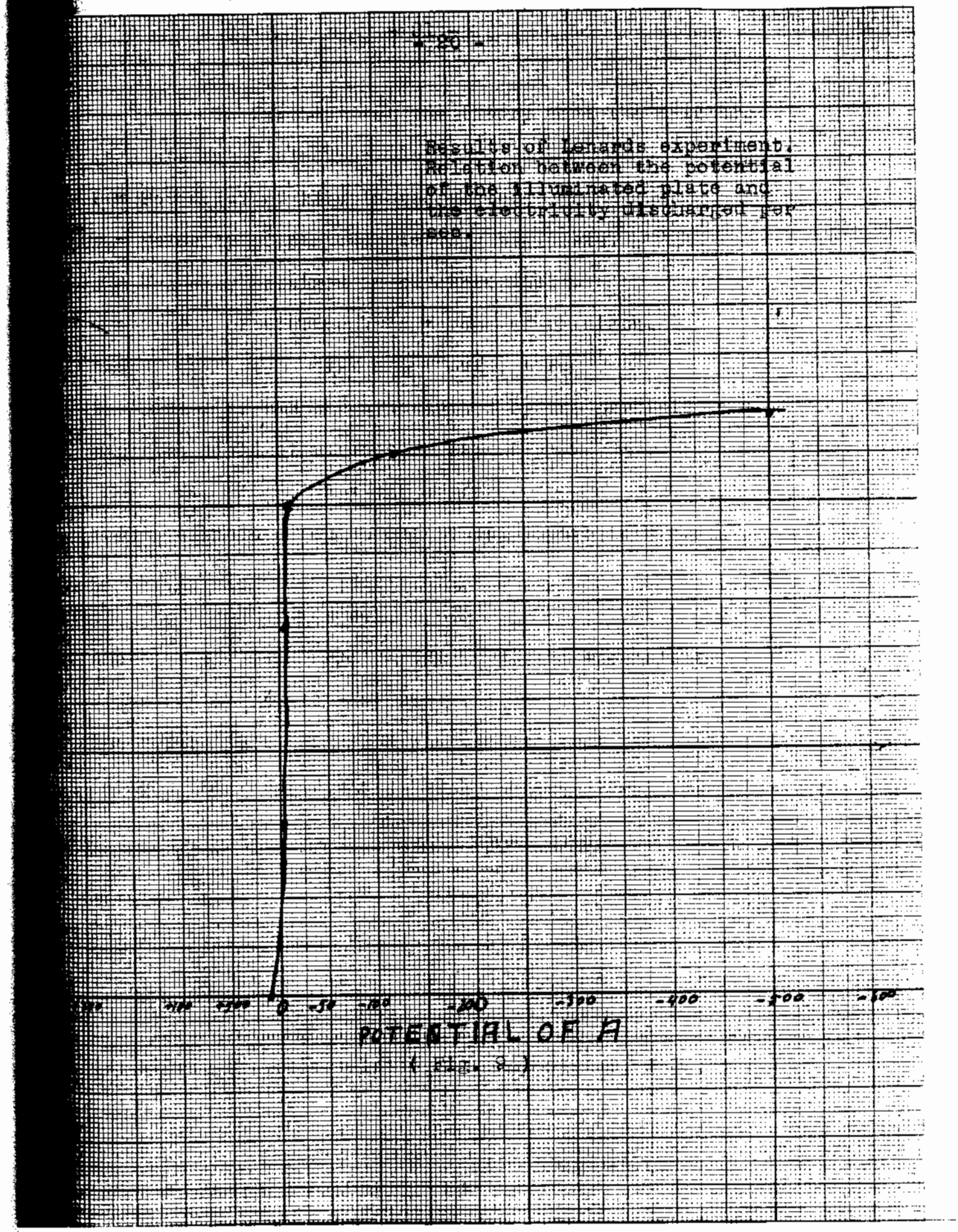
At the same time that determinations of the charge and mass of the electron were being carried out a celebrated experiment was being performed(4). The result of the experiment was that negatively charged bodies are emitted in a high vacuum if a metal surface is illuminated by ultraviolet rays. The apparatus used in the experiment is shown in figure 8 and the results are plotted in figure 9(5). The plate A was illuminated by the source S. The electrons emitted passed the opening B to the plate D. When a magnetic field is established perpendicular to the plates D and C, the electrons followed a curved path and reached C instead of D.

---

(2) Carried out by Varley and Crookes.
(3) Most accurate determination by Millikan, $e = 1.592 \times 10^{-20}$ E.M.U.
Average value of $e/m = 1.761 \times 10$ to the minus 7 E.M.U.
(4) By Lenard.
(5) Allen, Photoelectricity, Second Edition., P 30.



(Fig. 8)
A negatively charged plate struck by light emits electrons that may be deflected by a magnetic field.



Results of Lenards experiment. Relation between the potential of the illuminated plate and the electricity discharged per sec.

(Fig. 9.)

To further test the theory that the discharge is a stream of electrons let;

P = Poteneial of illuminated plate.

v_o = Velocity of particle leaving the plate.

v = Velocity acquired in electric field.

e = Charge of electron. m = Mass of electron.

then $$1/2\ m\ (\ V^2 - v_o^2\ ) = Pe$$

the radius of the curve described by the particle in a magnetic field of strength H is;

$$R = v/H \times m/e$$

let H_1 = field strength due to one ampere in a coil.

C = current in coil.

then $$H = H_1\ C$$

and $$P/C^2 = 1/2\ H_1^2\ R^2\ e/m = \text{constant}$$

assuming that v_o is very small.

The apparatus of figure 8 was used to test the above relation, the results are given in the following table(6).

P	C	P/C^2	$e/m = P/C^2 \cdot 2/H_1^2R^2$	$v = 2P/H_1R\ C$
607×10^8	0.65	144×10^9	11.7×10^6	0.12×10^{10}
4380 "	1.78	138 "	11.2 "	0.32 "
12600 "	2.94	146 "	11.8 "	0.54 "

(6) Allen, Photoelectricity, Second edition, P 32.

VI Photoelectric Active Substances

Many attempts have been made to establish a qauntitative relation between the photoelectric activity of a substance and its physical and chemical properties. All of these attempts have been, more or less, failures; the reasons being that it is extremely difficult to experiment with different substances and yet keep the conditions under which the experiments are carried out identically the same. If it is desired to compare the photoelectric properties of two substances, the following points should be kept in mind:

1. the intensity of the source should be the same in both cases.
2. the source should be strictly monochromatic for both substances.
3. the e.m.f. applied should be the same in magnitude and character.
4. the degree of vacuum in both cells should be the same.
5. the little gas that remains in the cells after evacuation should be of identical composition.
6. the surface of the substances under investigation should be prepared and polished by identical methods.

All of the above mentioned conditions are very difficult to fulfill; that is why very little progress has been accomplished along this line.

By the photoelectric activity of a substance is meant the potential necessary to cause an electron to leave the surface under the action of a source of light of certain frequency. The smaller the potential the greater the activity. If the potential is kept constant, it will be measured by the frequency necessary to cause emission; the lower the frequency the more active the substance will be.

Some substances emit electrons under the action of sunlight, some need ultraviolet rays, others require X-rays. Some of the earlier determinations gave the following results which are in the order of decreasing activity(1):

rubidium
potassium
potassium-sodium (alloy)
sodium
lithium
magnesium
thallium
zinc

The list, in general, shows that the more electropositive

---

(1) Carried out by Elster and Geitel. Allen, P75

an element is, the greater its activity will be provided the determination is carried out at atmospheric pressure as is the case above.

Two other classifications are the following(2):

1	2
aluminium	aluminium
magnesium	zinc
zinc	magnesium
tin	tin
cadmium	bismuth
lead	cadmium
bismuth	lead
gold	copper
nickle	nickle
cobalt	cobalt
copper	silver
silver	gold
iron	iron

The foregoing results were obtained in fair vacuum, and the results are very different.

---

(2) First determination by Ramsay and Spencer.
Second determination by Herrmann.

The following are results obtained in high vacuum(3):

1	2
copper	copper
brass	gold
zinc	nickle
bismuth	brass
platinum	silver
nickle	iron
iron	aluminium
gold	magnesium
silver	antimony
	zinc
	lead

The above results are in remarkable disagreement partly due to the different methods used in preparing the surface and partly to the difference in the vacuum obtained.

Some of the most dependable results are given in the following table(4). The procedure followed was to clean the surface in vacuum by knife edges.

---

(3) First determination by Ladenburg.
Second determination by Millikan and Winchester.
(4) By Millikan and Winchester.

metal	+ potential in volts at 26°C measure of velocity of emission of electron	rate of discharge at 25°C
silver	1.340	17.16
iron	1.225	16.40
gold	1.215	24.70
brass	1.174	23.80
copper	1.135	25.10
nickle	1.126	24.00
magnesium	0.839	11.00
aluminium	0.738	04.90
antimony	0.394	04.00
zinc	0.197	01.20
lead	0.000	00.90

All the substances considered up to the present time have been metallic elements. The next step is to study the behaviour of some of the more important non-metallic elements and inorganic compounds.

The following data(5) gives the photoelectric current of some of the more important compounds that have been tested photoelectrically:

(5) Taken by Dima.
Bulletin of the National Research Council, April, 1921, P 135.

compound high valency	current	compound low valency	current
HgI_2	10	HgI	112
$HgCl_2$	32	HgCl	12
HgO	70	Hg_2O	280
$Hg(C_6H_5CO_2)_2$	12	$Hg(C_6H_5CO_2)$	18
SnO_2	24	SnO	1220
SnS_2	186	SnS	1440
Fe_2O_3	202	FeO	7200
$FeCl_3$	1	$FeCl_2$	26
CuO	4800	Cu_2O	14400
$CuCl_2$	10	CuCl	50000
PbO_2	1700	PbO	3200
CrO_3	1	Cr_2O_3	50
BiO_3	70	Bi_2O_3	110
MnO_2	48	Mn_2O_3	130
		MnO	500

From the foregoing table it may be noticed that when a metal combines with a non-metal in two ways, that compound in which the metal has the lower valency hashowsthe greater photoelectric activity(6). While getting the data ofrthe foregoing table, Dima noticed that the photoelectric fatigue was greater in the compound in which the metal had a low valency than in the corresponding compound in which it had a higher valency. The explanation given was that the illumination changed the metal to a more stable state of a higher valency with the exception of some compounds in which case Dima proved by the following table that the illumination caused a chemical reduction:

metal	chloride	bromide	iodide
K	67	320	1200
Pb	31	97	3000
Hg(ous)	15	19	1400
Hg(ic)	5	14	230
Ag	200	430	750

The experimental difficulties that confronted investigators proving the photoelectric activity of gases and vapours were very great due to the fact that they were

(6) Bulletin of the National Research Council, April 1921, P 122.

dealing with separate molecules and that the hard X-rays used produced strong photoelectric currents from the surface of the containing vessel thus necessitating a special protective non-photoelectric substance.

The method of detecting whether a gas or vapour is photoelectrically active or not is based upon the theory of ionization. If a gas or vapour is photoelectrically active, its molecules must loose electrons under the action of X-rays, therefore the gas will contain electrons and ions which are the agents in rendering a gas conductive. If that is the case, a gas, under the action of X-rays, should conduct a current of electricity.

Lenard was the first to show that some of the gases found in the air were photoelectrically active, but his results were criticised by J.J. Thomson(7) and disproved by Bloch who showed that the effect was due to dust particles and small drops of water in the air. After avoiding dust and water particles, and using hard X-rays, some experiments(8) conclusively proved that gases and vapours are active and could conduct comparatively large currents(9).

(7) Allen, Photoelectricity, Second edition, P 101.
(8) Hughes, Pallen, Haye.
(9) 0.1 of an ampere at 700 volts.

Further advance in the subject was made when an important piece of work was carried out(10) proving that gases and vapours are photoelectrically active and pointed out the following difficulties in connection with work on dust free gases:

1. "the formation of electrical carriers of molecular size caused by selective absorption of the light."
2. "chemical action; that is the production of ozone from oxygen."
3. "the formation of condensation nuclei; that is the formation of solid or liquid products by the direct action of the light on the gas."

Due to the fact that Lenard and Ramsauer pointed out the above mentioned difficulties in connection with work on the photoelectric activity of gases and vapours, it became easy to guard against them; and from then on the advance along that line became noticeable.

---

(10) By Lenard and Ramsauer at the Radiologisches Institute of Heidelberg.

VII Influence of different Conditions on Photoelectric Emission

A Influence of Frequency and State of Polarization

One of the earliest experiments carried out for studying the effect of wavelength on photoelectric emission was performed by Elster and Geitel(1). They measured the effect of different parts of the spectrum on the rate of discharge from sodium, potassium, and rubidium. Their results are given in the following table:

color of light	rate of leakage of electricity		
	sodium	potassium	rubidium
white	21.0	53.1	537.0
blue	7.5	50.3	96.5
white	22.6	52.9	527.7
yellow	3.2	3.5	339.7
white	21.9	53.9	532.3
orange	3.1	2.2	132.0
white	21.9	52.9	527.7
red	0.2	0.1	21.0

From the above table it may be noticed that sodium is most active(2) with yellow light, potassium with blue and rubidium with yellow.

---

(1) Allen, Photoelectricity, P 135.
(2) Within the range of the visible spectrum.

The quantitative results obtained by Ladenburg are given in the curves of figure 10 in which A = saturation current, B = energy of incident light, C = A/B and OX = wavelength(3). The ratio A/B is given the name specific photoelectric activity.

To knock out an electron from a surface, that electron must be supplied with enough energy to give a velocity large enough to allow the electron to leave the surface. An electron once supplied with enough energy cannot remain on the illuminated plate and therefore the effect of the frequency of the incident light is to increase the velocity of the ejected electron.

let V = the positive potential that is necessary to just prevent an electron from flying off.

e = charge of an electron.

m = mass of an electron.

v = velocity acquired by electron.

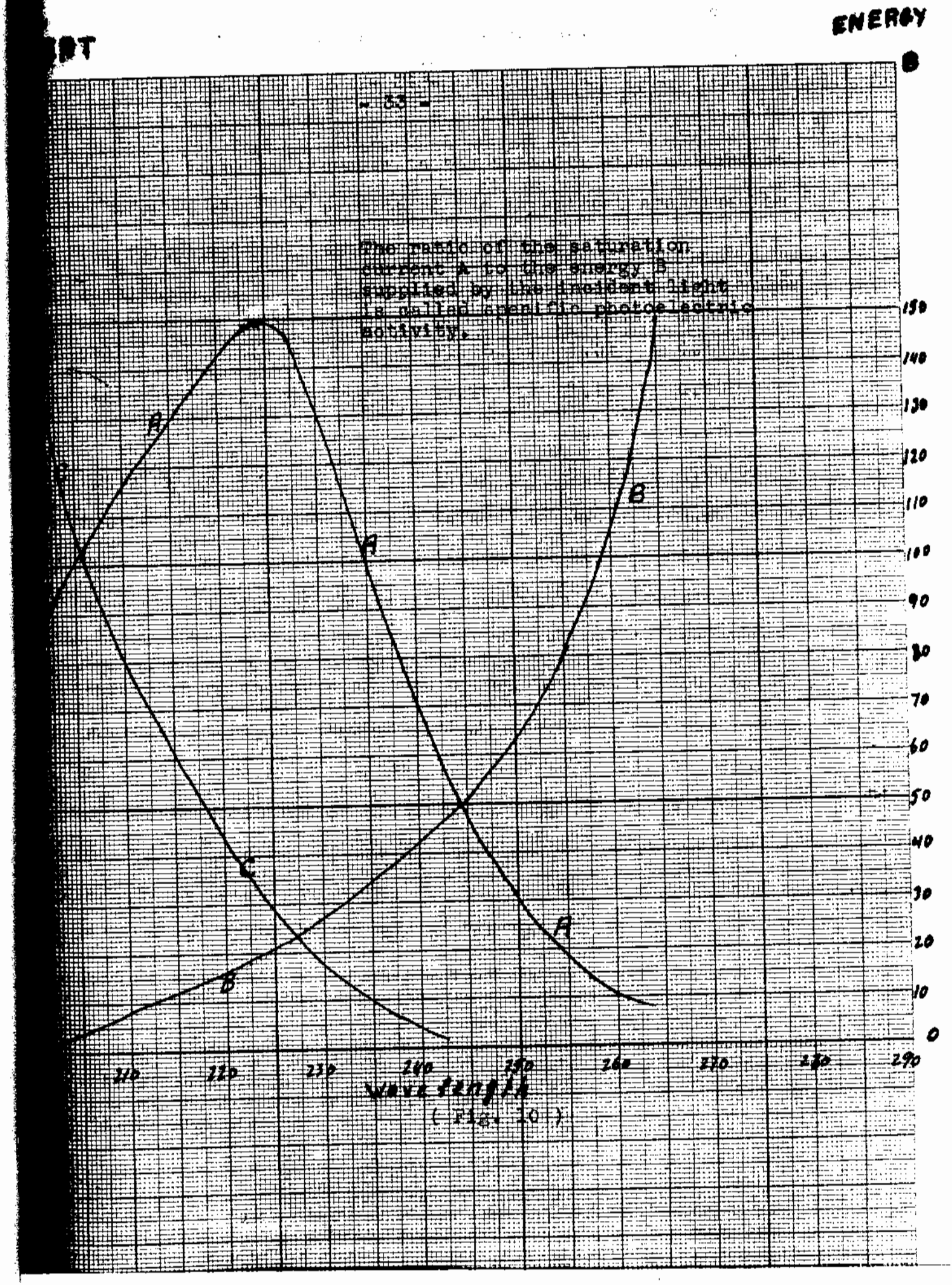
then Ve will be the amount of energy with which the electron has to be supplied to leave the surface. That energy will be converted into kinetic energy,

therefore $Ve = 1/2\ m\ v^2$

The effect of the frequency of the incident light on the velocity of the discharged electron was

---

(3) Allen, Photoelectricity, P 138



(Fig. 20)

The ratio of the saturation current A to the energy B supplied by the incident light is called specific photoelectric activity.

found(4) to be an increase in the velocity with a decrease in wavelength. The results of the experiment are given in the following table and plotted in figure 11.(5)

wavelength u u	positive potential in volts platinum	copper	zinc
260	1.075	1.01	0.685
242	1.28	1.16	0.79
229	1.49	1.33	0.95
218	1.60	1.46	1.00
210	1.76	1.55	1.07
201	1.96	1.69	1.12

When the subject of the relation between the frequency and the velocity was taken up, it was supposed that they were linear functions of each other; but later on experiment proved(6) that the maximum energy, $1/2\ m\ v^2$, and not the maximum velocity is a linear function of the frequency. Up to the present time the formula used for connecting the kinetic energy of the electron and the work supplied to it has been,

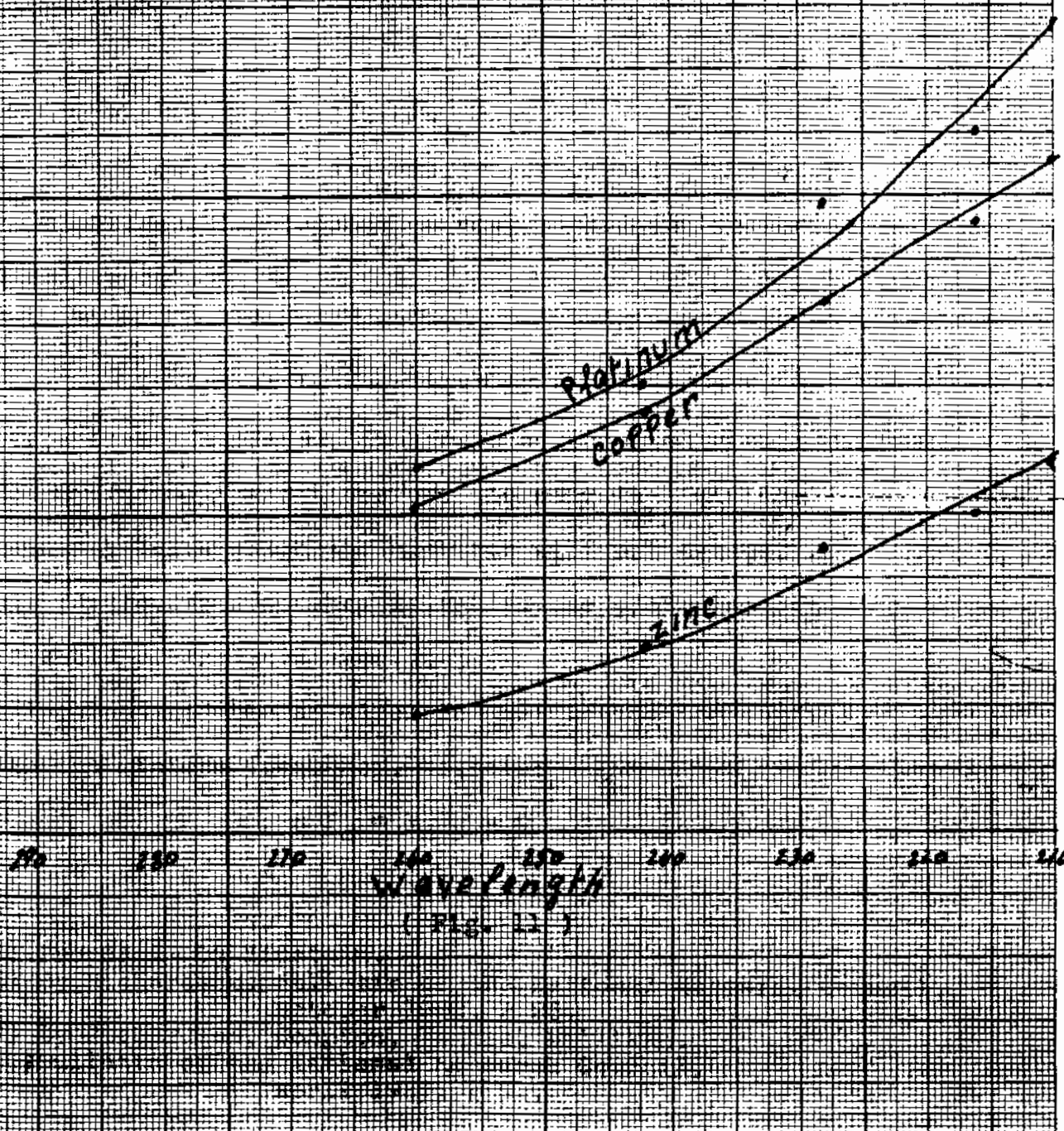
$$1/2\ m\ v^2 = Ve$$

but we know that $h\ f - w_o = Ve$

---

(4) By Ladenburg.
(5) Allen, Photelectricity, P 143.
(6) By Hughes.

The kinetic energy of the electron as a linear function of the frequency.



(Fig. 12)

where h = planks constant

f = frequency of incident light

w_o = work done by electron in escaping from metal

therefore we can put $1/2\ m\ v^2 = hf - w_o$

The above(7) equation was proved(8) to be a direct result of plank's radiation formula and its validity was proved beyond doubt(9).

In the above formula w_o is very small as compared to hf, therefore we can put $1/2\ m\ v^2 = hf$

All of the quantities are easily measureable, therefore the above equation becomes an easy method for measuring plank's constant.

It is easily seen that if an electron is to escape from a surface , it should be supplied with a minimum amount of energy and therefore there exists a minimum frequency below which the electron will not escape. This particular frequency is called the photoelectric threshold of the substance(10-).

At the instant when an electron just leaves the surface, with the minimum frequency, we have:

$$h f_o = V_o e = 0$$

---

(7) Proposed by Einstein.
(8) By Richardson. Bulletin of the National Research Council. October 1922, P 25.
(9) By Richardson, Compton, Hughes, Millikan.
(10) Bulletin of the National Research Council, April 1921, P 91.

To measure plank's constant we have only to measure the velocity of the electron, and this is done by measuring the photoelectric current with retarding and accelerating fields. The results for different wavelength are plotted in figure 12(~~11~~).

If we plot the frequency of the incident light against the maximum emission energies we come out with a straight line as indicated in figure 13.

The slope of this curve represents plank's constant and its point of intersection with the X-axis represents the photoelectric threshold of the substance under investigation.

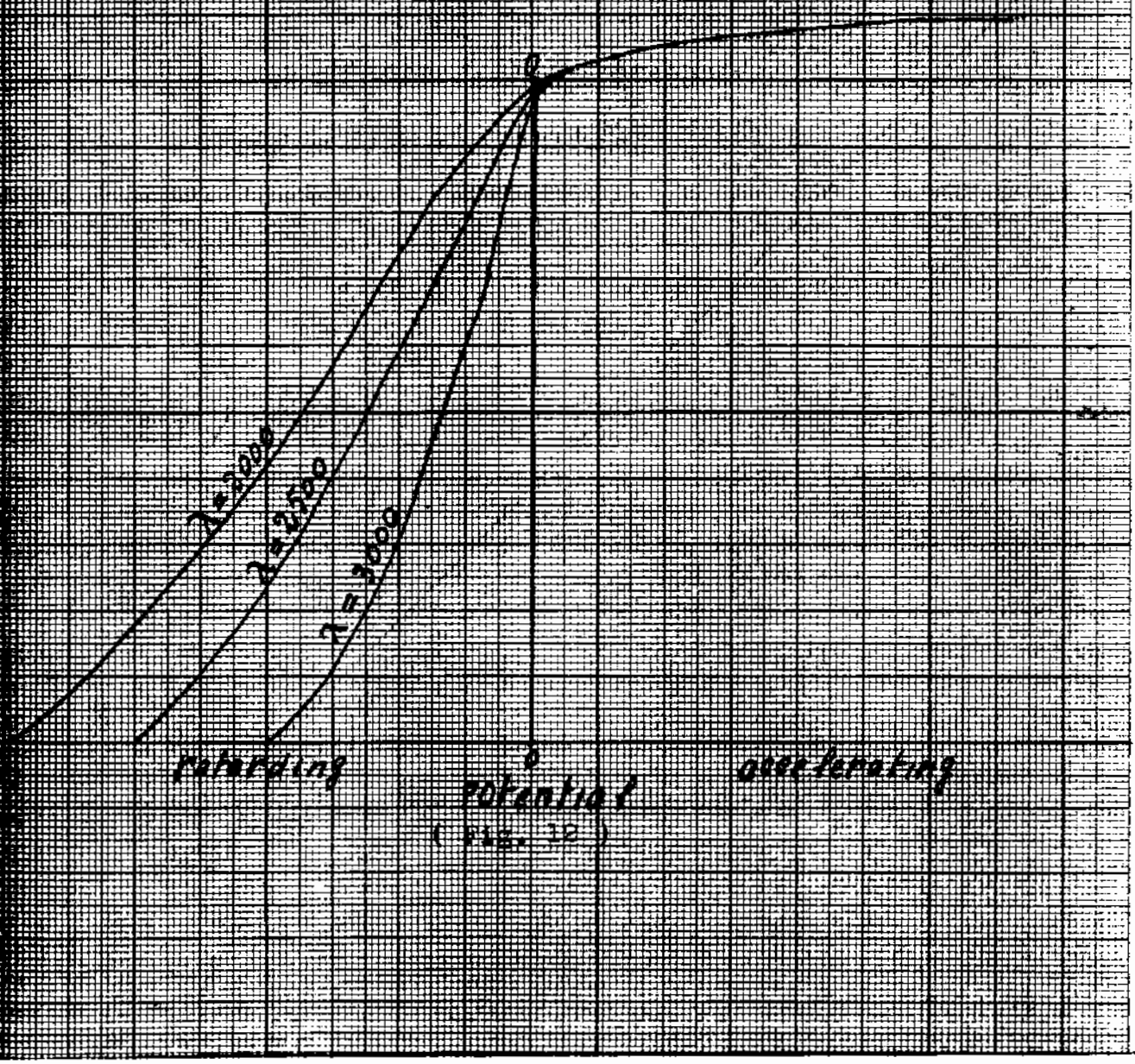
The foregoing discussion leads us to the conclusion that the energy with which an electron leaves an active surface is a linear function of the frequency and that the magnitude of the photoelectric threshold may supply us with a means for measuring the magnitude of the binding force between the electron and its molecule(12).

So far the effect of the frequency of the incident light has been discussed not considering the state of polarization of the source.

---

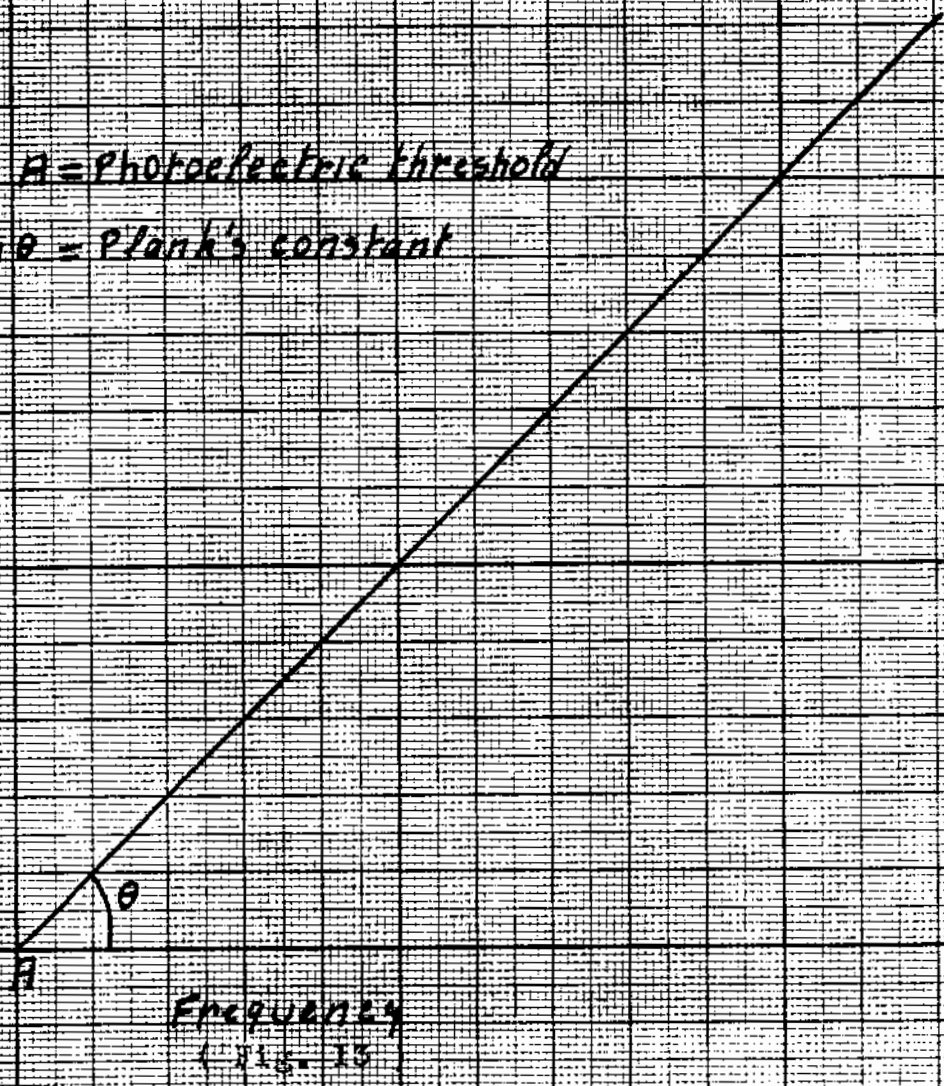
(12) The Philosophical Magazine, December 1913, P1023.

The fact that the velocity of the
retarding electrons increases with
the frequency supplies us with a method for
for determining $\frac{e}{m}$ and h constants.



(Fig. 12)

The kinetic energy of the electron is a linear function of the frequency of the incident light.



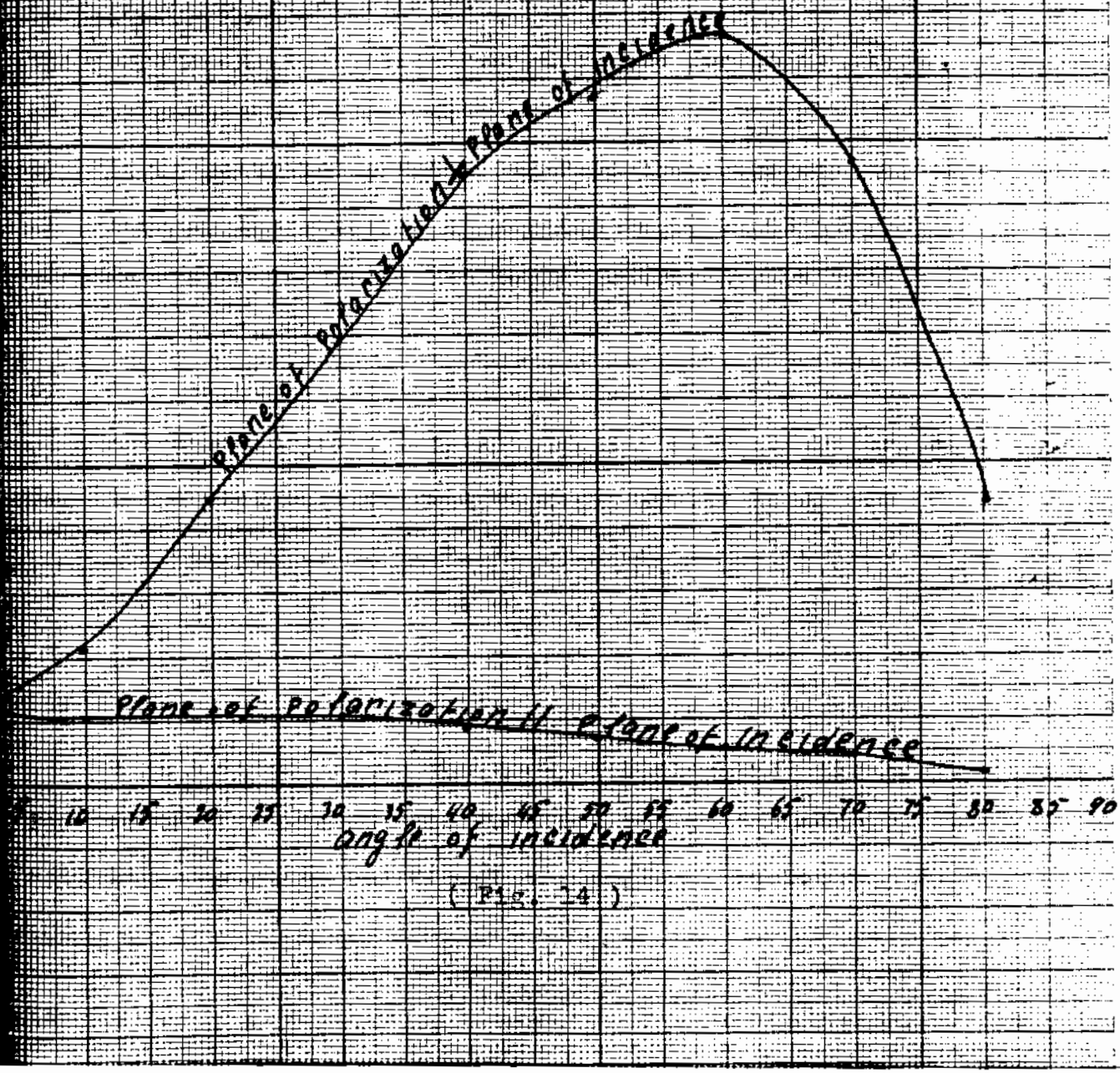
(Fig. 13)

The first piece of work done along this line was by Elster and Geitel who used a liquid alloy of sodium and potassium for the active substance and white plane polarized light for the exciting agent. The conclusion they drew from their results given in the following table(13) and plotted in figure 14, was that the photoelectric current was a maximum when the plane of polarization was perpendicular to the plane of incidence, and a minimum when the planes were parallel; the ratio between maximum and minimum was about 10 to 1.

angle of incidence. in degrees.	light polarized at 90° to plane of incidence.	light polarized in plane of inci.
0	2.8	...
3	...	2.8
10	3.2	2.79
20	11.2	2.87
30	17.4	2.85
40	23.4	2.24
50	27.0	1.80
60	28.7	1.51
70	23.8	1.01
80	11.0	0.33

(13) Allen, Photoelectricity, P 132.

The maximum current occurs when the plane of polarization is perpendicular to the plane of incidence and a minimum when the planes are parallel.



(Fig. 14)

From the above table it is evident that the maximum value of the current occurs at 60° when the light is polarized at an angle of 90° to the plane of incidence. The formula suggested for giving the relation between the photoelectric current I, and the angle a, between the planes of incidence and polarization was the following,

$$I = A \cos^2 a + B \sin^2 a$$

where A and B are constants.

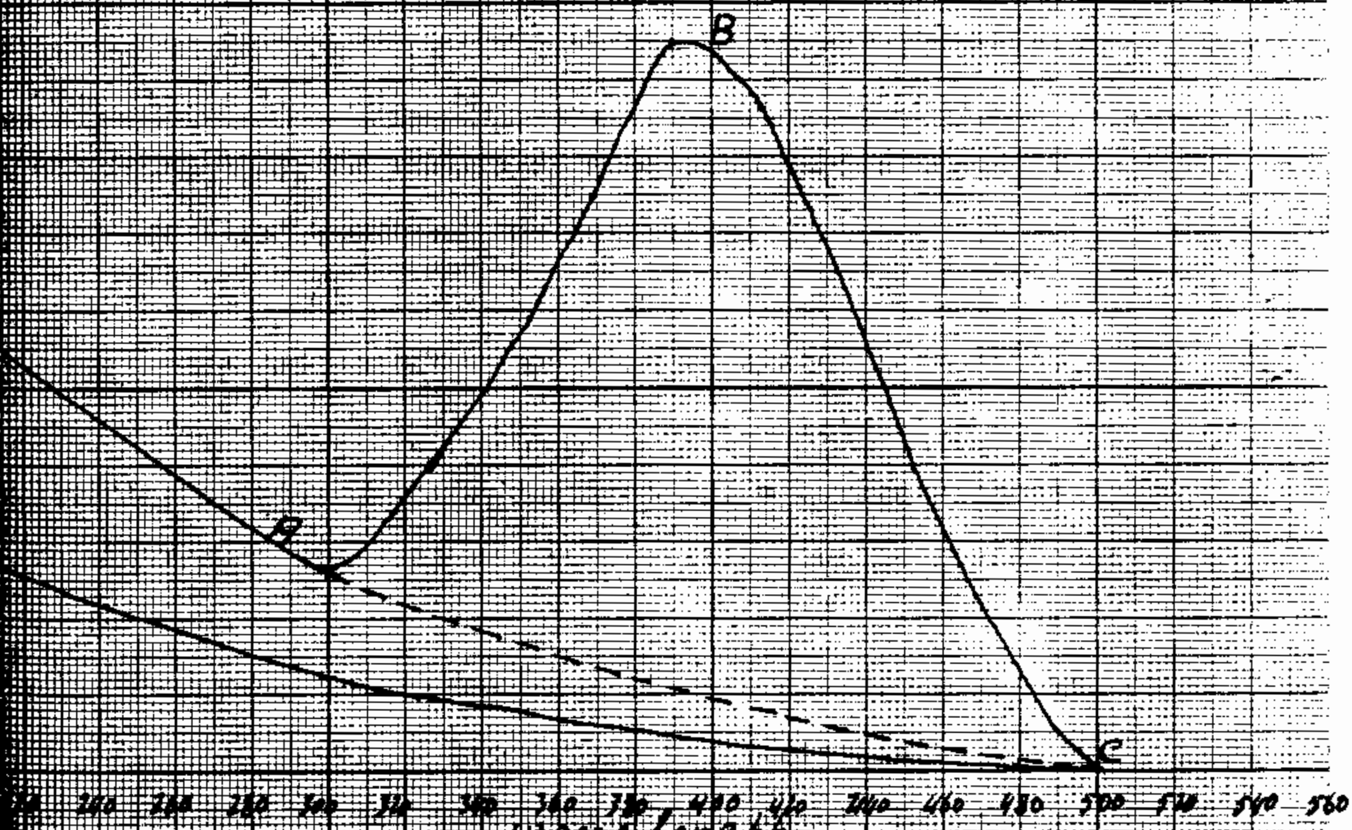
The conclusions that were drawn from the foregoing piece of work were the following:

1. "light polarized perpendicular to the plane of incidence causes the emission of more(up to 50 times as many) negative electrons than light polarized parallel to the plane".
2. "the maximum velocities of the electrons are about the same for both positions of the plane of polarisation."
3. "the number of electrons with a velocity less than the maximum is greater if the plane of polarisation is perpendicular to the plane of incidence than if it is parallel to that plane."

A little after the work of Elster and Geitel, Pohl and Pringsheim pointed out that the photoelectric activity of a surface depends on the angle of incidence

of the exciting light and the orientation of the plane of polarization. The results of their accurate measurements are plotted in figure 15. The ratio between the light absorbed and the photoelectric current is independent of the angle of incidence if the electric vector is at an angle of 90° with the plane of incidence as shown in curve DC, but if the electric vector is parallel to the plane of incidence, it varies with the angle of incidence as shown in curve ABC which indicates that if the electric vector is parallel to the planeof incidence, a maximum current occurs at a wavelength of 400 u u. This phenomenon is called the selective photoelectric effect and differs for different substances.

If the electric vector is parallel to the plane of incidence, a maximum current occurs at a particular wavelength depending on the substance. This phenomenon is called the selective photoelectric effect.



(Fig. 12)

B Influence of Intensity

If light falls on the active substance of a photoelectric cell, it will liberate electrons whose velocity depends on the frequency of the incident light, and when an electron receives enough energy from the incident light to overcome the attraction of the particles around, it has to leave the surface; therefore if the intensity of the light is increased, the excess energy goes into increasing the number of electrons that leave the surface.

Elster and Geitel investigated the relation between the intensity and the number of electrons emitted and found that the number of electrons varies directly with the first power of the intensity.

A little after the work of Elster and Geitel, Lenard reasoned that if the current and intensity are in direct proportion, their quotient E/I = current/intensity should remain constant and on investigation he found that to be true.

In order to prove that the variation is due to the change in the intensity of the light, Ladenburg measured the current against the variation of the angle

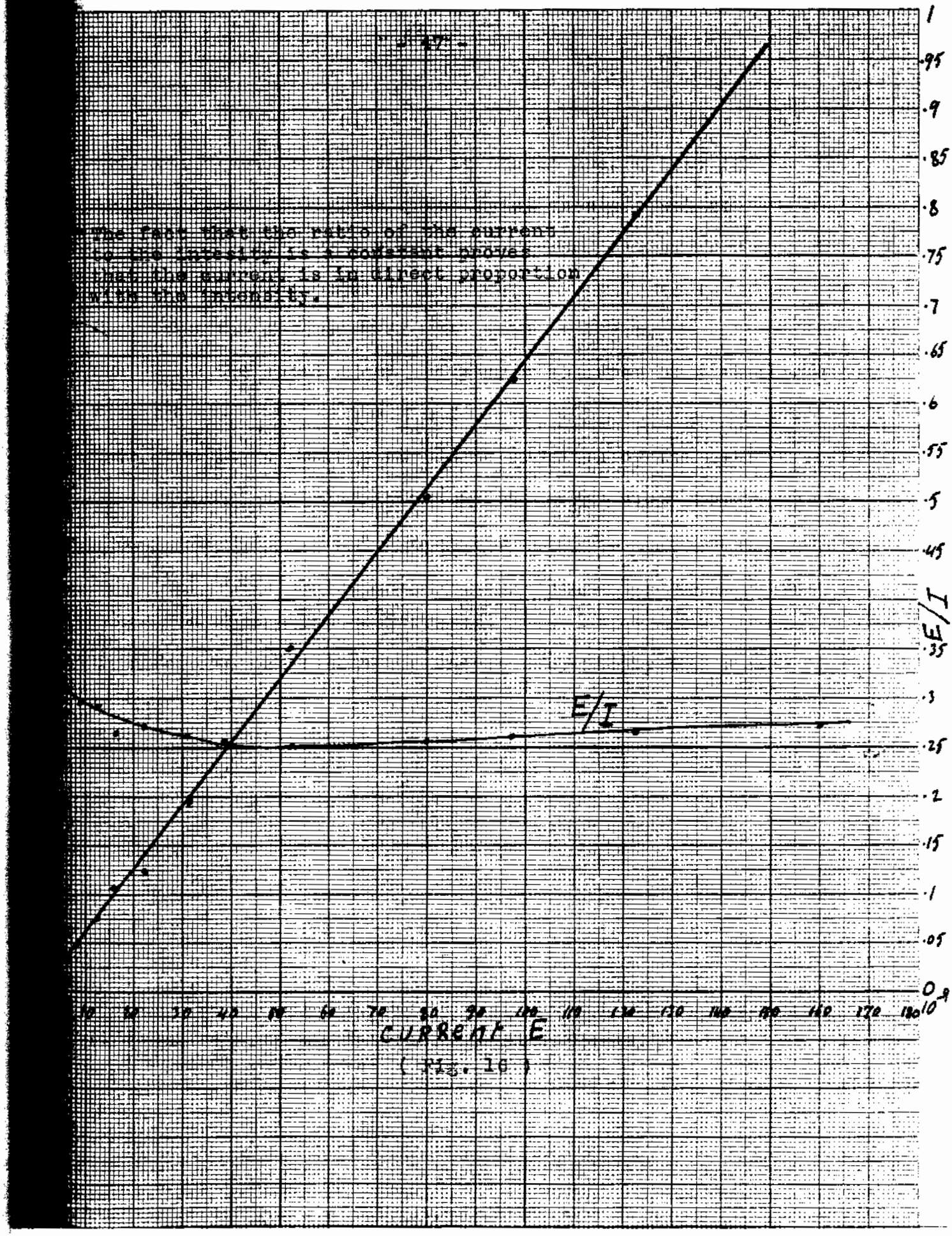
of incidence. The results he came out with were that the current divided by the angle of incidence is a constant thus proving Lenard's reasoning.

Kichtmyer, having in mind to find whether the quotient of the current and intesity is a constant over a wide range of light intensity, measured the current very accurately and used a very wide range of intensity. His results are given in the following table(14) and plotted infigure 16:

distance of arc from cell.	illumination in foot candles.	photoelec. current amperesx10^{-9}	E/I
10.00	19	5.9	.310
8.00	30	8.7	.290
6.50	45	12.5	.278
5.50	63	16.4	.260
4.75	84	22.6	.269
4.00	118	31.4	.266
3.50	155	38.8	.250
3.00	210	52.6	.250
2.50	304	79.5	.258
2.25	375	97.5	.259
2.00	475	123.0	.260
1.75	620	160.0	.262

(14) Allen, Photelectricity, P 127.

The fact that the ratio of the current to the intensity is a constant proves that the current is in direct proportion with the intensity.



(Fig. 16)

Before an electron leaves the surface of a photoelectric active substance, it should absorb from the incident beam of light a quantity of energy equal to

$$q = hf$$

where h = plank's constant.

f = the frequency of the incident light.

therefore the total amount of energy absorbed by N electrons will be $Q = N h f$

This quantity of energy should be supplied by the beam of light that contains an amount of energy equal to

$$E T$$

where E = energy of the source incident upon the substance.

T = absorption coefficient.

therefore we can equate the energy supplied by the source to that absorbed by the electrons and get the useful relation

$$N h f = E T \quad (15)$$

(15) Bulletin of the National Research Council, October 1922, P 29.

C Influence of Pressure

The electrons liberatedfrom a photoelectric active surface move in straight lines following the strain due to the applied electric field provided they are produced in vacuum. If hoever the electrons are liberated under pressure, the path and conduction of the current are different and are affected in many ways by the gas in the cell. The electrons after leaving the active surface become attached to the molecules of the gas thus forming ions that move with relatively small velocities. If the liberated electrons go out with a high velocity, they very often produce ions by collision, and therefore increase the conductivity of the gas. Before outlining the work that has been done along that line it may be well to state that the photoelectric current is conducted in three ways:

1. "by the elctrons liberated by the ultraviolet light."
2. "by the ions formed by the adhesion of gaseous molecules to these electrons."
3. "by the ions produced by collision."

Staletow, using an arc lamp for a source and two metal plates the distance between which could be measured accurately, measured the photoelectric current against the potential difference applied for different

distances between the plates. His results are given in figure 17 in which x represents the initial distance in mm between the plates.

The same investigator measured the changes of the current against the pressure keeping the potential difference constant. His results are given in figure 18. From figure 18 we observe that as the pressure is increased, up to a certain maximum value , the current increases and then decreases. The pressure at which the current is a maximum is called the"critical pressure" at that potential difference. The value of the critical pressuremay be determined from the relation,

$$P\ d/E = K$$

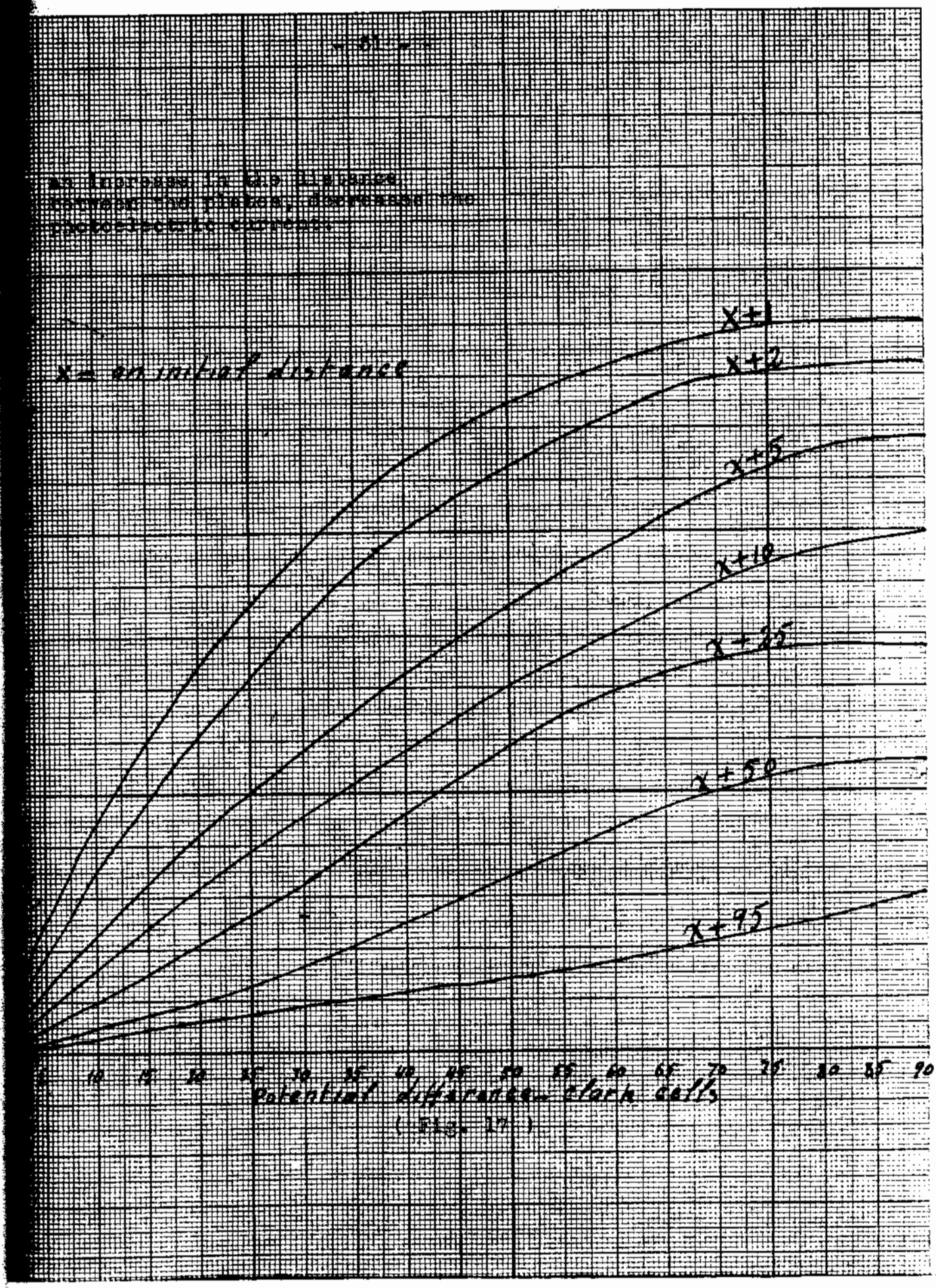
where P = critical pressure in mm of mercury.

d = distance between plates measured in cm.

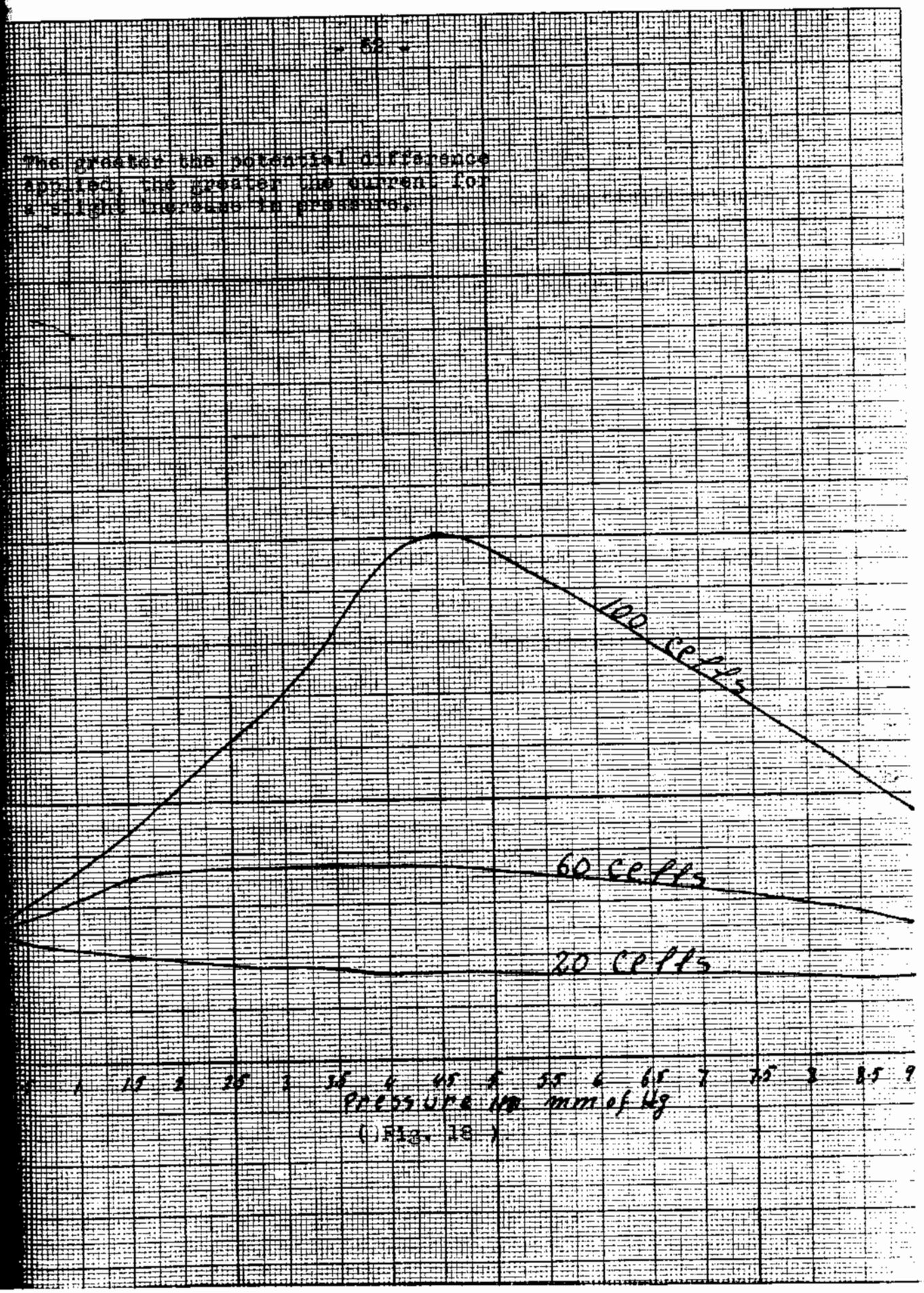
E = applied difference of potential in volts.

K = a constant.

It was mentioned that in the presence of a gas, the current is conducted in three ways, therefore if the pressure is decreased to the extent where the free path of the electron becomes equal to the distance between the molecules, no ions will be formed, and the conduction of the current will depend on the electrons alone. Therefore we expect the current to decrease.


x = 0.1 mm
As increase in the distance between the electrodes, decreases the photoelectric current.
x = an initial distance
x+1
x+2
x+5
x+10
x+25
x+50
x+95
Potential difference - Clark cells
(Fig. 17)

The greater the potential difference applied, the greater the current for a slight increase in pressure.

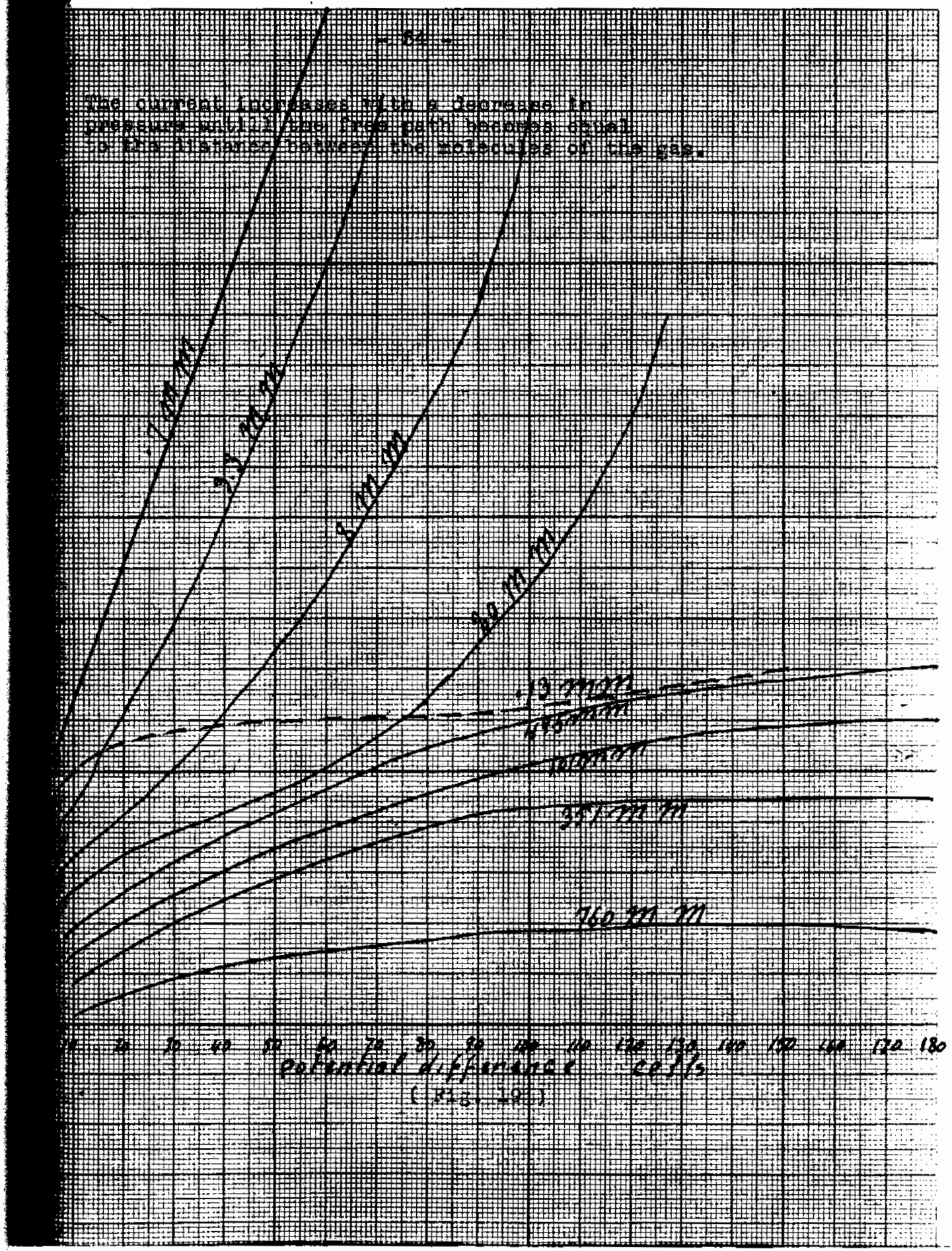


(Fig. 18)

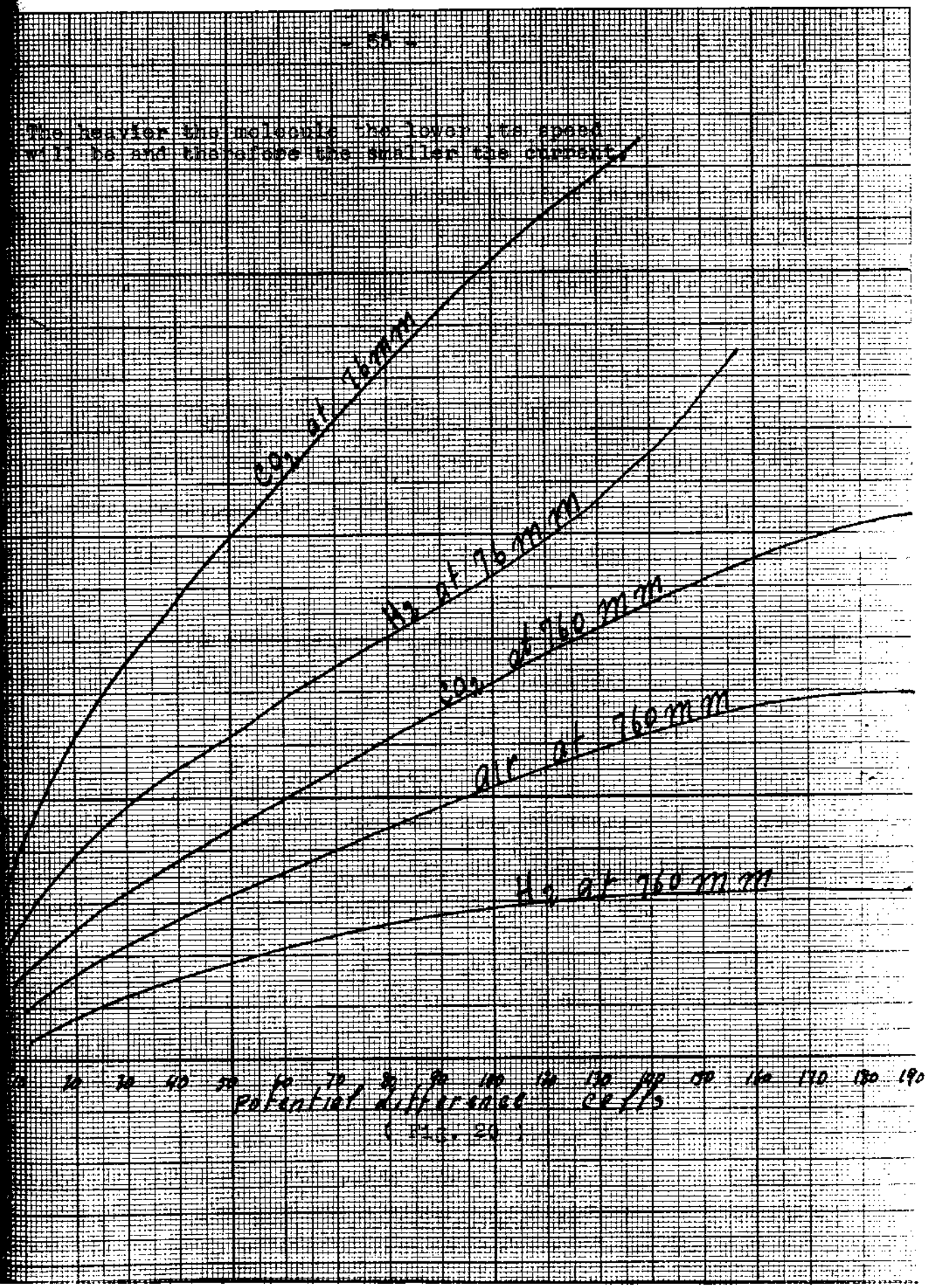
Varley investigated the variation of the current with potential difference for different pressures. His results are given in figure 19 from which it can be easily seen that the current increases more rapidly for a certain potential difference as the pressure is decreased untill a pressure of 0.13 mm is reached when the current falls down rapidly.

The variation of the photoelectric current with potential difference depends not only on the pressure of the gas in the cell but also on the nature of the gas because the molecules of some gases are different in properties from those of another gas. Varley studied the variation for air, carbon dioxide, and hydrogen. His results are given in figure 20.

The current increases with a decrease in pressure until the free path becomes equal to the distance between the molecules of the gas.



The heavier the molecule the lower its speed will be and therefore the smaller the current.



(Fig. 20)

D Influence of Temperature

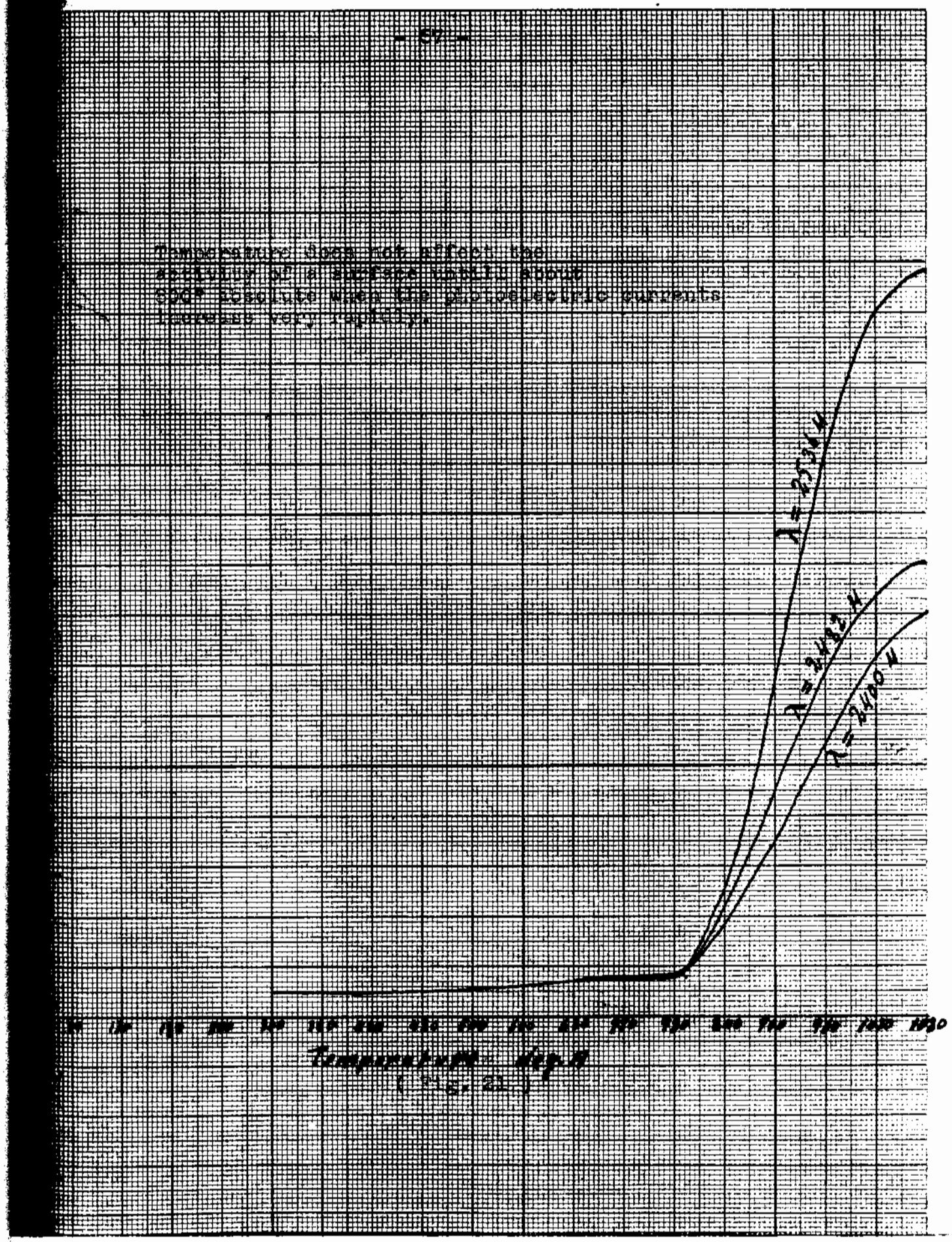
On the bases of the quantum theory we may argue that the velocity of a photoelectron leaving a surface will be greater the higher the temperature of the active surface. This was not found to be the actual case over a long range of temperature variation but that the photo-electric current remains constant in value untill a temperature of 800°A when the current starts increasing very rapidly, reaching a saturation point at a certain temperature depending on the wavelength of the exciting light used.

Warner(16) using very ellaborate pieces of apparatus and under the most favorable conditions obtained very accurate readings of temperatures and photoelectric currents. His results are plotted in figure 21 for three different wavelengths. The same investigator measured the current as affected by wavelength for different temperatures. These results are plotted in figure 22 which shows that the "long wave limit" did not change appreciably, so that the electrons escaped against the same work function for all temperatures.

---

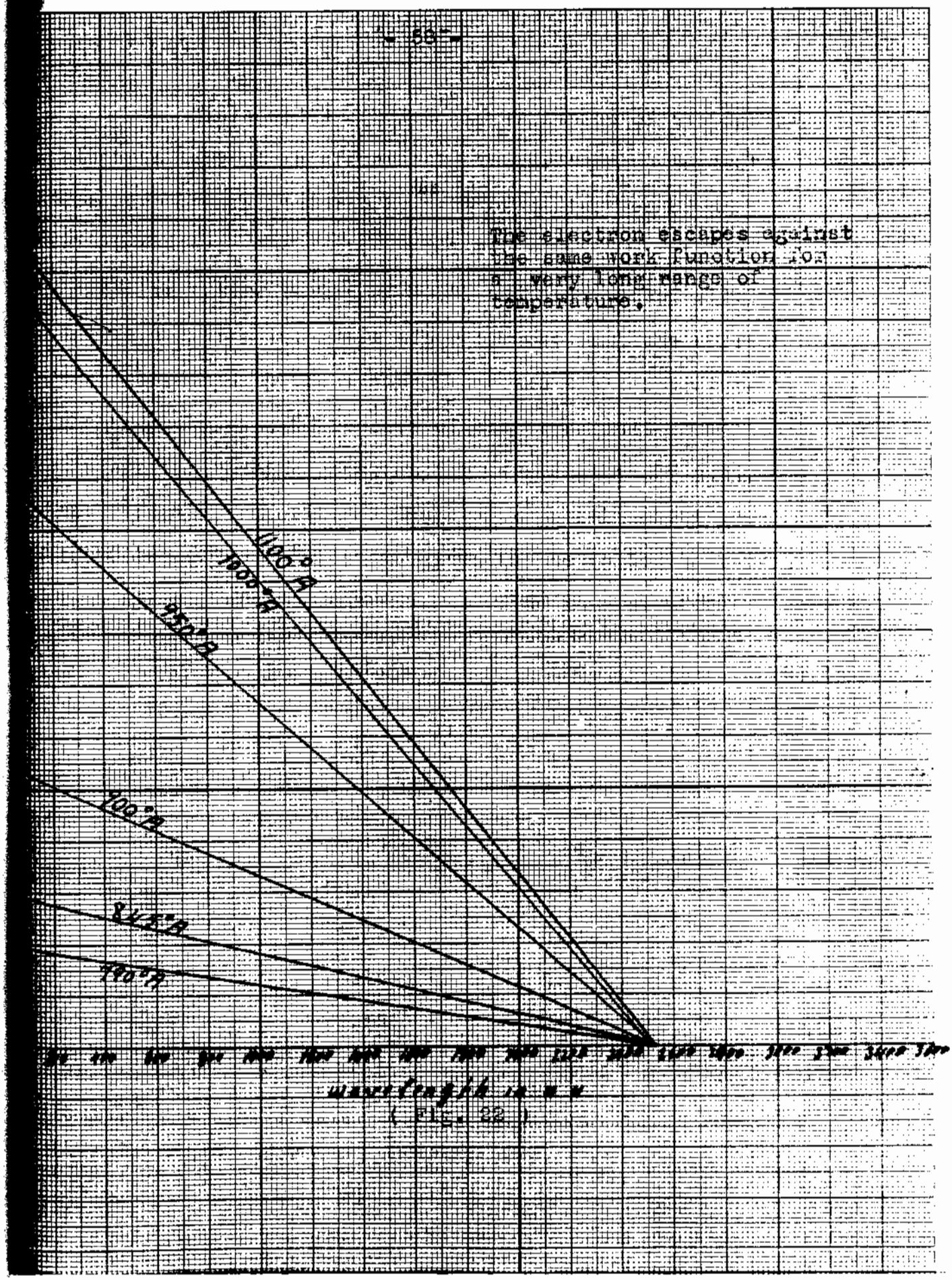
(16) The Physical Review, May 1929, P 817.

Temperature does not affect the activity of a surface weakly acidic oxide absolute when the photoelectric currents increase very rapidly.



(Fig. 21.)

The electron escapes against the same work function for a very long range of temperature.



(Fig. 22)

Nielson(17) studied the variation of the photo-electric current as affected by temperature up to 400°C. The current was measured by the rate of deflection of an electrometer. The active metal was aluminium which was heated to a temperature of 400°C and then cooled slowly and at definite intervals after the cooling, the current was determined by the electrometer and the temperature by a thermocouple. The results of the experiment show that the current remains constant, for wavelength=2537 A.U., between the temperatures dealt with, namely, 100° and 400°C(18). The results are given in the following table:

Time in min. after cooling is started.	current.	Time in min. after cooling is started.	current.
110	28.20	120	28.13
111	28.18	121	28.12
112	28.15	122	28.15
113	28.14	123	28.10
114	28.11	124	28.13
115	28.13	125	28.15
116	28.12	126	28.10
117	28.15	127	28.20
118	28.15	128	28.12
119	28.14	129	28.14

(17) The Physical Review, January 1925, P 30.
(18) " " " " " P 39.

E Influence of Electric and Magnetic Fields

1 Influence of electric Fields

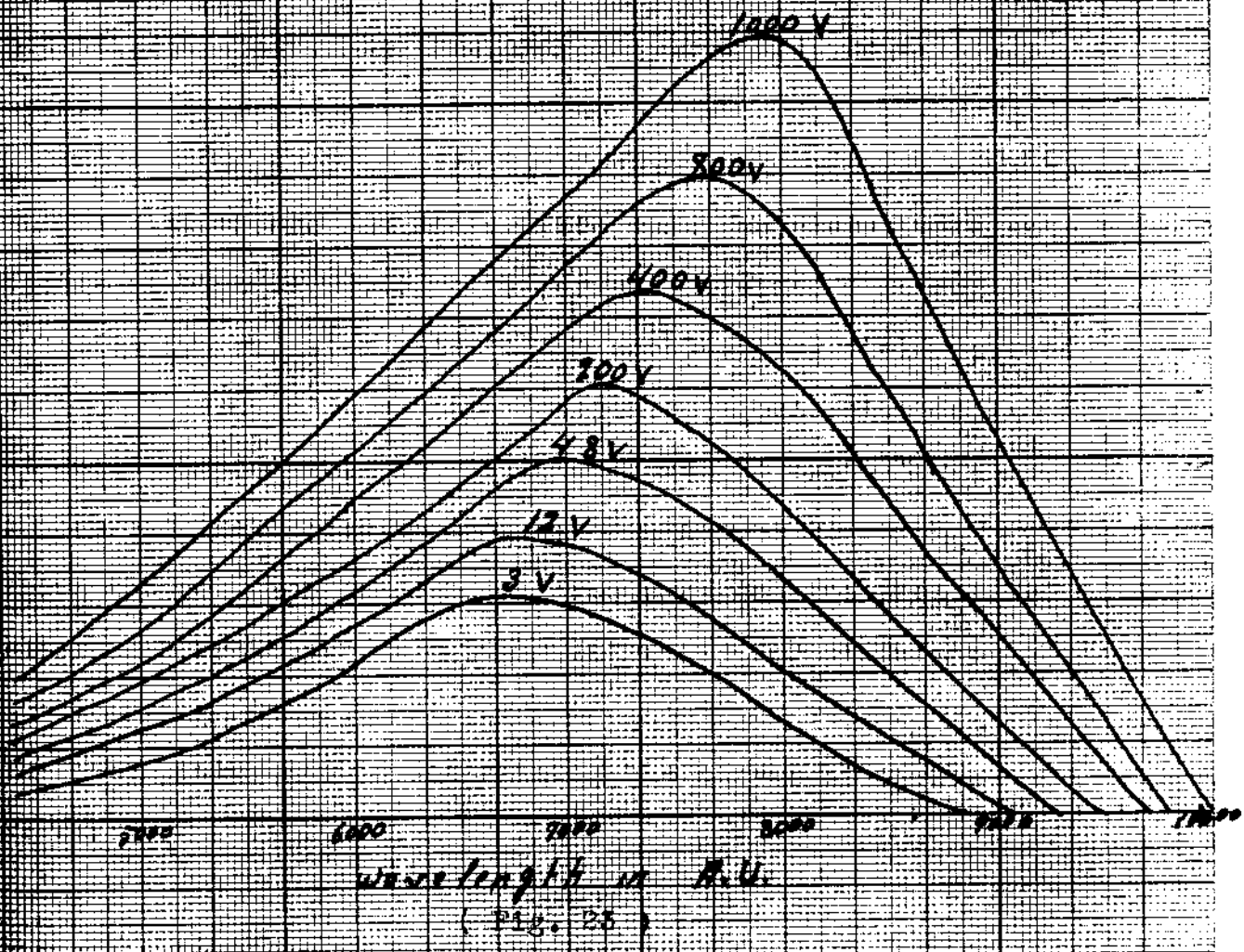
Up to the present time, we have seen that the intensity of illumination affects the number of electrons leaving the active surface, the frequency of the incident light affects the velocity of the electrons, pressure affects the velocity and the number of electrons leaving the surface, heat has no effect untill a temperature of 800° A is reached when the current goes up very rapidly reaching a point of saturation.

Now we want to see what the effects of electric and magnetic fields are on the photoelectric current. A thorough investigation of the subject was carried out by W. S. Huxford(19). The tube he used was a heater type radio tube number A-IV. He applied a certain accelerating potential and measured the photoelectric current against the wavelength and repeated the measurements for the same range of wavelength for different accelerating potentials. His results are plotted in figure 23. Using the above tube, Huxford measured the frequency at which emission starts as he varied the applied accelerating electric field. He found that the threshold frequency

---

(19) The Physical Review, August 1, 1931, P 379.

The applied potential increases the
the currents produced by a cell.



(Fig. 25)

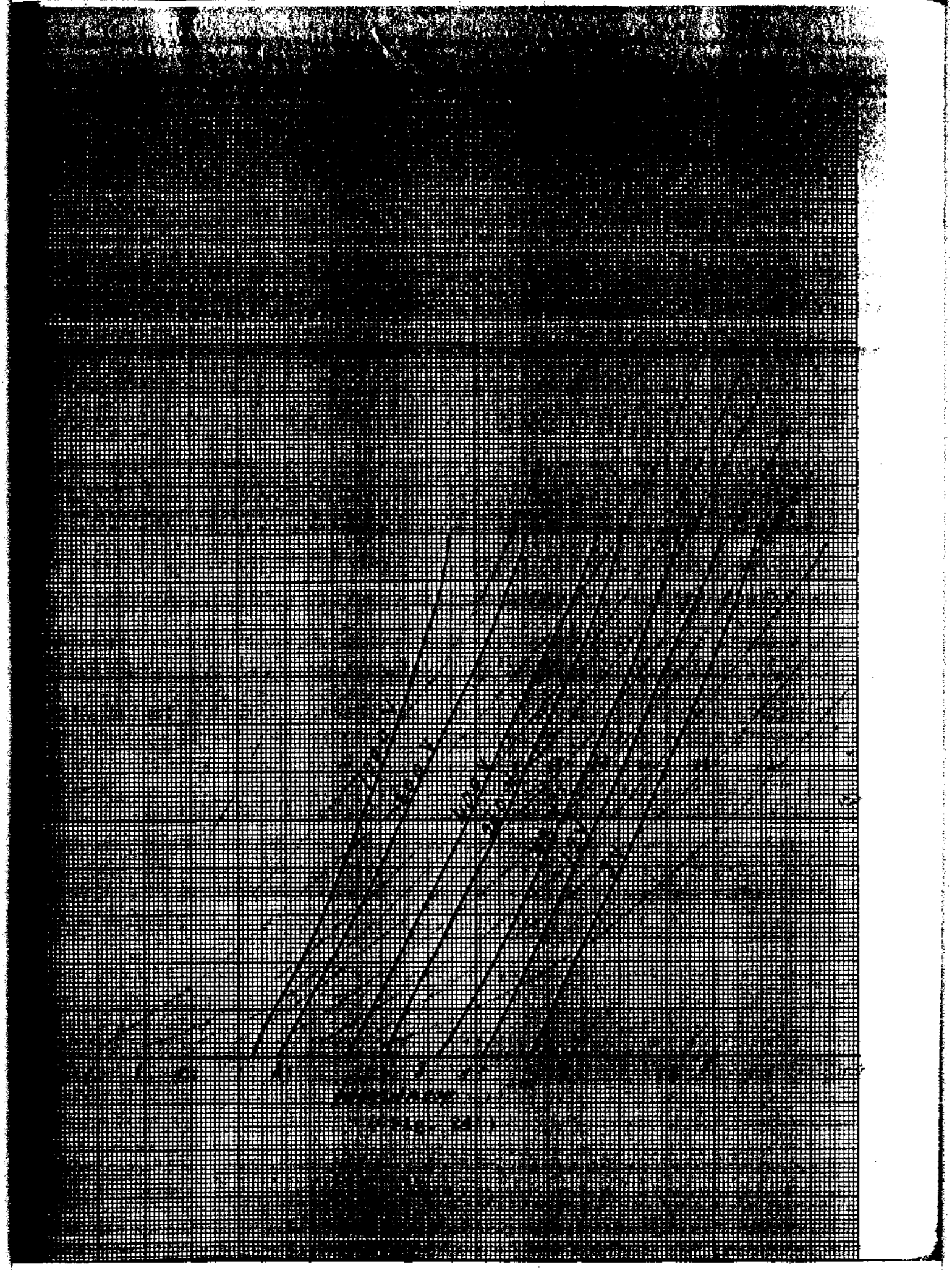
decreases as is shown in figure 24. This is to be expected because before an electron leaves the surface it should possess a certain amount of kinetic energy, and the mass of the electron being constant, then the velocity that is needed to supply the electron with enough kinetic energy is determined. Therefore if the applied potential is low, we shall have to depend upon a high frequency to accelerate the electron, whereas if the accelerating potential is high, the frequency required will be a little lower.

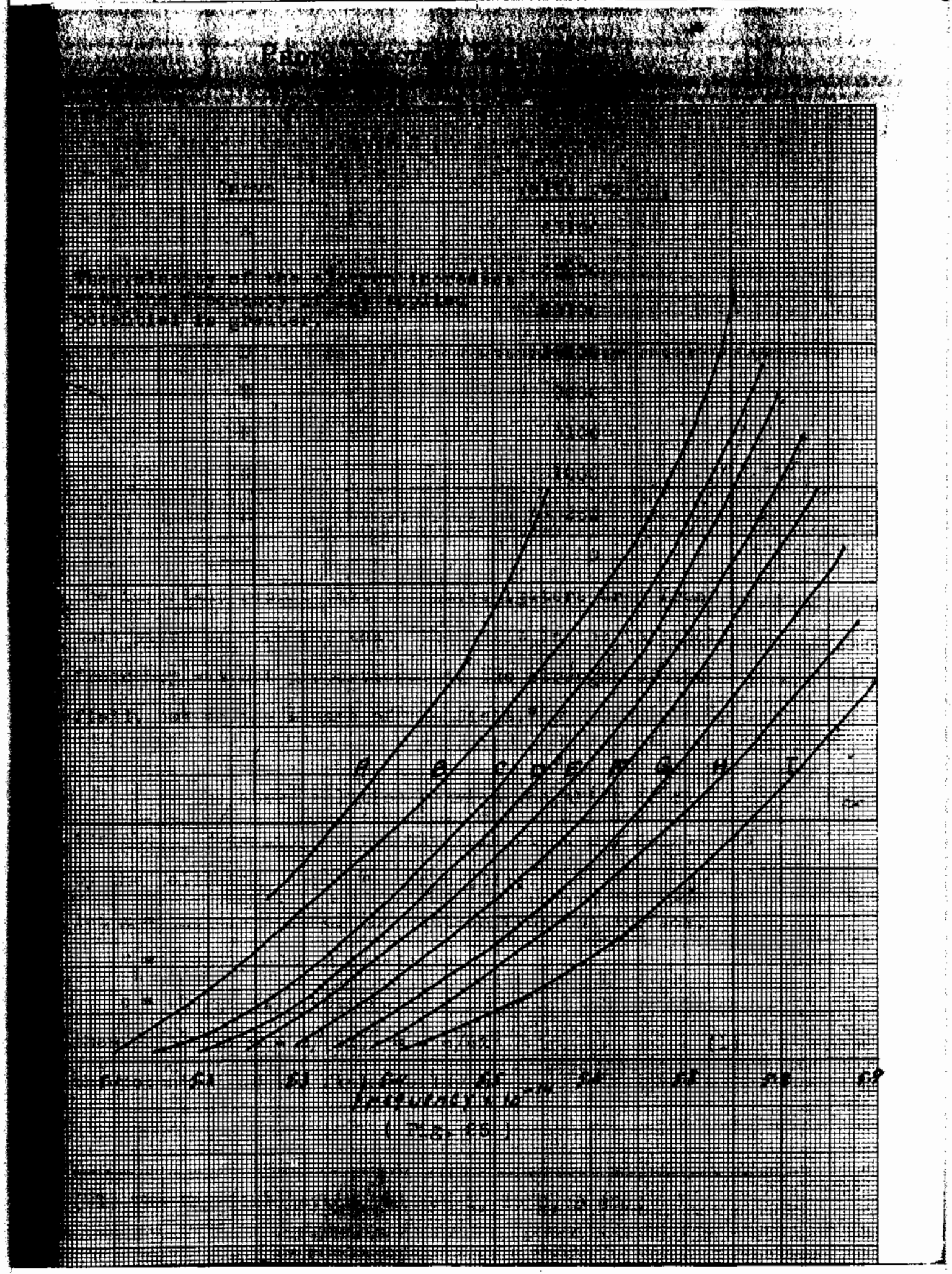
Lawrence and Linford(20) using accelerating electric fields as high as 63000 volts per cm. obtained a somewhat quantitative relation between the accelerating field applied and the threshold frequency. They used a potassium cell of small dimensions. The cell was baked at 500°C for 12 hours. Their results are given in figure 25 which shows the relation between the frequency and the photo-electric current per unit light intensity for different accelerating fields.

The potentials used in determining the curves of figure 25 were:

---

(20) The Physical Review, Augustl, 1930, P 422.





Curve	Volts per cm.
A	63100
B	36200
C	22100
D	15800
E	9000
F	3100
G	1000
H	260
I	0

The important result that the investigators drew from this piece of work was that "the shift in the threshold frequency was not proportional to the strength of the field, but to the square of the field."

The above relation between the shift of the threshold frequency and the electric field may be reached by the following simple reasoning(21):

let x = the distance of the elctron from the surface.

E_i = field produced by electron.

e = charge of electron.

then $E_i = -e/(2x)^2 = -e/4x^2$ (1)

the potential of the field would be

---

(21) The Physical Review, August 1, 1930, P 490.

$$V_i = -\int_{\infty}^{x} E_i\, dx = -\int_{\infty}^{x} -e\, dx/4x^2 = -e/4x \qquad (2)$$

if E_a = applied external accelerating field

then the potential due to this field at a distance x would be

$$V_a = -E_a\, x$$

therefore the potential resulting from the two fields would be

$$V = -e/4x - E_a\, x \qquad (3)$$

to find the maximum potential we equate the derivative of (3) to zero and get

$$-dV/dx = E = -e/4x^2 + E_a = 0$$

$$x(\text{max.}) = 1/2\ (e/E_a)^{1/2} \qquad (4)$$

substituting (4) in (3) we get

$$V(\text{max.}) = -e/4\ 2(E_a/e)^{1/2} - E_a/2(e/E_a)^{1/2} = -(e\, E_a)^{1/2} \qquad (5)$$

If equation (5) is plotted, it would give us curves that are similar to those of figure 25.

2 Influence of Magnetic Fields

The electrons present in an atom may be divided into 6 classes(22).

1. Nuclear electrons.
2. Free or conductivity electrons.
3. Dispersional or emission electrons.
4. Valency electrons.
5. Photoelectric electrons.
6. Revolving electrons.(present only in magnetic substances).

Some scientists believe that the dispersion and valency electrons are identical, but ther is not any conclusive proof to support that view.

It is very well known that the photoelectric and the revolving or magnetic electrons are the same because the magnetic and photoelectric properties of an elementdepend on its chemical state of combination, and therefore if we suppose that photoelectric and magnetic electrons in a ferromagnetic substance are to be identified by the valency electrons , then it might be expected that magnetizing a substance might have an effect on its photoelectric properties.

---

(22) J. H. J. Poole, Philosophical Magasine, September 1921, P 339.

It might be stated that two suggestions of the origin of the photoelectric electron have been given:

1. The photoelectron is liberated from the nucleus.
2. The photoelectronis a free or conductivity electron.

The first suggestion is a remote possibility because the only substances found to eject electrons from the nucleus are radioactive substances and then the velocity is so great that changing conditions have almost no effect onit.tAnother thing that disproves the first possibility is that in all cases observed where an electron leaves the nucleus, there has been detected a change in the atomic weight which is accompanied by a change in the chemical and physical properties of the substance.

The support of the second possibility is that the photoelectric activity of an element has a connection with its chemical properties, that is "the more chemically electropositive the element is, the more active it is photoelectrically." The objection to this possibility is that no connection has been detected between the photoelectric activity of a substance and its electrical conductivity; and change of temperature which is known to affect electrical conductivity appreciably, was found to have no effect(within certain limits) on the photoelectric electron emitted from a metal in a vacuum.

Poole, using very strong fields, studied the effect on photoelectrons emitted from the face of the magnet. His results are given in the following table(23):

Time in seconds taken for a deflection of 10 div.

Iron unmagnetized.	Iron, N P.	Iron, S P.
20.2	17.2	18.2
14.8	15.2	17.6
17.0	16.2	16.4
14.8	15.8	18.2
19.4	17.2	17.8
18.6	16.2	16.4
18.2	14.8	14.8
15.2	15.4	16.0
16.8	16.4	17.6
18.6	17.6	21.0
21.4	19.8	21.4
19.6	18.6	21.0
20.0	19.2	19.8
18.4	19.2	19.2
Average 17.6	17.1	17.7

The above table shows that the magnetic field has almost no effect on the photoelectric current, and to be sure, the investigator repeated the above process seven times as is shown in the following table:

---

(23) Philosophical Magazine, September 1921, P 341.

Rise of voltage per second.

	A	B	C	
Experiment	Unmag.	M.P.	S.P.	Arc current.
1	.061	...	.062	2.7
2	.064	...	.066	2.6
3	.046	...	.045	2.6
4	.030	.030	.030	2.6
5	.043	.043	.044	2.6
6	.046	.047	.049	2.7
7	.043	.043	.044	2.7

Other substances were tried and in this case the angle of incidence was changed. The results as follows show no effect due to the field:

Rise of voltage.

Substance.	Angle of incidence.	Field off.	Field on. MP	Field on. SP	Arc current.
Iron	45° to surface	.0088 .017	.0091 .017	.0086 .017	1.6 1.6
Bismuth	90° to surface	.16 .056 .046 .040	.16 .056 .046 .040	....	2.7 2.6 2.6 2.6
Magnetite	.....	.0078 .0082 .0043	.0076 .0081 .0043	.0081 .0083 .0044	2.6 2.6 2.6
Nickel	.....	.0084 .0084	.0079 .0088	.0088 .0086	1.7 1.7

VIII Fatigue due to Photoelectric Emission

A fact that has always been associated with photoelectric emission is a change in the sensitivity of the photoelectrically active subsatnce with time. The greater majority of investigators in this field agree that there is no change in sensitivity if the active substance is placed in a very high vacuum, but if the substance is under pressure, many things affect the sensitivity; such things as the size of the vessel, its shape, the pressure of the gas inside, the nature of the gas, the ingrediants in the gas, water vapour, the chemical activity of the active substance, the way the active substance is prepared, the time that has elapsed between the preparation and the use of the active substance, the intensity of illumination, the character of the light used.

A phenomenon that is affected by so many things is something very difficult to find an explanation to, especially if the thing to be observed or measured, such as current or pressure, is very small.

Photoelectric fatigue has been attributed to one or more of the following causes:

1. A chemical change such as oxidation of the surface(1).
2. A physical change of the metal itself, as,for example, a roughening of the surface(2).
3. An electrical change in the formation of an electrical double layer(3).
4. A change in the surface film of gas, or in the gas occluded in the metal(4).

Kreusler investigated the effect of light on photoelectric fatigue and came to the result that fatigue depends on the action of the ultraviolet rays on the surface of the kathode and that fatigue is proportional to the duration of the illumination. His results are given in the following table:

	photoelectric current amperes
initial	1.36 x 10^{-11}
after 8 min. in darkness	1.33 "
after 5 min. in light	1.19 "
after 6 min. in darkness	1.19 "
after 5 min. in light	1.02 "
after 5 min. in darkness.	1.02 "
after 6 min. in light	0.85 "

(1) Knoblauch
(2) Allen
(3) Lenard
(4) Hallwachs

Hallwachs, as a result of an experiment whose reuslts are given in the following table came to the conclusion that the percentage of fatigue does not depend on the illumination:

	percentage fatigue			
in light	40	78	88	93
in darkness	44	81	89	94
time of illumination in min.	6	24	82	135

Many experiments were performed to discover the relation between the size of the containing vessel and fatigue. The results are astonishingly contradictory to one another but the belief at the present time isthat " the rate at which fatigue proceeds diminishes with the size of the containing vessel"(5).

Hydrogen has no effect in producing fatigue in certain metals but has a strong effect on others. Ozone and chlorine behave as hydrogen does but have very strong effects in producing fatigue in some metals.

Schweidler, Hallwachs, Sadzewicz and Allen, all hold to the idea that neither the electrical condition of the surface nor the potential applied has any effect on the rate at which fatigue takes place.

---

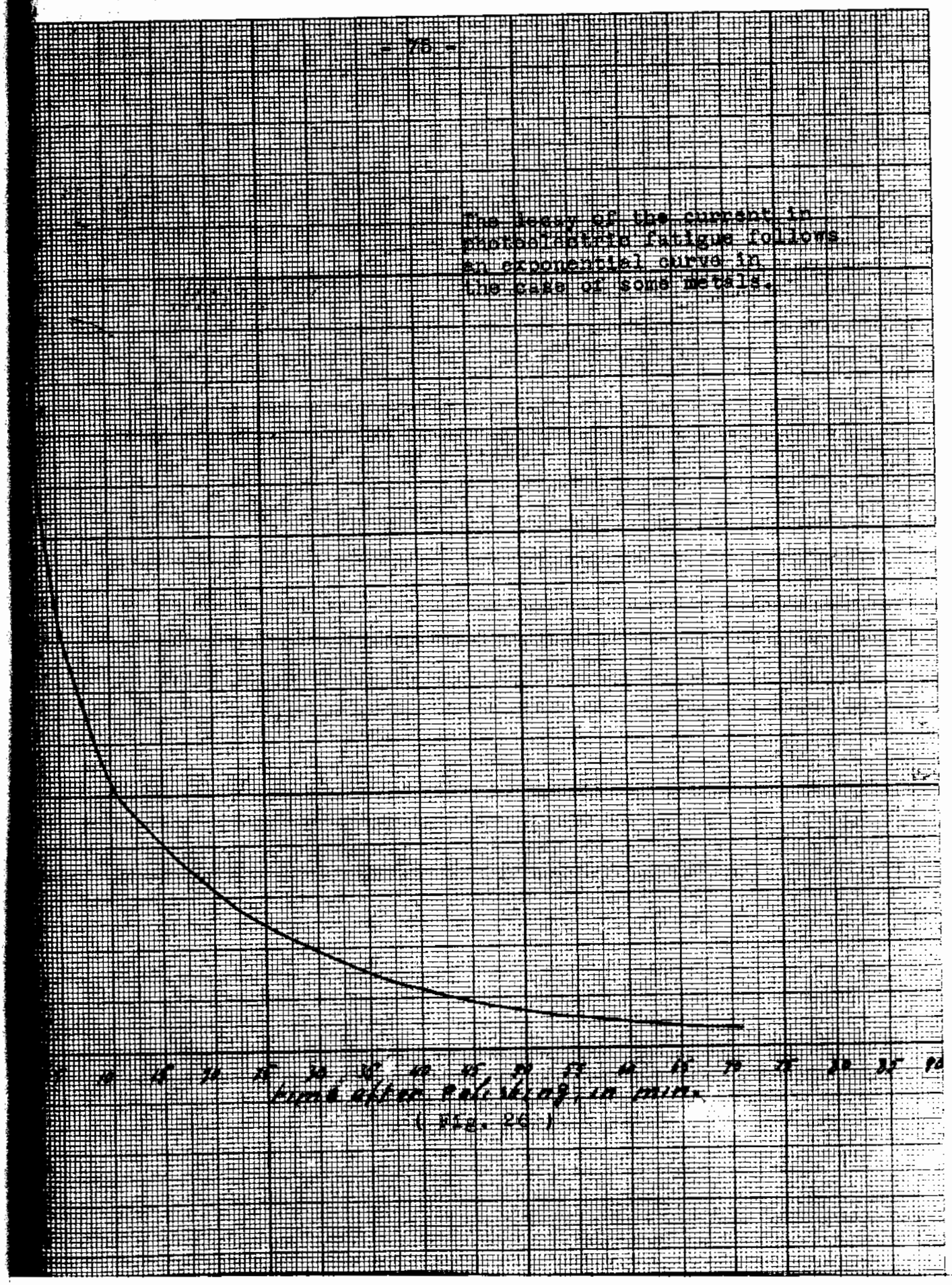
(5) Allen, Photoelectricity, P 193.

Allen found, experimentally, the relation between the time after the metal was polished and the photoelectric current. He came to the conclusion that the decay of the current follows an exponential curve, a view that was supported by Schweidler. The results of Allen are given in figure 26.

Robinson, J., investigated the fatigue of zinc and alluminium polished by steel and placed in a very high vacuum(6). His results for zinc are given in the following table and plotted in figure 27.

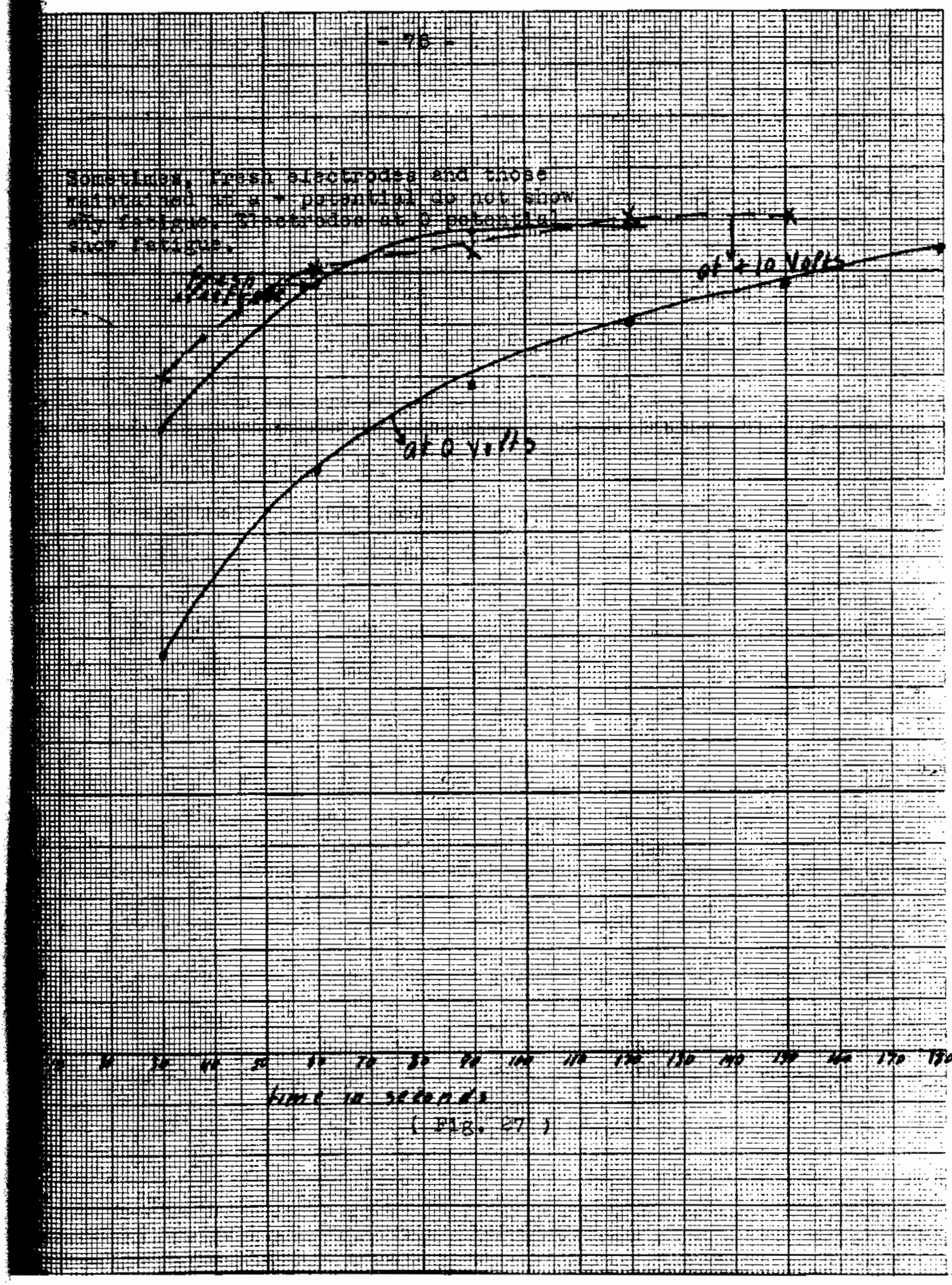
fresh electrode.		electrode after being exposed to light for 5 min. at + 10 volts.		electrode after being exposed for 5 min. at + 20 v.	
time	charge	time	charge	time	charge
30	60	30	65	30	38
60	74	60	75	60	50
90	79	90	77	90	64
120	79	120	80	120	70
		150	80	150	74
				180	77
				210	79

(6) The Philosophical Magazine, February 1912, P 255.


The decay of the current in
psychogalvanic fatigue follows
an exponential curve in
the case of some metals.

(Fig. 26)

Sometimes, fresh electrodes and those maintained at a + potential do not show any tendency to fatigue.

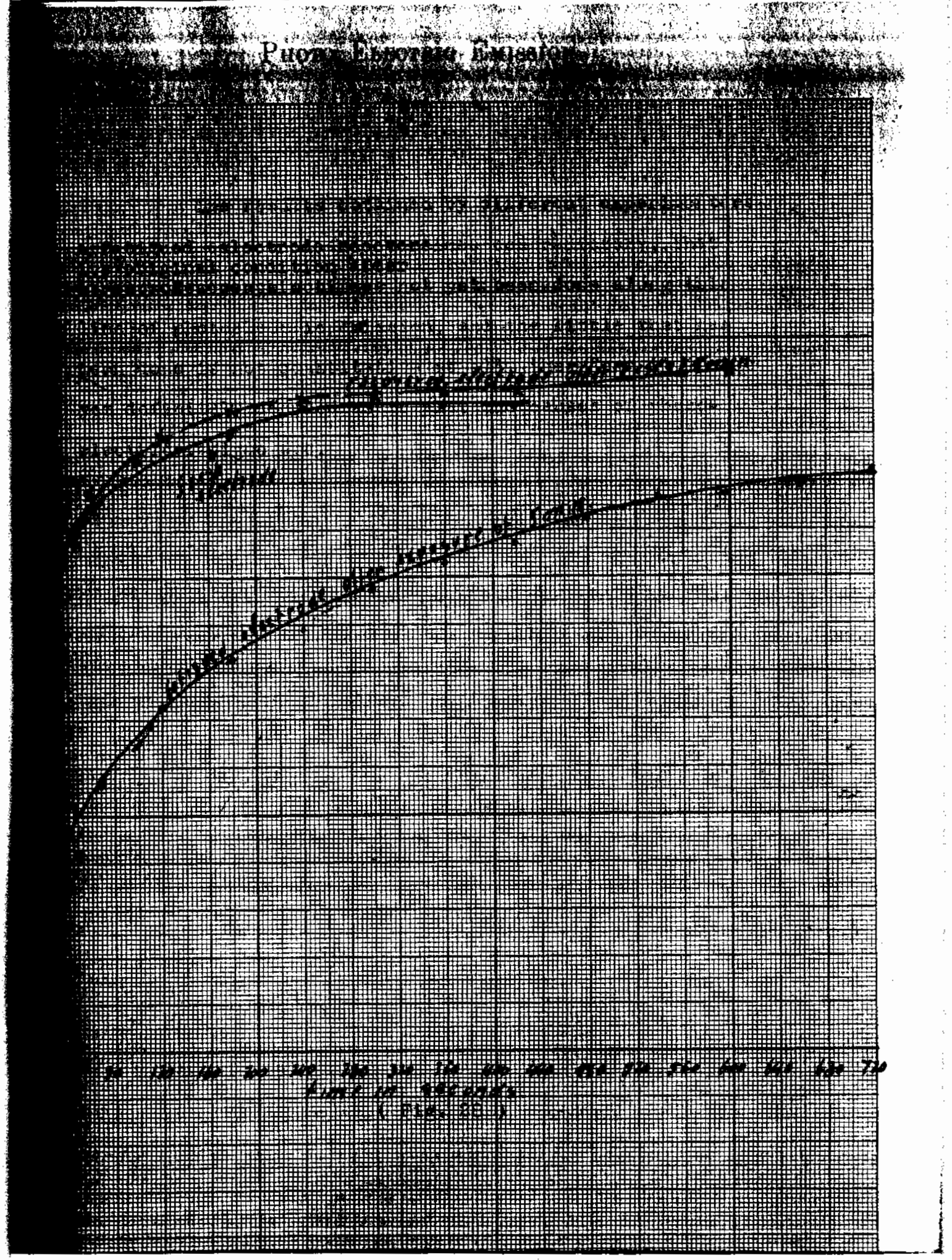


(Fig. 27)

The results with zinc show that the fresh electrode and that exposed to light but maintained at a positive potential of 10 volts did not show any fatigue or in other words that the rate of charging was the same. On the other hand, when the electrode was exposed to ultraviolet light at zero potential, it showed a decrease in the rate of charging proving that the metal was fatigued.

Robinson's results for aluminium are the following. They are plotted in figure 28.

fresh electrode		fatigued electrode after an exposure of 5 minutes		recovered elec. after rest of 5 minutes.	
time	charge	time	charge	time	charge
15	176	15	58	15	176
30	201	30	86	30	206
45	220	45	101	45	218
60	230	60	114	60	234
90	241	90	130	90	250
135	254	120	145	120	261
180	260	180	166	180	269
240	271	240	179	240	274
360	271	300	196	300	274
420	271	360	208	360	278
		420	215	420	278
		480	224	480	280
		540	233	600	286
		600	235		
		660	239		
		720	245		



The results obtained by different experimenters are out of egreement and sometimes contradictory, that is because enough work has not yet been done along this line of photoelectric emission, and the little that has been done is not quantitative at all, therefore it is not yet definitely decided as to what the causes of photo-electric fatigue are.

IX Theories of Photoelectric Emission

Inspite of all the experimental work that has been done to studyithe behaviour of photoelectrically active substances and discover the different laws that govern them, not much is known about the cause of photoelectric emission and a satisfactory explanation that may be put in the form of a law has not yet been reached. Not one of all the different theories and explanations forewarded by the great physicists accounts completely for the phenomenon. Every one of the theories explains some one or more phases of the phenomenon and fails to explain others. The tendency at the present time is to support the theory that explains more things about the subject and to try and group the differnt simpler explanations under one big generalisation.

Up to the present time no explanation has been able to prove the nature of the electrons emitted by the action of light. The greater part of the suggestions state that the photoelectric electrons are of the same nature as the conductivity electrons that is electrons to which the electrical onductivity of metals is due. One support of the above view is the following: the light incident on a surface consists of an electric and a magnetic vector at right angles to each other. The speed of the conductivity electrons may be increased by the action of the electric vector to such an extent

Against this explanation there are two drawbacks: the first is that in a high vacuum, the photoelectric current is independent of the temperature, a fact that the above explanation does not account for; the second is that experiments show that the photoelectric current is, over some range, independent of the intensity of the light.

The fact that an electron leavinga surface requires a certain amount of energy needs an explanation. One explanation may be; the atom under the action of light bacomes unstable and therefore ejects electrons that are supplied by energy from the incident light thru the atom and therefore the action may be grouped under radioactivity. This view does not account for the fact that the energy involved in radioactivityis independent of external agencies.

A second explanation of the phenomenon is afforded by resonance between the incident light and the electron that is assumed to have a definite period of vibration. The energy of the incident light increases the amplitude of vibration of the electron and therefore its velocity. When the electron acquires enough kinetic energy , it overcomes the attraction of the surface and goes off. The great difficulty that this hypothesis has to meetis this: the velocity of the vibrating

electron increases untill the energy is great enough to overcome the attraction of the surface, therefore the electron should leave with a velocity of zero. But the fact that the electron leaves the surface with a reasonably large velocity shows that it acquired that velocity during the last half vibration, a reasoning which throws the above theory off its feet due to the fact that half a vibration of the incident light is known not to contain an amount of energy large enough to give the ordinary escaping electron that velocity.

Einstein, using the idea of the energy of plank's quanta put a kinetic energy theory on mathematical bases. If m represents the mass of the electron and v ~~the~~ the velocity of the electron after it escapes, then

$$1/2\ m\ v^2$$

will represent the kinetic energy of the electron. The above amount of energy should be equal to

$$h\ f - P$$

where h = plank's constant.

f = the frequency of the incident light.

and P = the energy the electron loses in overcoming the attraction of the surface.

The above h f is the total amount of energy that the electron ~~tron~~ gained from the incident light.

$$1/2\ m\ v^2 = h\ f - P$$

must be equal to V e

where V = the positive potential necessary to prvent the escape of the electron.

and e = the charge of the electron.

X Experimental Work Done in Connection with this Thesis

Experiment 1 June 25, 1932.

Object- To study the relation between the intensity of the light incident upon a surface and the photoelectric current produced.

Apparatus- (Fig. 38)

S- Source of light, incandescent lamp, 250 watts.

L- Leter sticks.

C- High vacuum sodium cell.

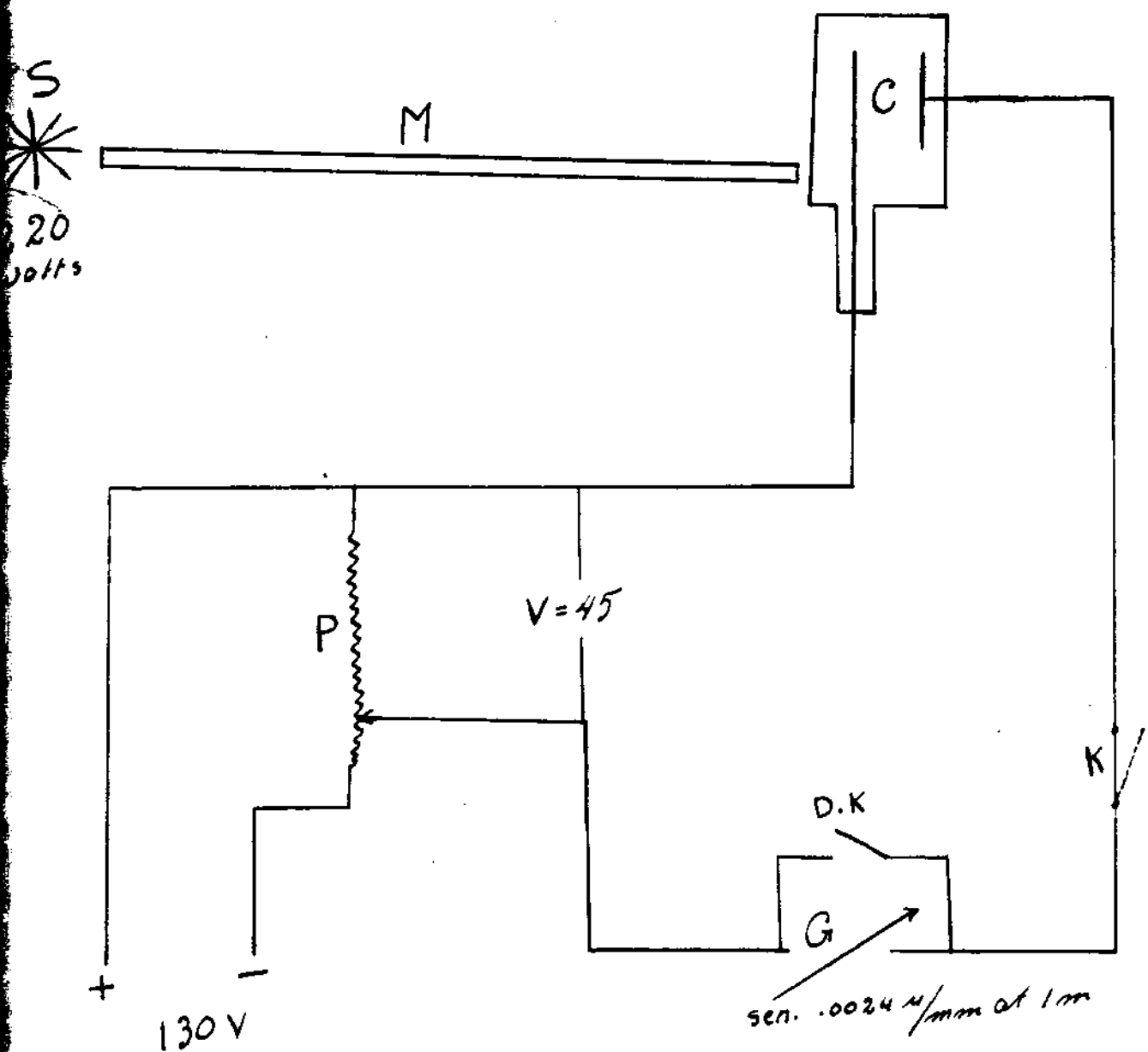
P- Potentiometer.

V- Voltmeter, adjusted at 45 volts.

K- Key.

D.K.- Damping Key.

G- Galvanometer, sensitivity- 0.0014 microamp./mm at 1 m.



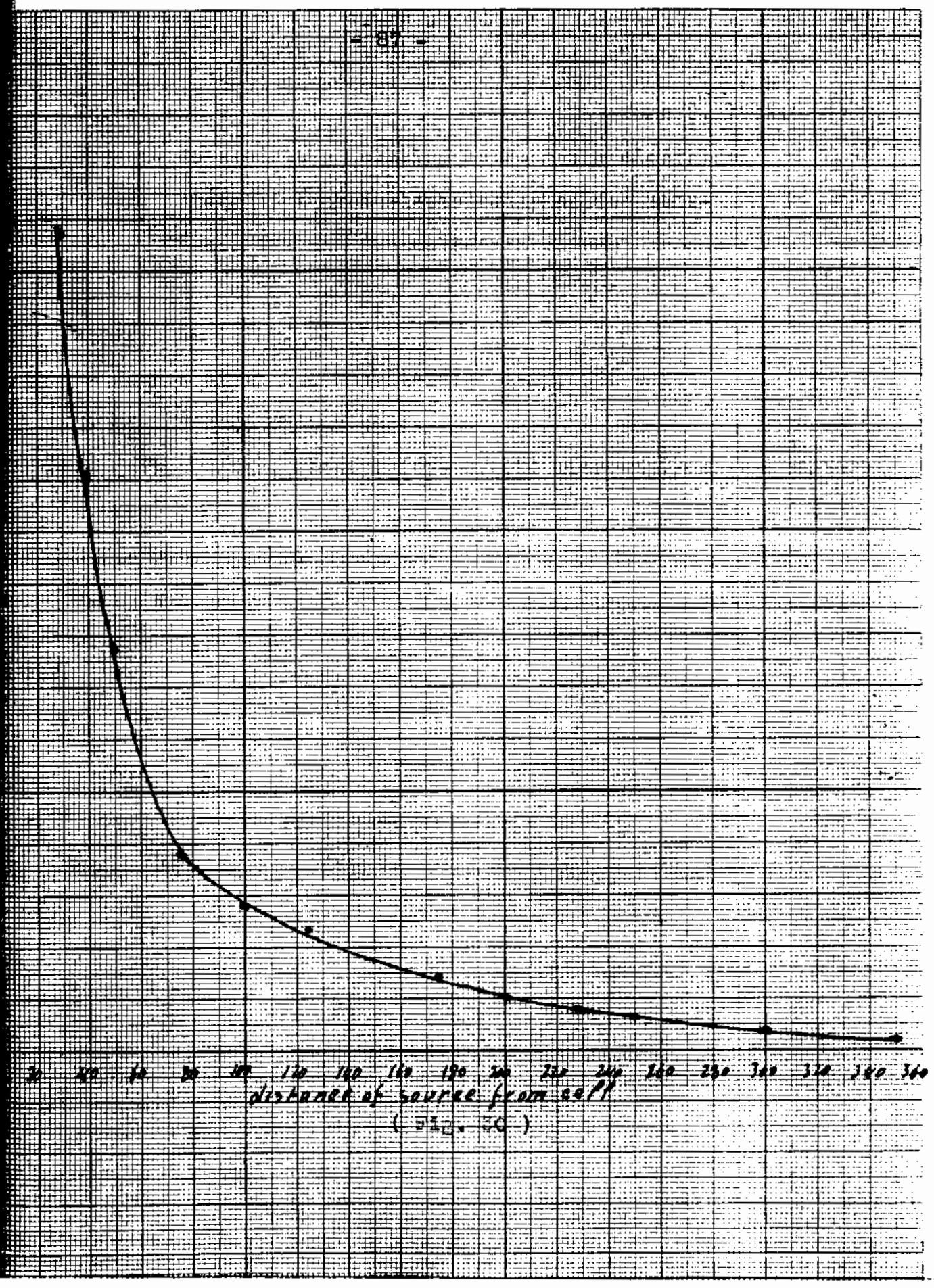
(Fig. 81)

Data-

Deflection due to dark current = 38 divisions

A distance of source from cell in cms.	B $\frac{1}{A^2}$	C total deflection	D C - dark current
400	160000	39	1
350	122500	41	3
300	90000	46	8
250	62500	50	12
200	40000	58	20
175	30625	65	27
150	22500	72	34
125	15625	84	46
100	10000	94	56
75	5625	113	75
50	2500	194	156
40	1600	290	252
30	900	354	316

Results- Plotted in (Fig. 30)



(Fig. 30)

Photo Electric Emission

Experiment 2 June29, 1932.

Object- To study the relation between the electrical state of a photoelectrically active substance and the photoelectric current produced.

Apparatus- (Fig. 31)

S- Source of light, incandescent lamp, 220 watts.

C- High vacuum sodium cell.

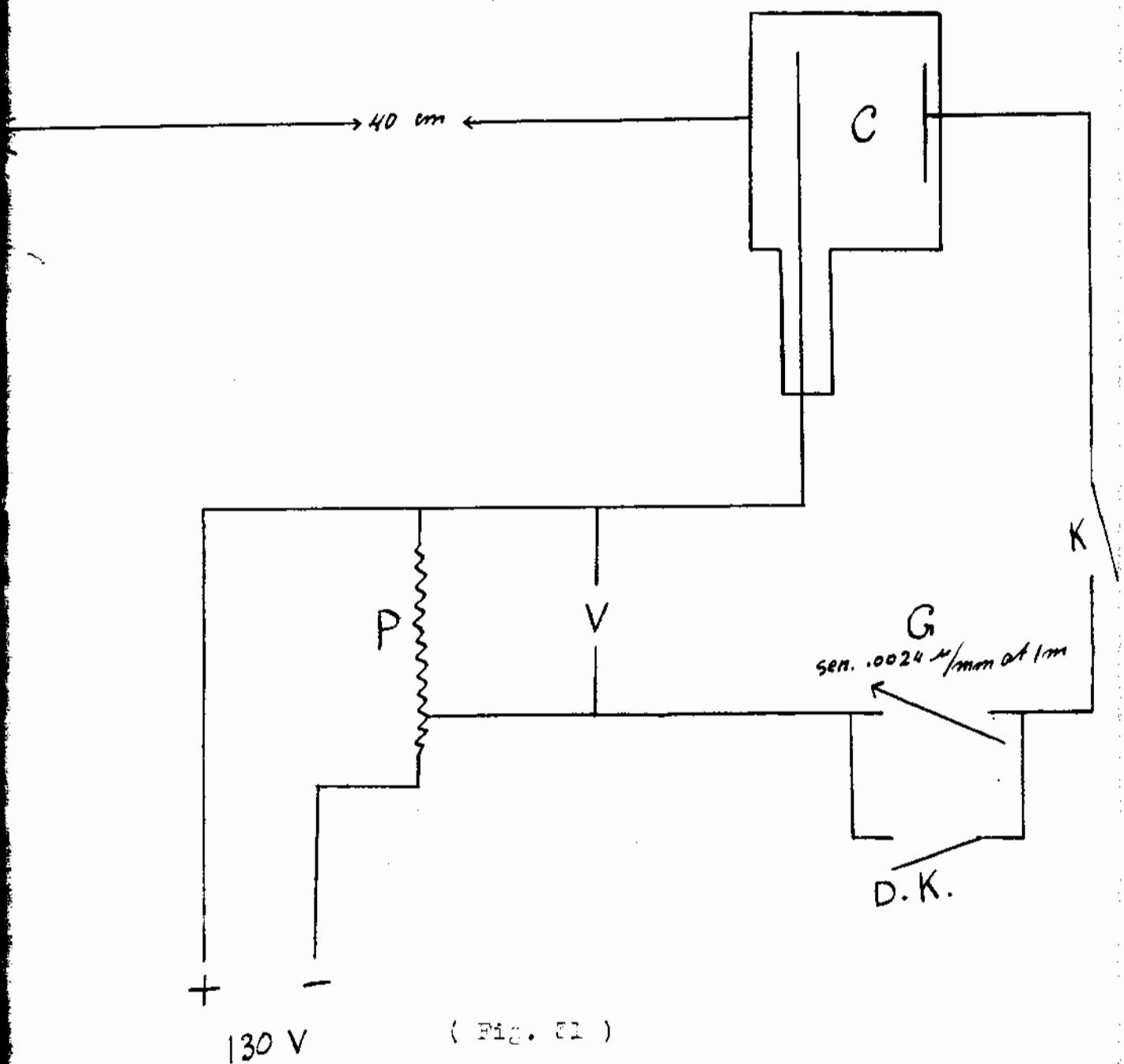
G- galvanometer, sensitivity- 0.0024 microamp./mm at 1 m.

K- Key.

D.K.- Damping key.

V- Voltmeter.

P- Potentiometer.

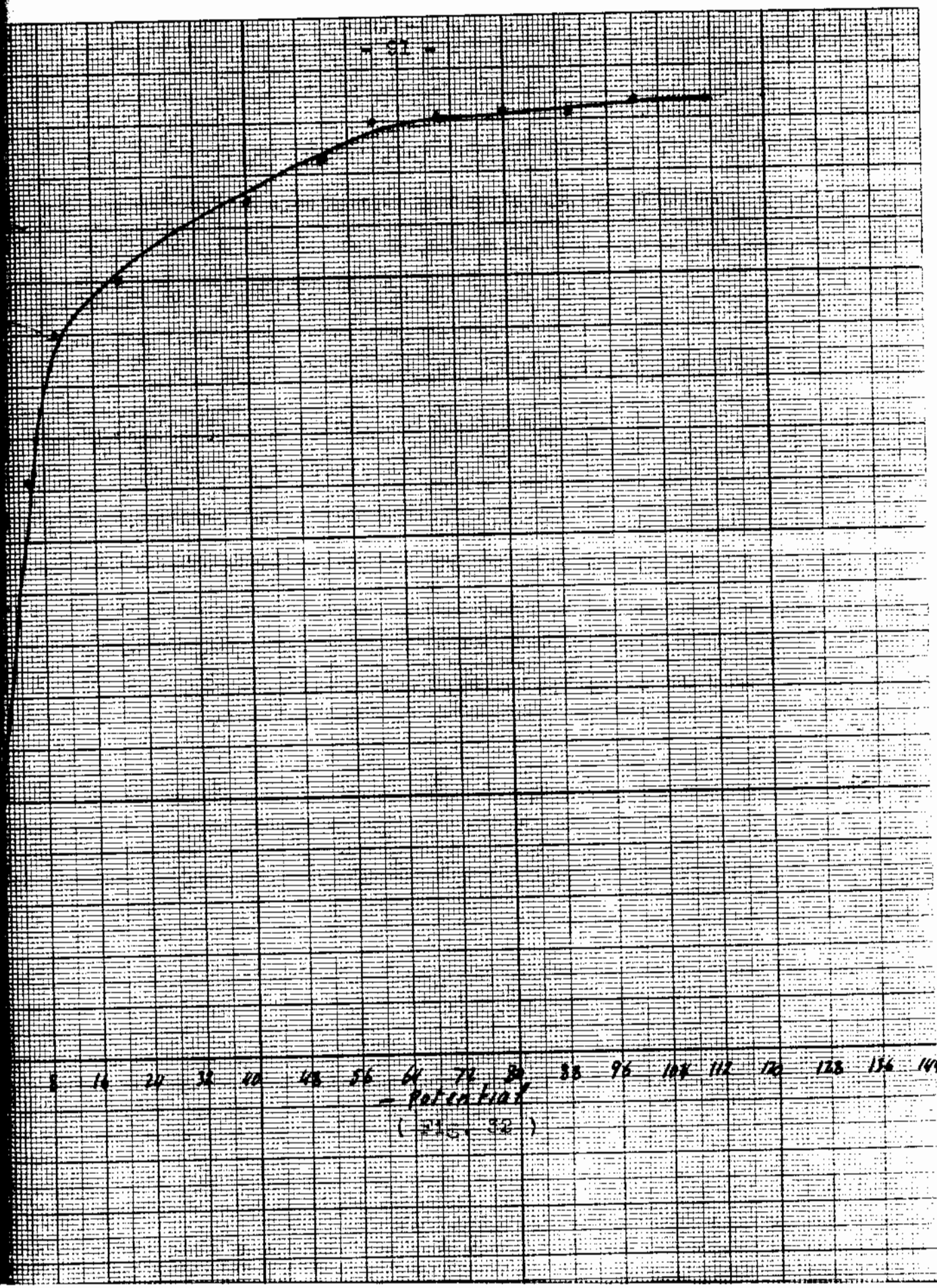


(Fig. 31)

Data-

A applied - poten.	B total deflec.	C dark current deflection.	D Net def. B - C
120	46.2	27.8	18.4
110	44.9	26.6	18.3
100	44.2	25.9	18.3
90	43.2	25	18.2
80	43	24.8	18.2
70	41.7	23.6	18.1
60	41	23	18
50	40.2	22.9	17.3
40	39.4	22.7	16.7
30	38.7	22.7	16
20	37.7	22.7	15
10	36.7	22.7	14
5	33.7	22.5	11.2
0	27.2	22.2	5

Results- Plotted on (Fig. 32)


8
16
24
32
40
48
56
64
72
80
88
96
104
112
120
128
136
144
Potential
(Fig. 32)

Experiment 3 July 6, 1932.

Object- To study the effect of different parts of the spectrum on the activity of sodium.

Apparatus- (Fig. 33)

A- Arc lamp as source, 250 watts.

L- Lens to produce approximate parallel rays.

G- Diffraction grating, 14460 lines/inch.

C- High vacuum sodium cell.

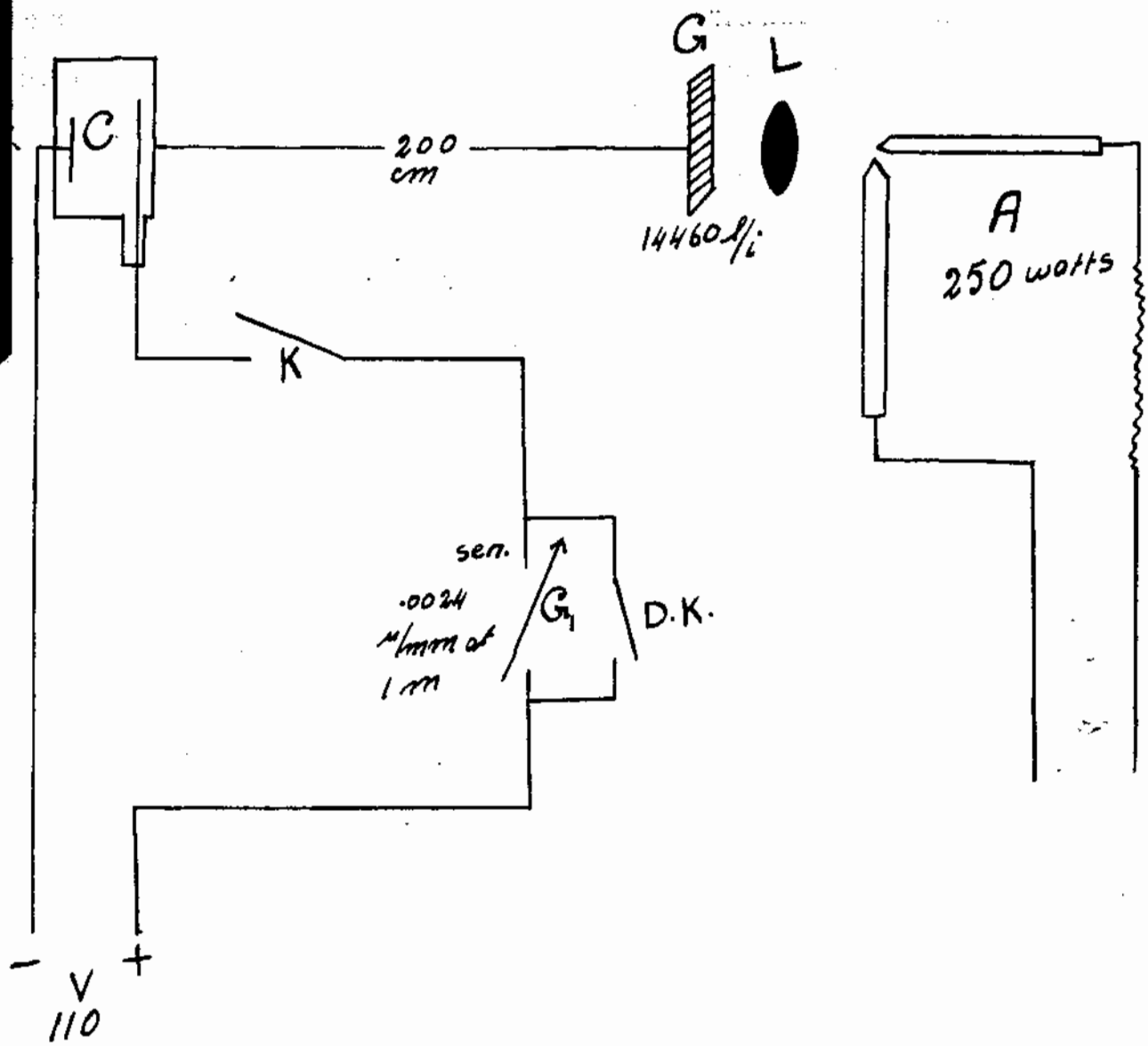
S- Spectrum, length 30 cms.

V- Voltage supply, 110 volts.

K- Key.

D.K.- Damping key.

G- Galvanometer, Sensi.- 0.0024 microamp./mm at 1 m.



(Fig. 33)

Data-

Deflection due to dark current at 110 volts = 31.5

A color	B total def.	C B - dark current
red	36.07	4.57
orange	37.35	5.85
yellow	38.12	6.62
green	35.07	3.57
blue	33.45	1.95
indigo	35.4	3.9
violet	35.17	3.67
white	60	28.5

Results- The effect of different parts of the spectr um upon sodium in decreasing order are:

yellow

orange

red

indigo

violet

green

blue

Experiment 4 July 10, 1932.

Object- To study the effect of change of temperature upon the activity of a photoelectric substance.

Apparatus- (Fig. 34)

S- Source, incandescent lamp, 220 watts.

C- High vacuum sodium cell.

T- Thermometer.

G- Galvanometer, sen.- 0.0024 microamp./mm at 1 m.

K- Key.

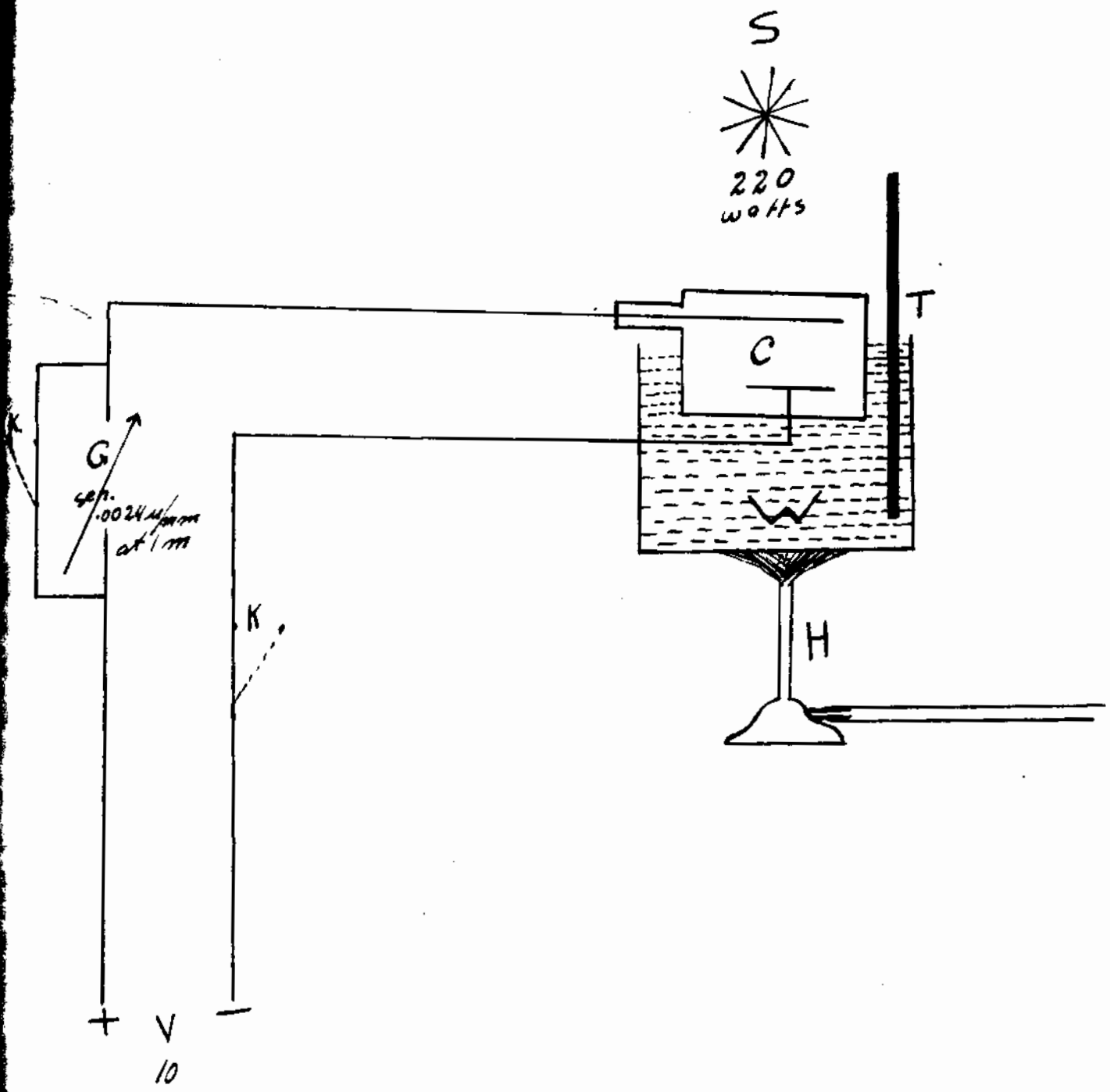
D.K.- Damping key.

V- Source of e.m.f., - 10 volts.

W- Water.

H- Bunsen burner.

Photo Electric Emission

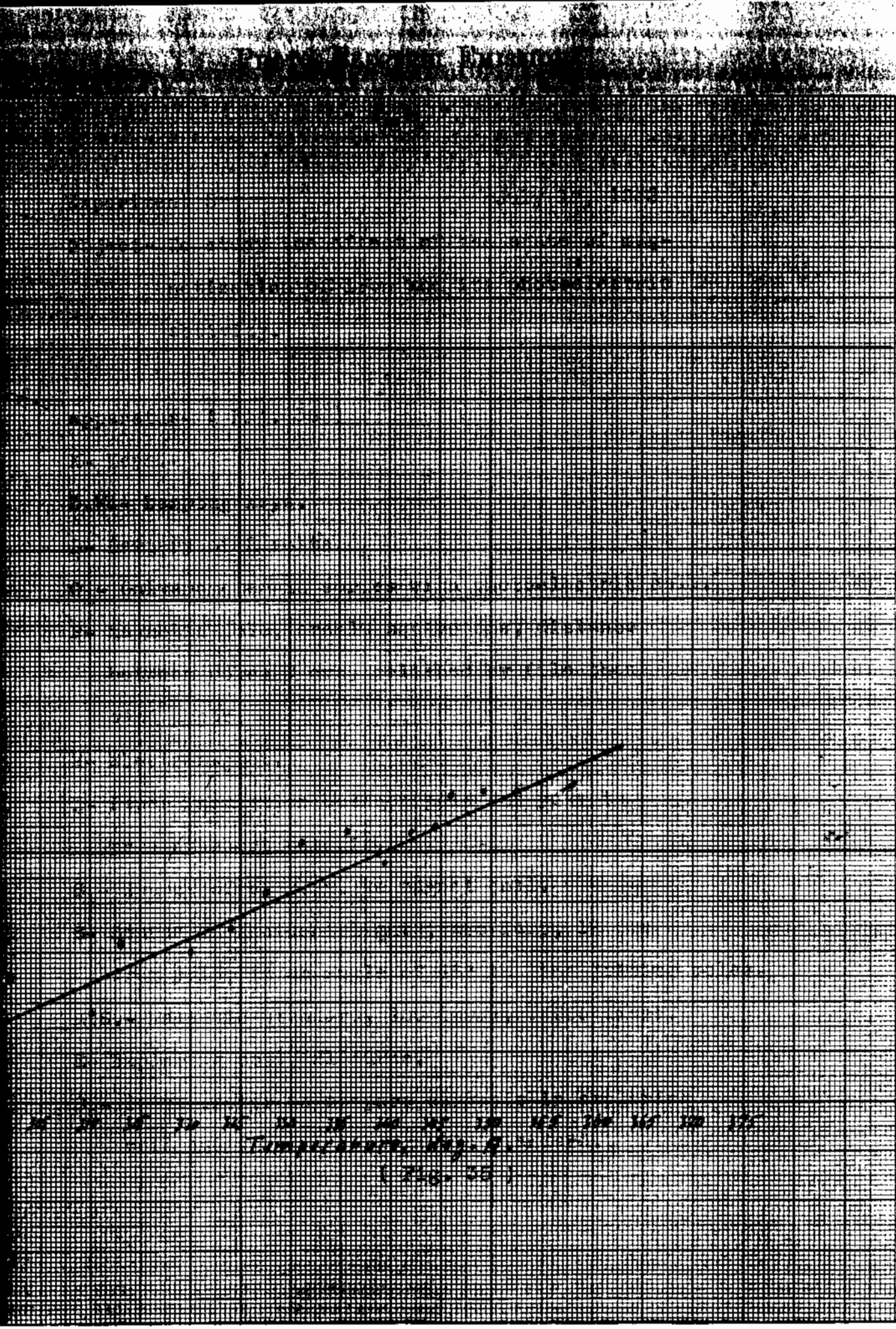


(Fig. 54)

Data-

A temperature in °C	B deflection	C temperature in °A
29	27.5	302
37	26.8	310
40	28.2	313
47	28	320
51	28.5	324
54.5	29.2	327.5
58	30.2	331
62.5	30.4	335.5
66.5	29.8	339.5
69	30.4	342
71.5	30.5	344.5
73	31.1	346
76.5	31.2	349.5
79.5	31.2	352.5
85	31.3	358

Results- Plotted in (Fig. 35)



Experiment 5 July 17, 1932

Object- To study the effect of the state of magnetization of iron and its photoelectric activity.

Apparatus- (Fig. 36)

K- Keys.

D.K.- Damping keys.

B- Battery of 2 volts.

G_1- Galvanometer in series with photoelectric cell.

P- magnetic pole, area19 square cms, distance between poles 2 cms, polished by file then sand paper.

M- Electromagnet.

I- Paper insulation between pole and yoke to prevent short cercuit.

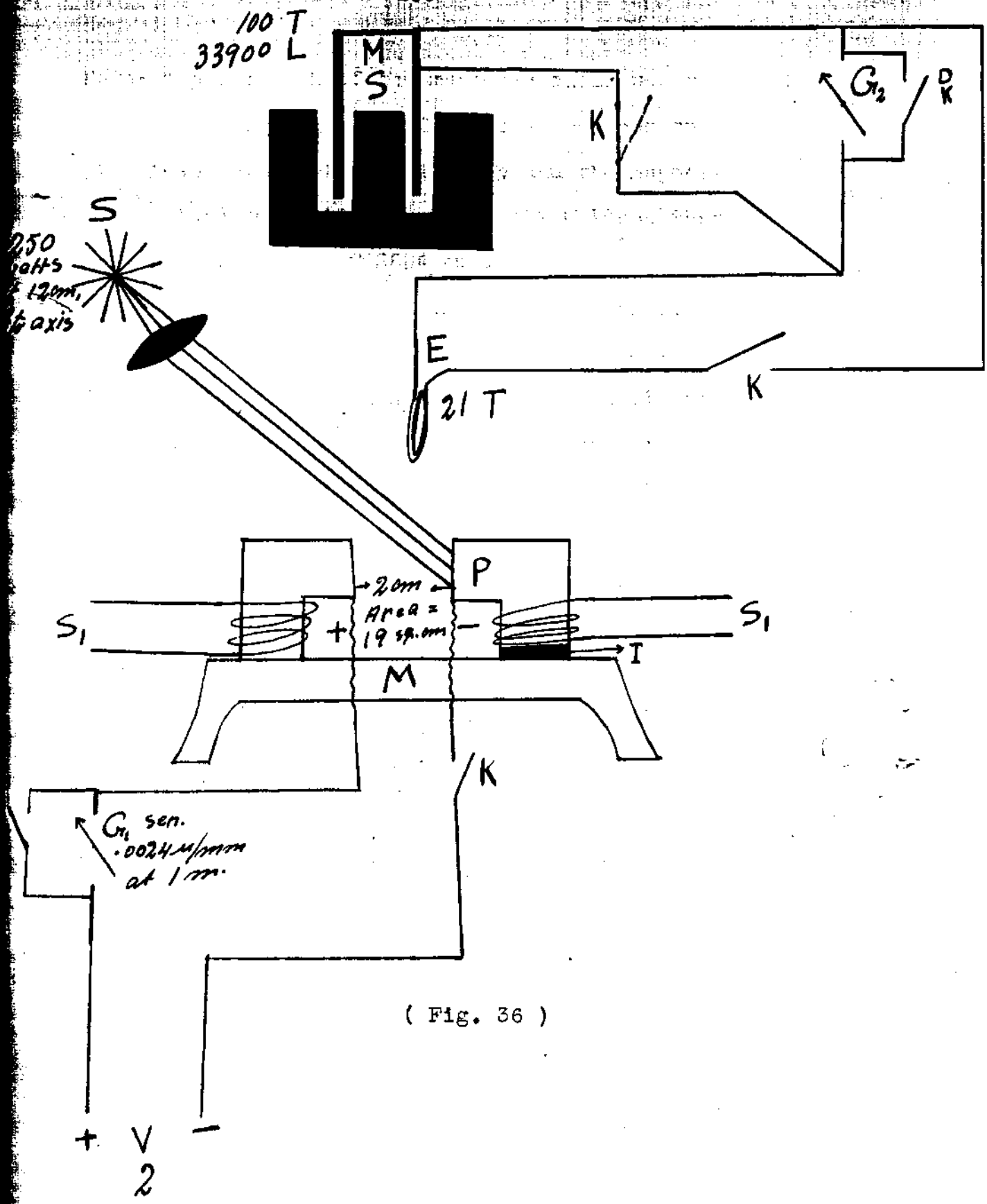
S_1- Source of e. m. f. to magnet coil.

S- Source of incident light , arc lamp, 12 cms from pole, at an angle of 45° to line joining poles.

M.S.- Magnetic standard, 100 turns, 33900 lines.

E- Exploring coil, 21 turns.

G_2- Galvanometer to compare currents in exploring coil and in coil of magnetic standard..


100 T
33900 L
M
S
K
G2
D
K
S
250
watts
12cm.
axis
E
21 T
K
P
2cm
Area =
19 sq.cm
S1
S1
+
−
I
M
K
G1 sen.
.0024 m/mm
at 1 m.
+ V −
2

(Fig. 36)

Note: The strength of the magnetic field was measuredd by comparing the deflections produced by an exploring coil of 21 turns and the magnetic standard of 100 turns and 33900 lines that gave a deflection of 28.4 cms.

The leakage current in this case was due to the increasing voltage applied to the coil of the magnet, even though the coil was insulated from the poles. When I touched the coil of the magnet, the galvanometer decreased its deflection showing that the leakage current was due to the voltage applied to the coil.

Data- The magnetic standard of 100 turns and 33900 lines gave a deflection of 28.4 cms.

A def. due to expl. coil. + 1000 oh.	B def. due to photo. + leakege current.	C leakage current at vol. applied.	D field strength = $\frac{33900 \times 100A}{21 \times 28.4}$	E net def. due to photo. current.
2	2	2.3	113680	.2
4.5	6.25	5.95	59682	.2
5	9.5	9.25	36946	.15
6.5	10.5	10.35	28420	.25
10.5	11.5	11.3	25578	.3
20	13.7	13.5	11368	.3

Results- Plotted in (Fig. 37)

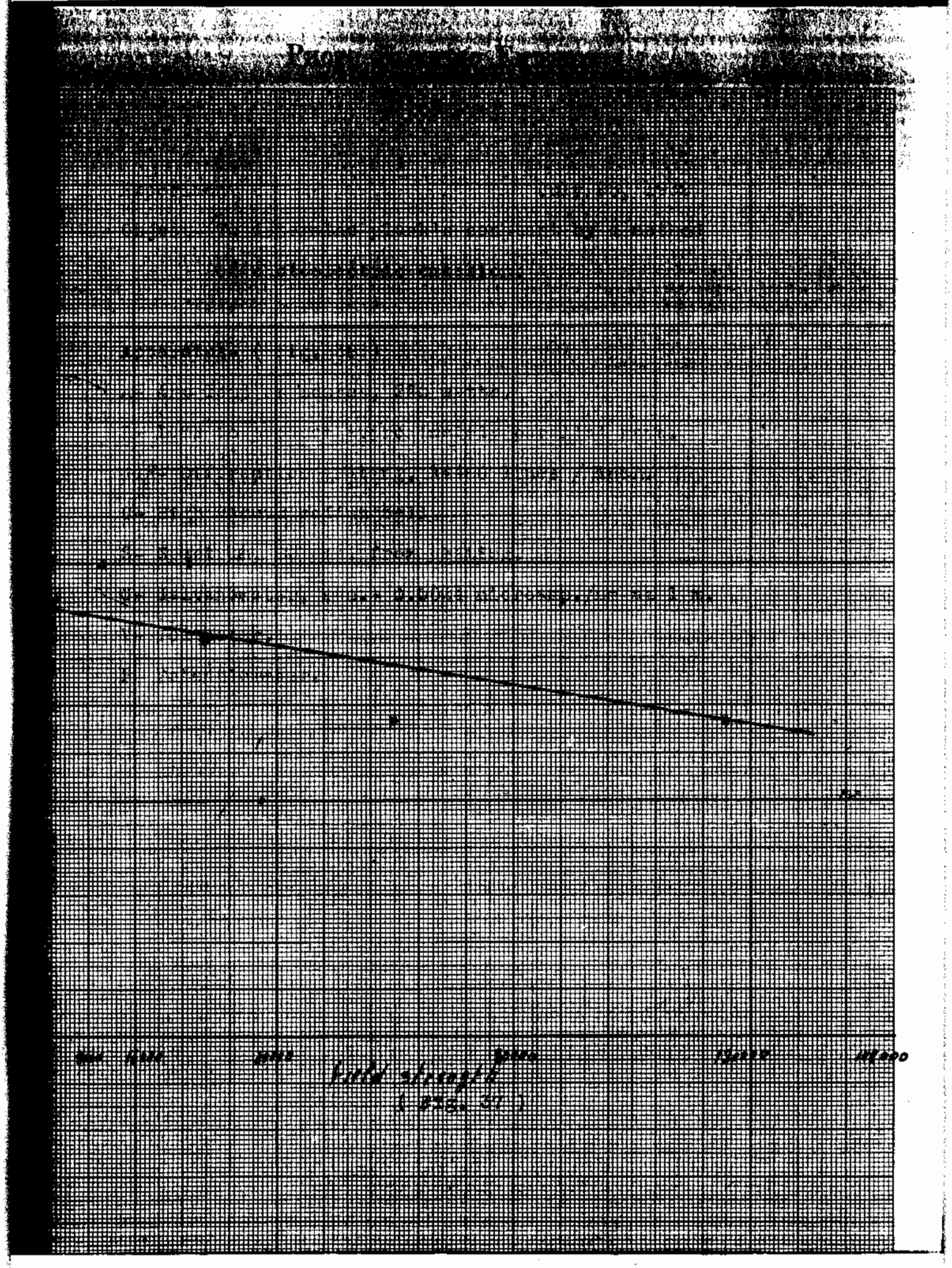

Field strength
(Oe.)

Photo Electric Emission

Experiment 6 July 25, 1932

Object- To determine plank's constant by a method of photoelectric emission.

Apparatus- (Fig. 38)

A- Arc lamp as source, 250 watts.

L- Lens to produce approximately parallel rays.

G.R- Diffraction grating, 14460 lines / inch.

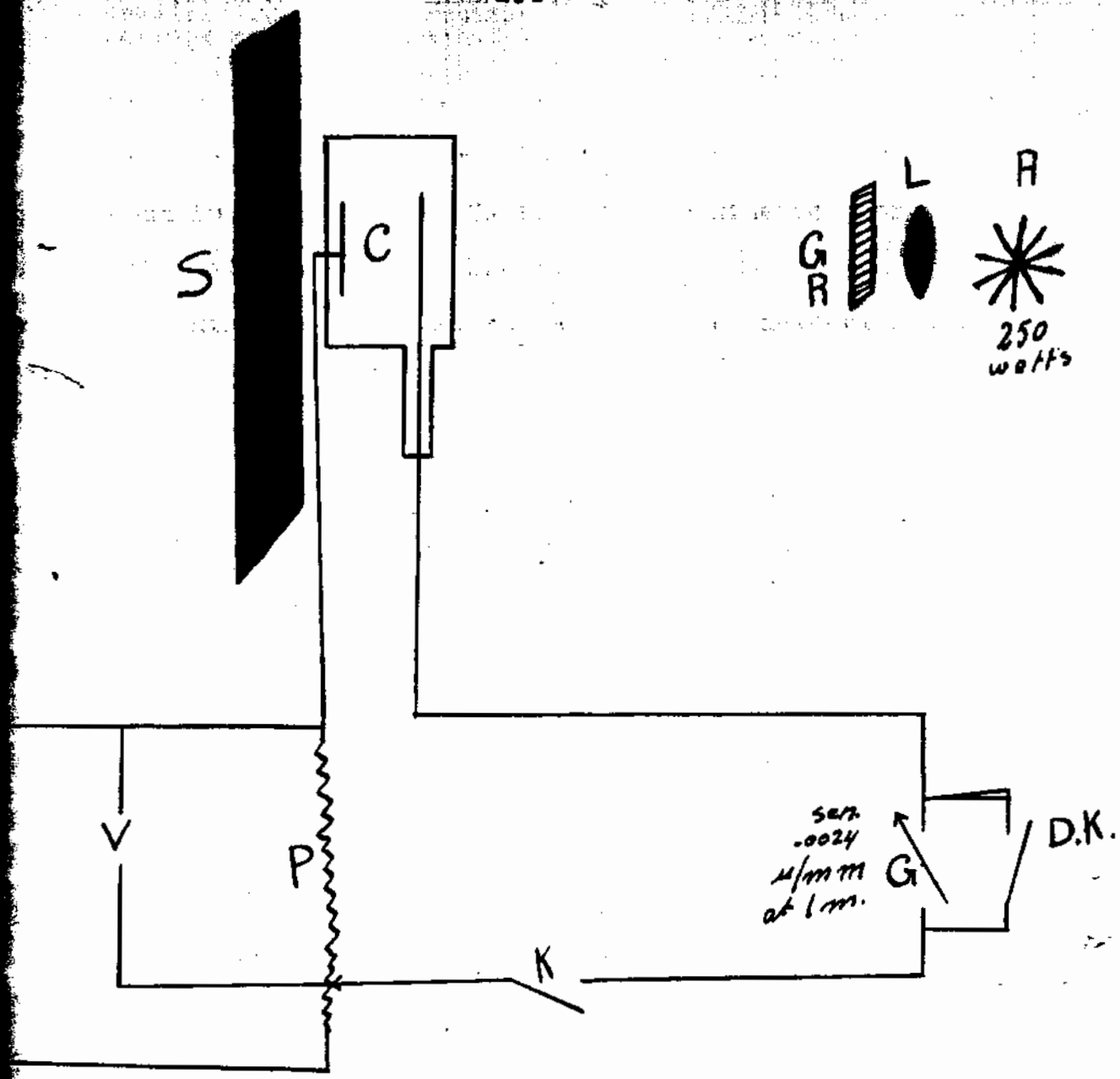
C- High vacuum sodium cell.

S- Spectrum, 80 cms. from grating.

G- Galvanometer, sen.- 0.0024 microamp./mm at 1 m.

V- Voltmeter.

P- Potentiometer.



(Fig. 38)

PHOTO ELECTRIC EMISSION

Theory and procedure-

If m is the mass of the electron and v its velocity when it leaves the surface, then its kinetic energy will be $1/2\ mv^2$

This kinetic energy is supplied by the incident light of frequency f, so that

$$1/2\ mv^2 = hf$$

If we apply to the plate a positive potential V large enough to draw the electrons back and therefore stop the current, then we have to supply an amount of energy equal to the kinetik energy of the electron. The energy we have to supply is Ve, where e is the charge of the electron.

Therefore $1/2\ mv^2 = Ve$

Equating the above two equations we get

$$hf = Ve$$

so that $h = Ve/f$

e is known,

V is the positive potential in e.m.u.necessary to decrease the deflection to zero,

f is the frequency of the incident lightwhich in this case will be the frequency of a part of the spectrum.

A zero deflection can never be obtained due to the leakage current at the varying potential applied, therefore the thing that was done was to measure the dark currentat different potentials and obtain the curve of (Fig. 39), then the cell was put in the beam of light and a certain positive potential applied; now to get no photoeleectric current does not mean getting no deflection, but getting a deflection that is equal to that produced by the dark current at the potential applied.

Therefore the thing to do isto apply a certain positive potential to the active substance, then determine from curve 39 the deflection due to the dark current at that potential; if the deflection comes out to bt the same, that means, thereis no photo-electric current, if not another voltage should be tried.

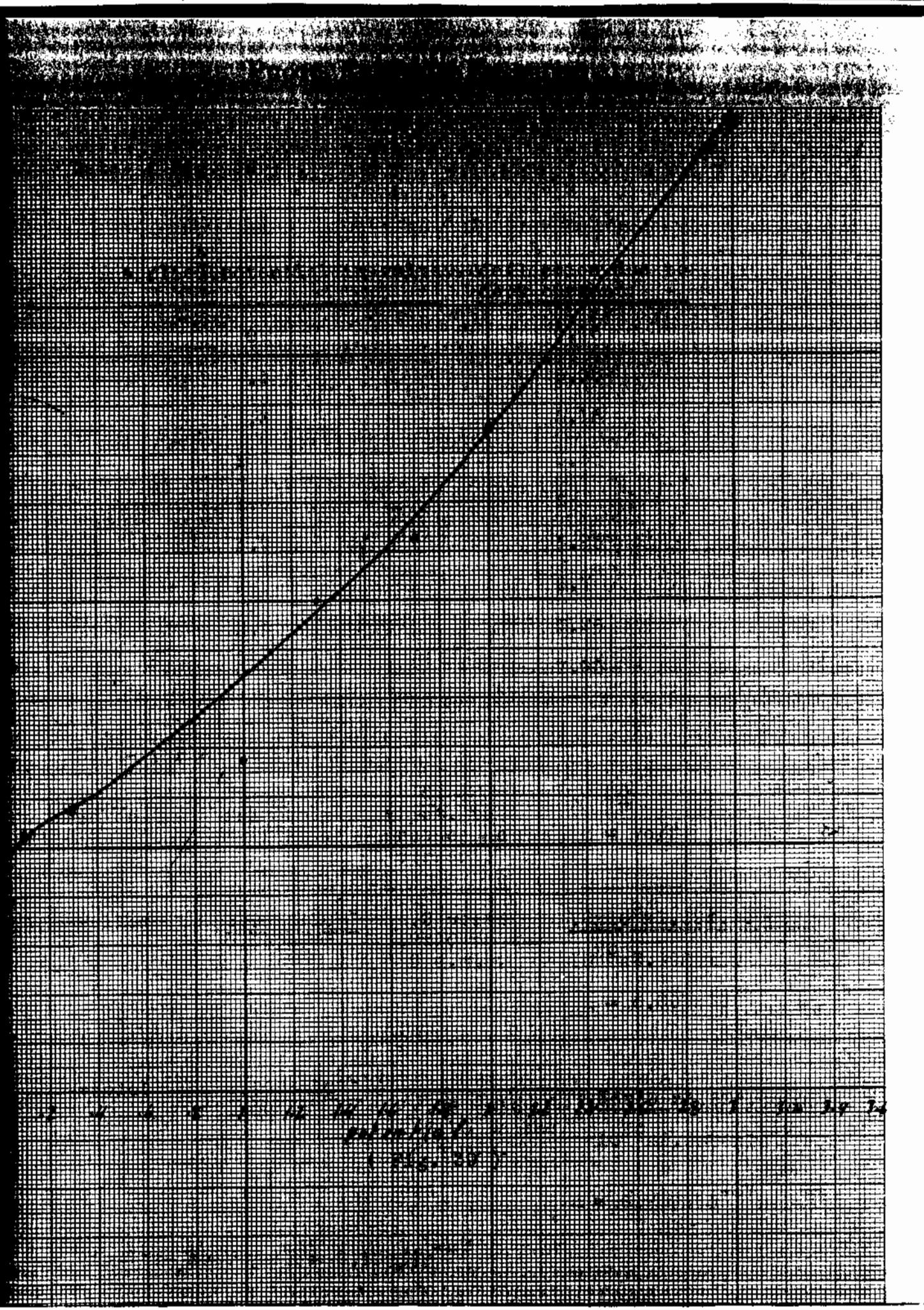


Photo Electric Emission

Data- (Fig. 39)

A applied potential in volts.	B deflection due to dark current.
0	4.95
.1	5.05
.3	5.15
1	5.35
1.3	6
1.7	6.25
2	6.7
2.4	7.26
3	7.95

Data- (Plank's Constant)

A color	B frequency f	C + pot. to produce no current.	D h = Ve/f
yellow	$\frac{2.9986 \times 10^{10}}{0.0000575}$	.2 volts .2x10 to the 9 e.m.u.	$\frac{.2 \times 10^{9} \times 1.59 \times .0000575}{10^{20} \times 2.9986 \times 10^{10}}$ $h = 6.098 \times 10^{-27}$
violet	$\frac{2.9986 \times 10^{10}}{.000033}$	.36 volts .36x10 to the 9 e.m.u.	$\frac{.36 \times 10^{9} \times 1.59 \times .000033}{10^{20} \times 2.9986 \times 10^{10}}$ $h = 6.299 \times 10^{-27}$

Results- Average $h = 6.198 \times 10^{-27}$

Experiment 9 July 30, 1932

Object- To study the relation between time and the activity of a photoelectrically active substance when in vacuum and under a negative potential.

Apparatus- (Fig. 40)

S- Source of light, incandescent lamp, 220 watts, 60 cms. from cell.

C- High vacuum sodium cell.

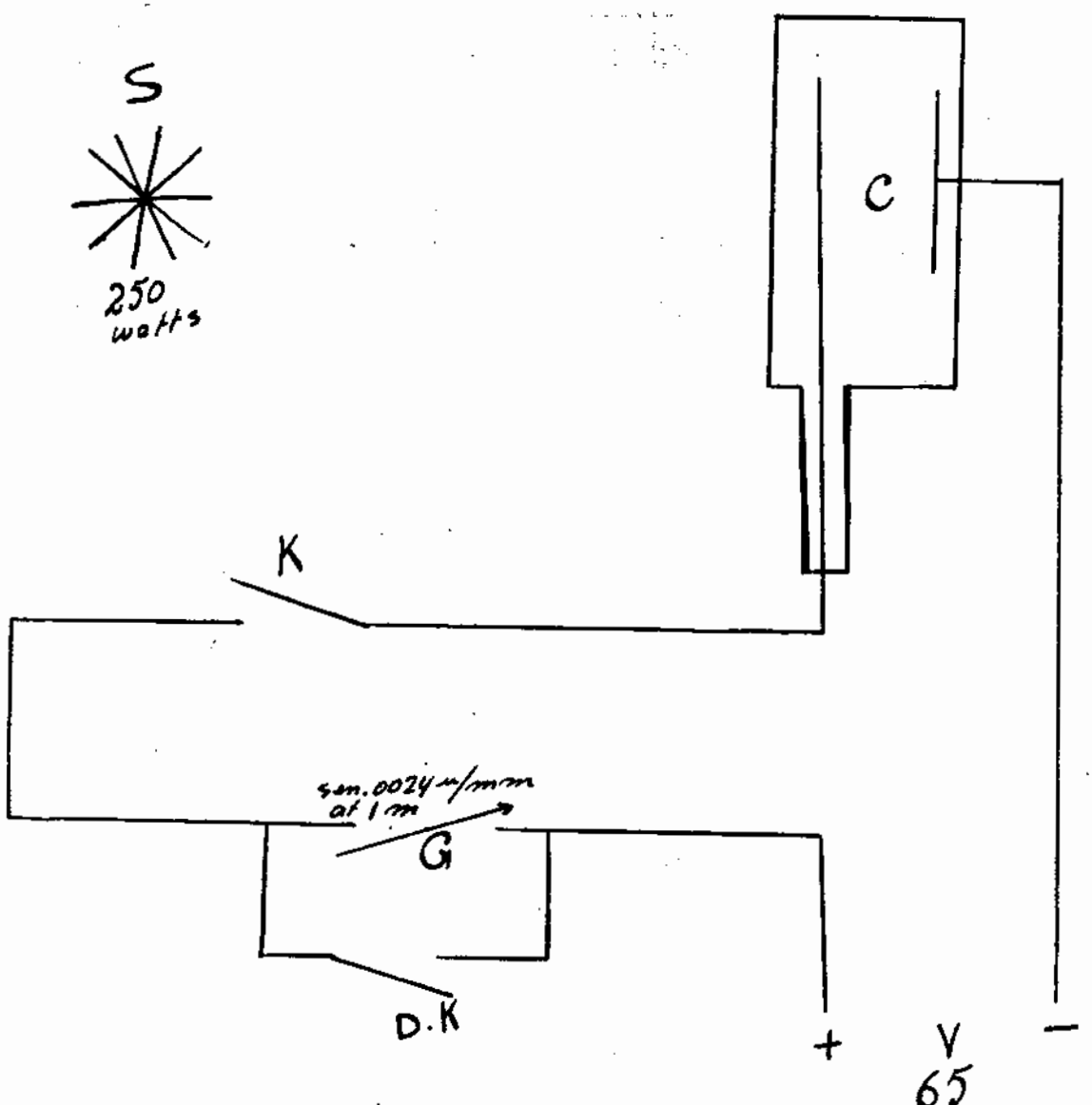
K- Key.

D.K.- Damping key.

G- Galvanometer, sen.0.0024 microamp./mm at 1 m.

V- e.m.f. supply, 65 volts.

a watch.

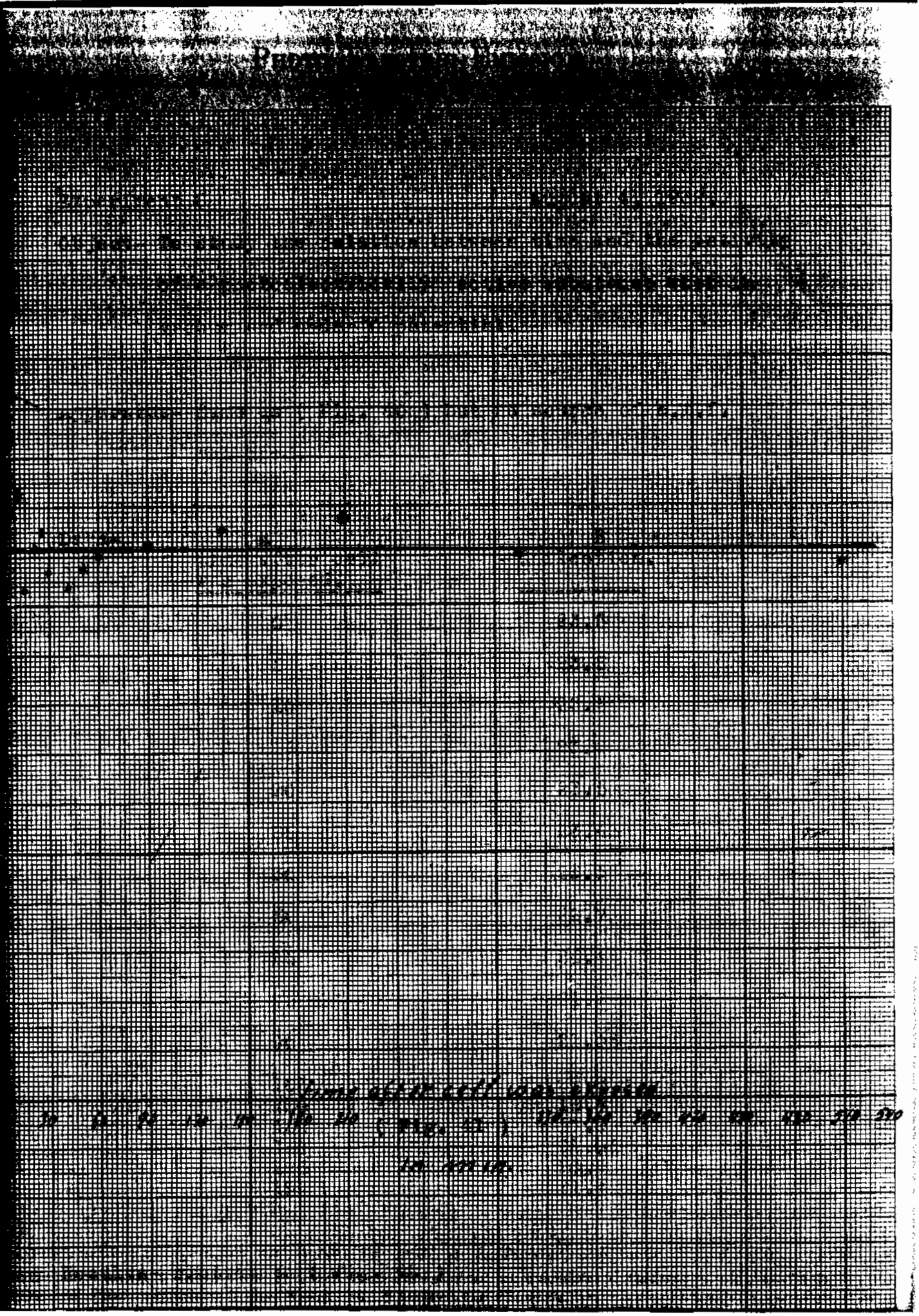


(Fig. 40)

Data-

A time in min. after cell was exposed to light.	B deflection.
0	42
5	41.95
10	42.3
15	40.2
20	41.2
25	41.5
30	40.7
40	40.4
50	40.7
60	41
90	41.2
135	41.5
210	41.8
315	41
510	40.7

Results- Plotted if (Fig. 41)



Experiment 8 August 4, 1932.

Object- To study the relation between time and the ectivity of a photoelectrically active substance when in vacuum and under 0 potential.

Apparatus- Same as (Fig. 40) but no source of e.m.f. was used.

Data-

A time after cell was exposed.	B deflection.
0	23.5
5	23.5
10	23.5
15	23.6
20	23.5
25	23.45
30	23.3
50	22.7
60	24.4
75	21.9
90	21.05
105	22.8
120	18.4
135	17.9
150	21.05
175	20.7
195	21.4

Results- Plotted in (Fig. 42)

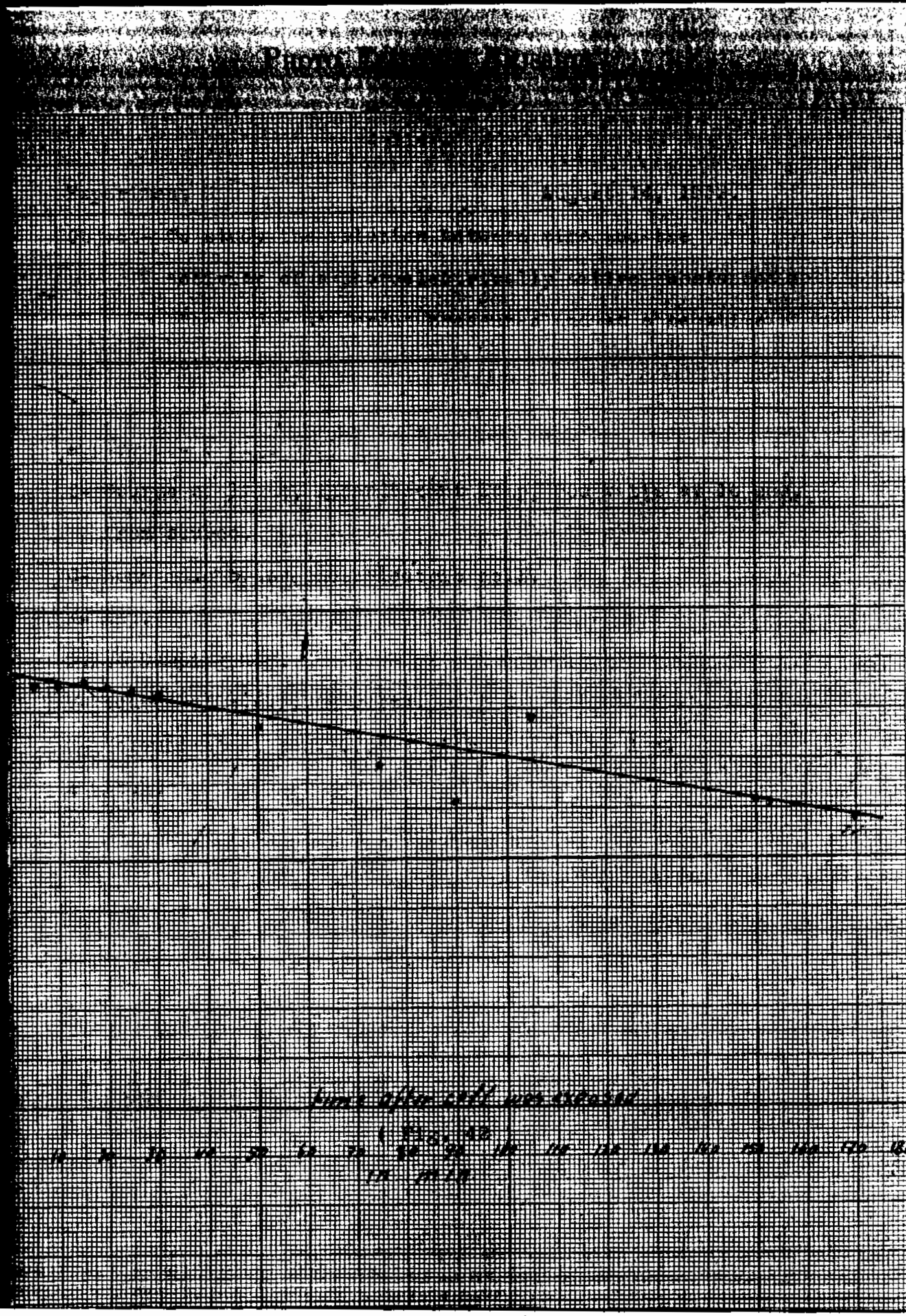


Photo Electric Emission

Experiment 9 August 14, 1932.

Object- To study the relation between time and the activity of a photoelectrically active substance when under different pressures and at a negative potential.

Apparatus- (Fig. 45)

S- Source of light, incandescent lamp, 500 watts at 10 cms. from source.

C- home made brass photoelectric cell.

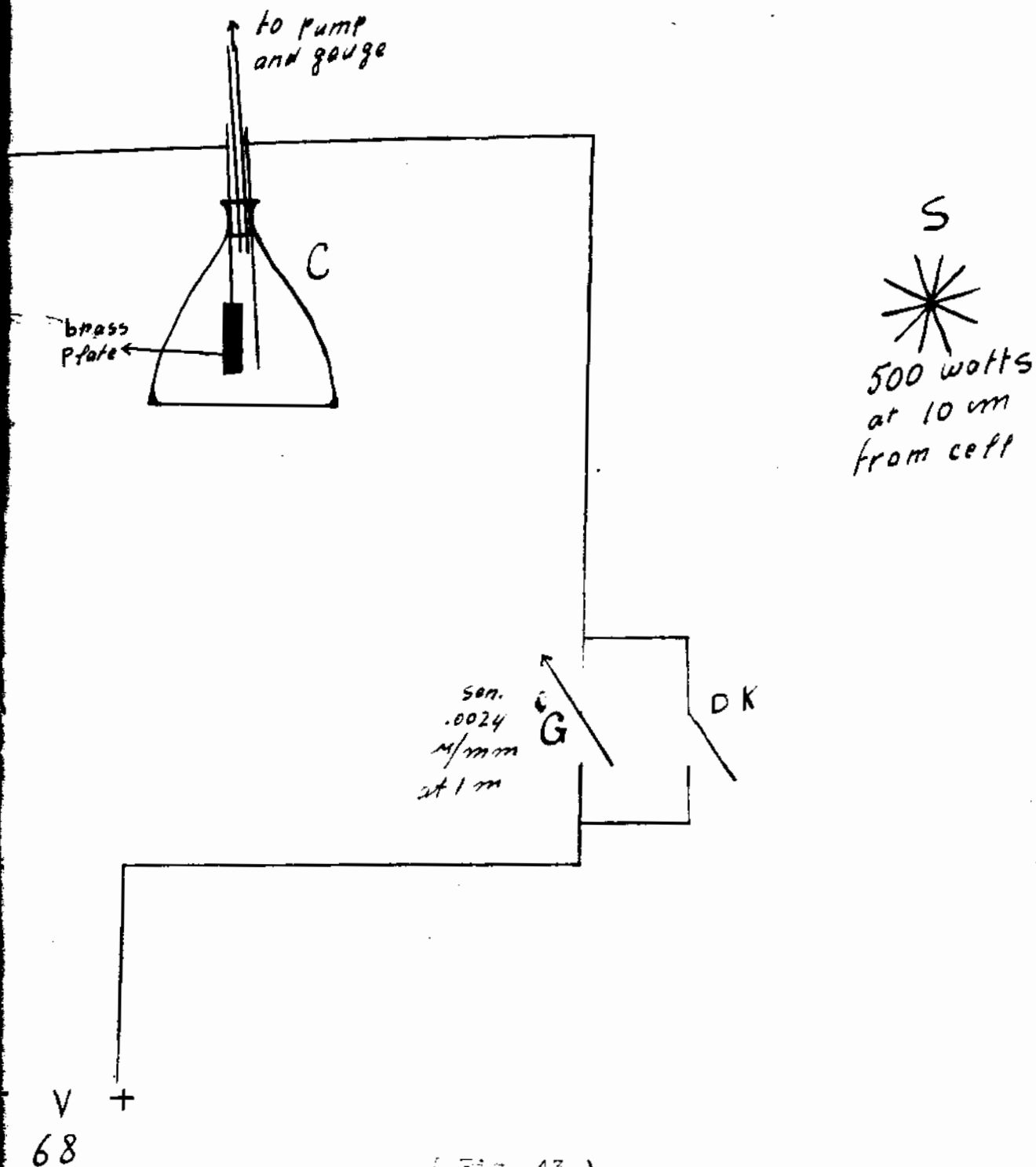
K- Key.

D.K.- Damping key.

V- source of e.m.f. 68 volts.

G- Galvanometer, sen. 0.0024 microamp./mm at 1 m.

A watch.


to pump
and gauge
C
brass
Pplate
S
500 watts
at 10 cm
from cell
sen.
.0024
M/mm
at 1 m
G
D K
V
68
+

(Fig. 43)

Data-

Pressure = 2 mm of mercury.

Deflection due to dark current = 19.1

A time after cell was exposed.	B total deflection.	C B - dark current.
0	25.9	6.8
1	25.4	6.3
2	25.2	6.1
3	24.6	5.5
4	24.5	5.4
7	23.6	4.5
8.5	23.2	4.1
9	22.7	3.6
9	21.9	2.8
10.5	21.3	2.2
12	20.6	1.5
14.3	20.3	1.2
18.5	19.4	.3
19	19.4	.3
21	19.3	.2

Pressure = 9 mm of mercury.

Deflection due to dark current = 19.1

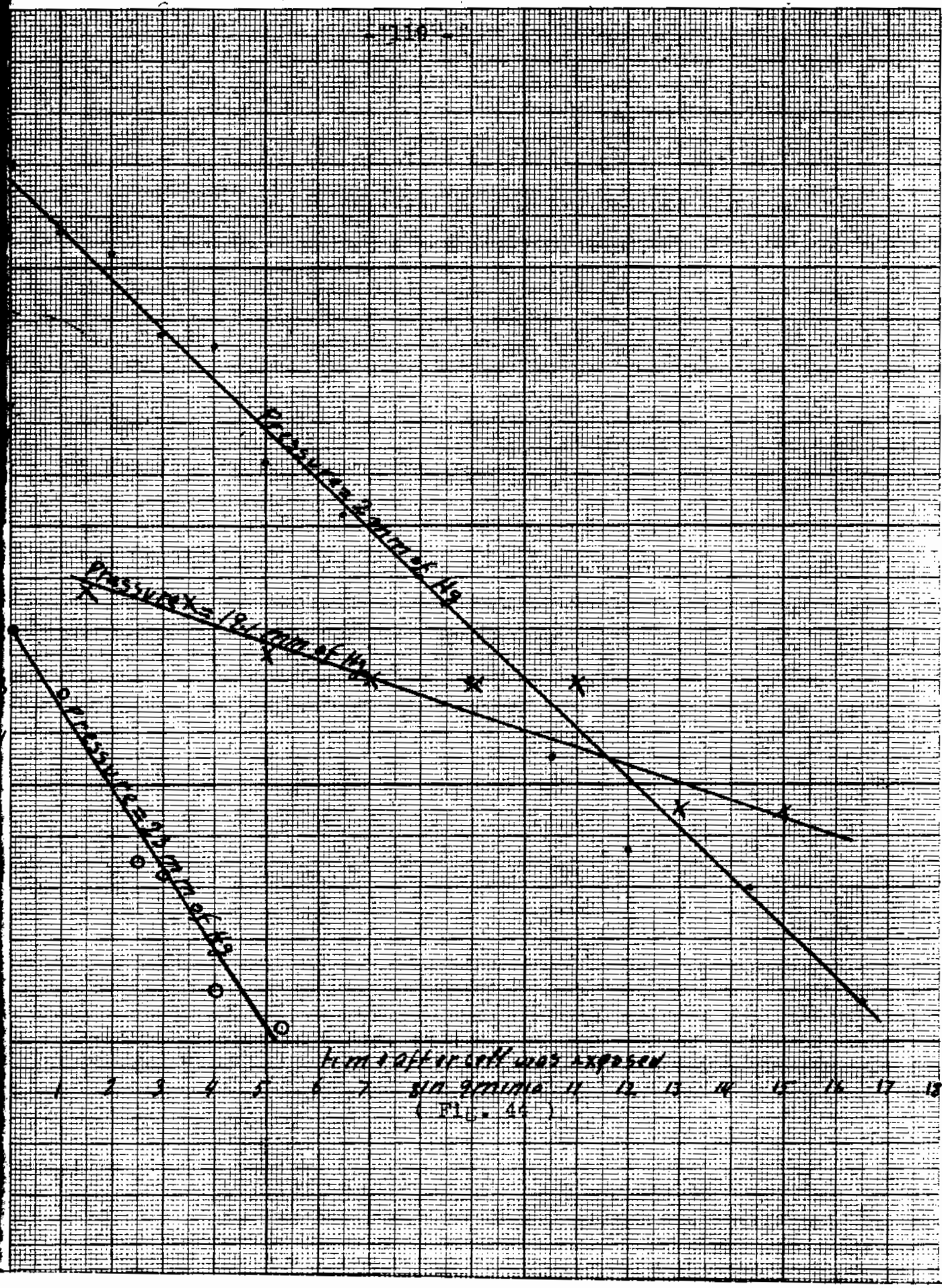
A time after cell was exposed.	B total deflection.	C B - dark current.
1.5	22.6	3.5
3.5	22.5	3.4
5	22.1	3
7	21.9	2.9
9	21.9	2.8
11	21.9	2.8
13	20.9	1.9
15	20.9	1.9

Pressure = 13 mm of mercury.

Deflection due to dark current = 22.5

A time after cell was exposed.	B total deflection.	C B - dark current.
0	25.7	3.2
1	25.2	2.7
2.5	23.9	1.4
3	23.8	1.3
4	22.9	.4
5.3	22.6	.1

Results- Plotted in (Fig. 44)


Pressure 2 mm of Hg
Pressure 18.4 mm of Hg
Pressure 45 mm of Hg
Time after cell was exposed
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

(Fig. 44)

Experiment 10 August 20, 1932.

Object- To study the relation between time and the activity of a photoelectrically active substance when under pressure and at a potential of zero.

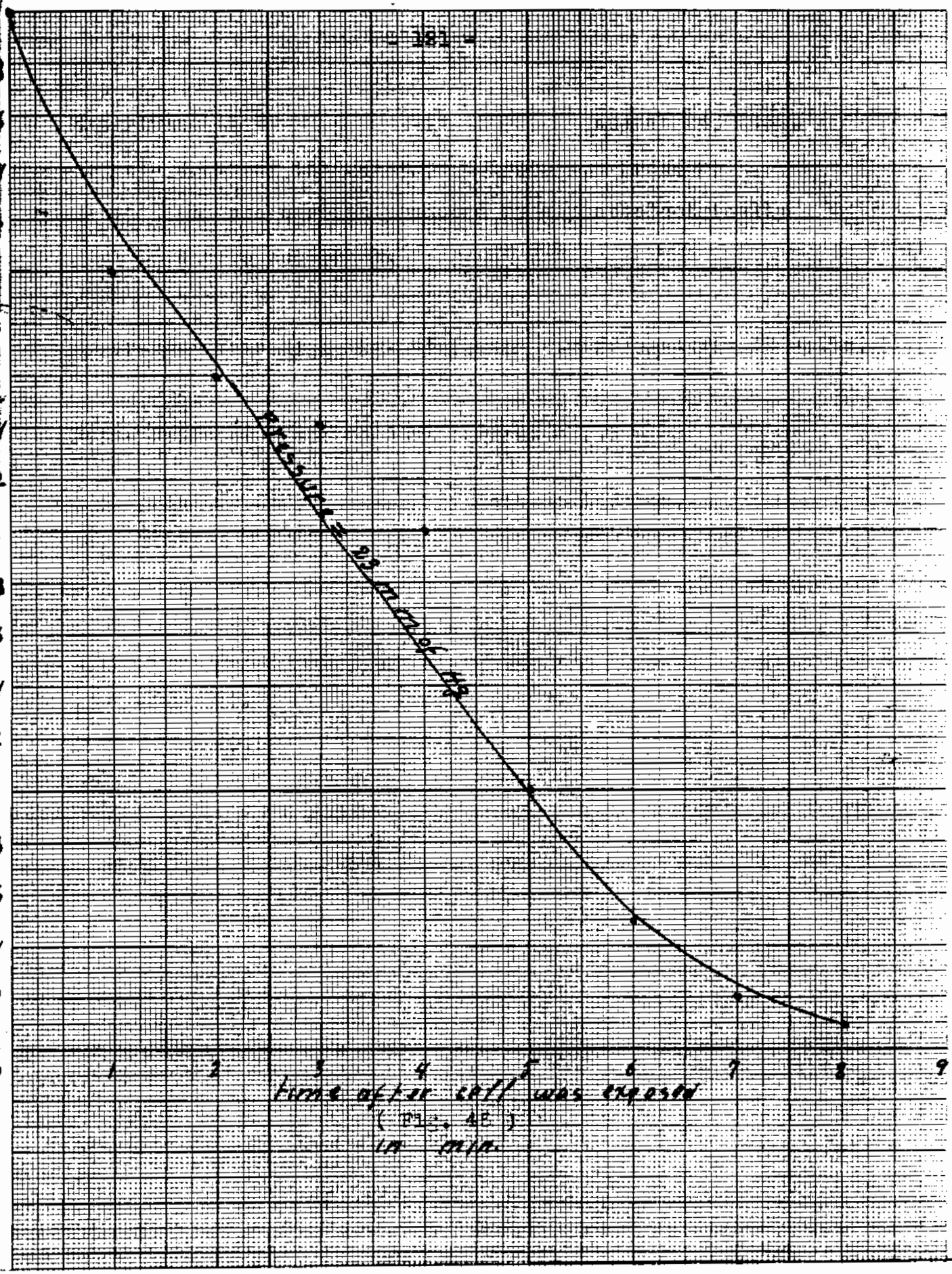
Apparatus- Same as figure 43 but no source of e.m.f. was used.

Data-

Pressure = 23 mm of mercury.

A time after cell was exposed.	B deflection.
0	.4
1	.3
2	.26
3	.24
4	.2
5	.1
6	.05
7	.02
8	.01

Results- Plottedin (Fig. 45)


Pressure = 23 mm of Hg
1
2
3
4
5
6
7
8
9
time after cell was exposed
(m.p. 4E)
in min.

Experiment 11 August 26, 1932.

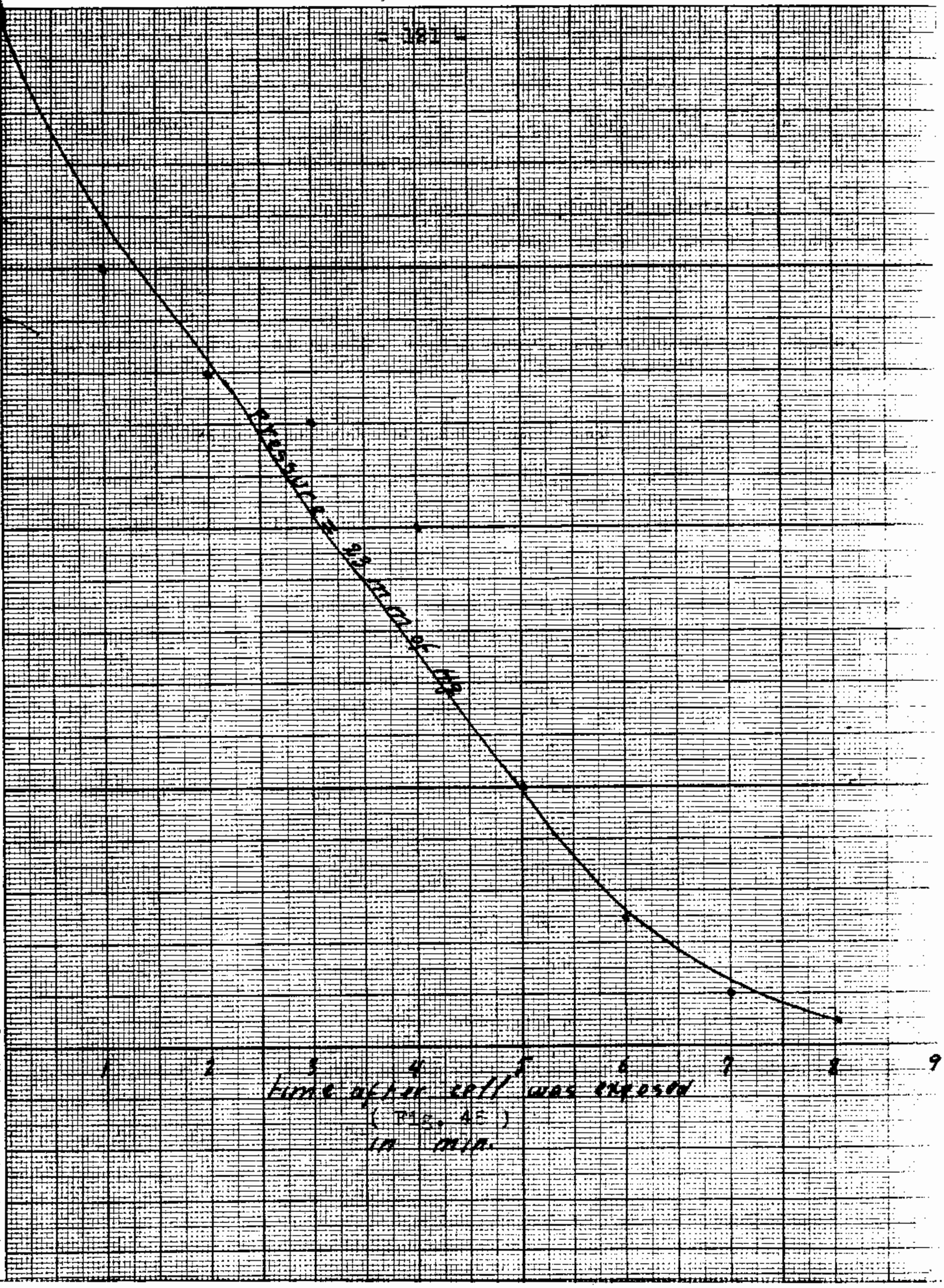
Object- To study the relation between the pressure and the current produced by a photoelectrically active substance.

Apparatus- Same as (Fig. 43), the e.m.f. used was 32 volts.

Data- Deflection due to dark current = 1.5

A pressure in mm of mercury.	B net deflection.
2	7.7
7	7.5
11	7.4
15.5	7.7
20.5	7.8
29	7.9
33.5	7.8
39	7.9
47.5	8
51.5	7.9
56.5	8
65	8
76	8.6
102	14.3

Results- Plotted in (Fig. 46)


Pressure = 33 mm of Hg
1
2
3
4
5
6
7
8
9
time after cell was exposed
in min.

(Fig. 4E)

Experiment 11 August 26, 1932.

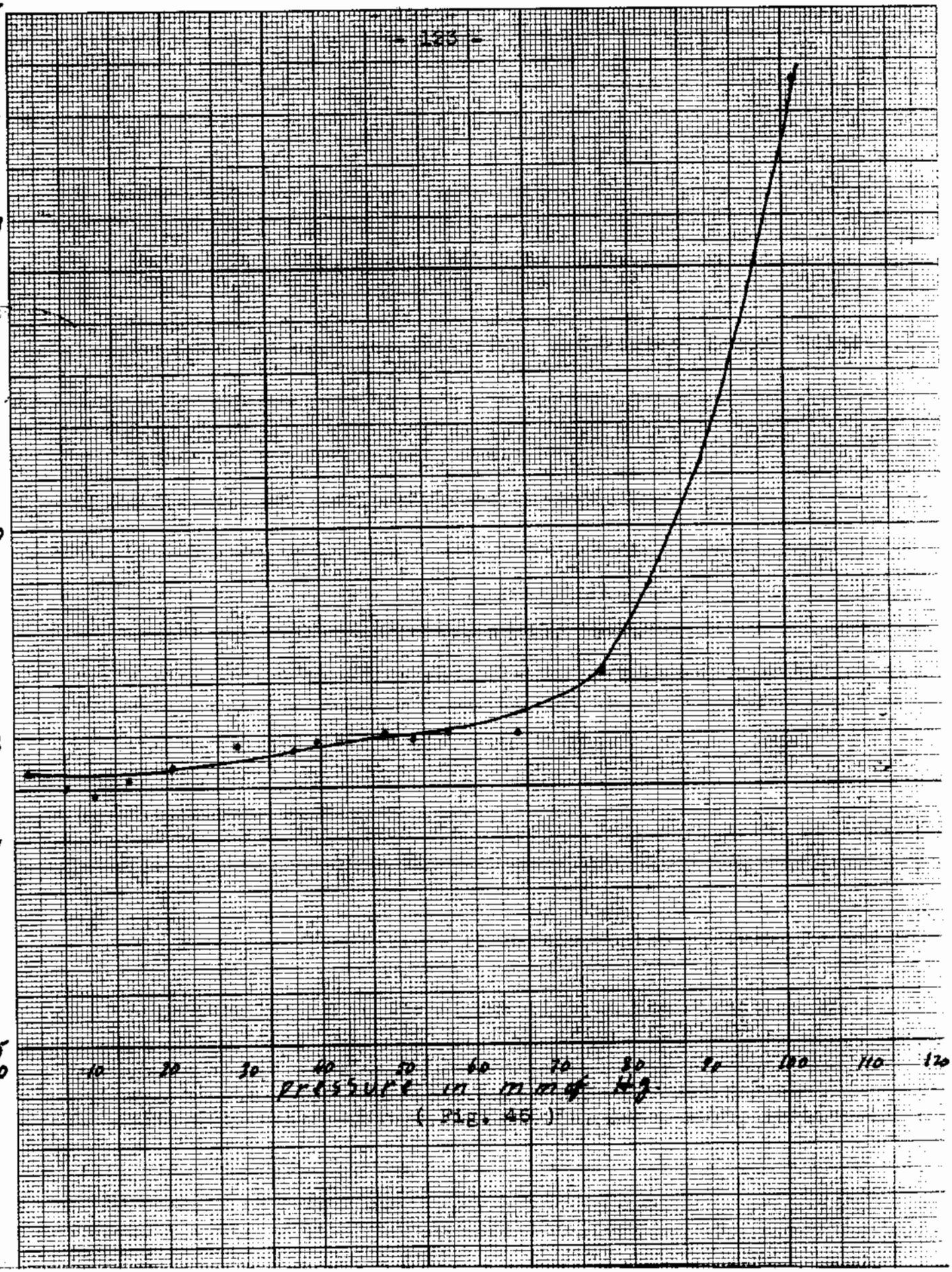
Object- To study the relation between the pressure and the current produced by a photoelectrically active substance.

Apparatus- Same as (Fig. 43), the e.m.f. used was 32 volts.

Data- Deflection due to dark current = 1.5

A pressure in mm of mercury.	B net deflection.
2	7.7
7	7.5
11	7.4
15.5	7.7
20.5	7.8
29	7.9
36.5	7.8
39	7.9
47.5	8
51.5	7.9
56.5	8
65	8
76	8.6
102	14.3

Results- Plotted in (Fig. 46)



(Fig. 46)

Bibliography

I Books

1. Allen, H. S.
Photoelectricity, Second Edition, 1925,
Longmans, Green and Company, London.

2. Richardson, O. W.
The Emission of Electricity from Hot Bodies, Second Edition,1921,
Longmans, Green and Company, London.

3. Richtmyer, F. K.
Introduction to Modern Physics, First Edition, 1928,
McGraw-Hill Book Company, New-York.

II Bulletin of the National Research Council

1. Compton, A. H.
Secondary Radiations Produced by X-Rays, October, 1922.

2. Hughes, A. L.
Report on Photoelectricity, April, 1921.

III Philosophical Magazine and Journal of Science, The

1. Hughes, A. L.
The Velocities of the Electrons Emitted in the Normal
and Selective Photoelectric Effect, February,1916,PP 100-107.

2. Richardson, O. W.
The Complete Photoelectric Emission,February, 1916, PP 149-155.

IV Philosophical Magazine, The

1. Allen, H, S.
The Photoelectric Fatigue of Metals, October, 1910, PP 564-572.

2. Bubb, F. W.
A Quantum Theory on the Asymmetries in the Direction of
Ejection of Photoelectrons, May, 1925, PP 824-838.

3. Burt, R. E.
The Constance of the Total Photo Current from Sodium
with Temperature Change, 20°C-190°C, June, 1925, PP 1168-1175.

4. Compton, K. T.
The Influence of Contact Difference of Potential between the Plates Emitting and Receiving Electrons Liberated by Ultra-violet Light on the Measurement of the Velocities of these Electrons, April, 1912, PP 579-593.

5. Compton, K. T. and Richardson, O. W.
The Photoelectric Effect, October, 1913, PP 549-566.

6. Foe, O. K.
Longitudenal Asymmetry in the Direction of Ejection of Photoelectrons, May, 1925, PP 817-823.

7. Hughes, A. L.
The Long Wave Limits of the Normal Photoelectric Effect. March, 1914, PP 473-374.

8. Hughes, A. L.
The Photoelectric Effect of some Compounds, Sebtember, 1912, PP 380-390.

9. Hughes, A. L.
A Sensitive Photoelectric Cell, May, 1913, PP 679-682.

10. Lawrence, E. O.
The Photoelectric Effect in Potassium Vapour as a Function of the Frequency of the Light. August 1925, PP 345-359.

11. Milne, H. L.
Saha's Ionization Formula and the Theoratical Value of the Photoelectric Absorption Coefficient, Sebtember, 1925, PP 547-550.

12. Pohl, R. and Pringsheim, P.
The Long Wave Limits of the Normal Photoelectric Effect. December 1913, PP 1017-1023.

13. Poole, J. H. J.
The Photoelectric Theory of Vision, March, 1921, PP 975-976.

14. Poole, J. H. J.
A Possible Connection between the Magnetic State of Iron and its Photoelectric Properties, September, 1921, PP 339-3

15. Richardson, O. W. and Compton, K. T.
The Photoelectric Effect. October, 1912, PP 575-593.

16. Richardson, O. W.
Photoelectric and Photochemical Activity,
May, 1924, PP 975-976.

17. Richardson, O. W.
The Theory of Photoelectric Action, October, 1912, PP 570-574.

18. Richardson, O. W.
The Theory of Photoelectric and Photochemical Action,
March, 1914, PP 476-487.

19. Richardson,,O. W. and Rogers, F. J.
The Photoelectric Effect, April, 1915, PP 618-622.

20. Robinson, J.
The Photoelectric Effect on Thin Films of Potassium,
October, 1916, PP 421-425.

21. Robinson, J.
Photoelectric Fatigue, February, 1912, PP 255-262.

22. Robinson, J.
The Photoelectric Properties of Thin Metals Films,
April, 1912, PP 542-550.

23. Shenstone, A. G.
The Effect of an Electric Current on the Photoelectric Effect,
June, 1921, PP 916-920.

24. Stuhlmann, Otto, Jr.
The Difference in the Photoelectric Effect Caused by
Incident and Emergent Light, December, 1911, PP 854-863,

25. Sutton, T. Carlton.
Photoelectric Constant and Atomic Heat, May, 1915, PP 734-736.

26. Swann, W. F. G.
The Pulse Theory of X)Rays, Gamma-rays, and Photoelectric Rays,
and the Asymmetric Emission of Beta-rays.April, 1913, PP 679-682.

27. Taylor, W.
The Photoelectric Activity of Chlorine,June, 1925, PP 1165-1167.

28. Welo, L. A.
Some Photoelectric Experiments on Platinum Relating to the Influence of Gases, March, 1923, PP 593-609.

29. Willows, R. S.
The Photoelectric Effect of Some Compounds, December, 1912, P 891.

V Physical Review, The.

1. Albers, V. M.
Photoelectric Valve Coated with Potassium, November, 1925, PP 671-677.

2. Bartlett, R. S.
Photo-Resistance Effect for Metals at Low Temperatures, August, 1925, PP 247-255.

3. Berger, C. E.
Effect of Light on the Electron Emission from Cerium Dioxide, December 15, 1929, PP 1565-1574.

4. Brewer, A. K.
The Effect of Adsorbed K^+ Ions on the Photoelectric Threshold of Iron, August 1, 1931, PP 401-407.

5. Brewer, A. K.
Photoelectric and Thermoionic Properties Of Platinum coated Glass Filaments, June 1, 1930, PP 738-742.

6. Bridgman, P. W.
General Considerations on the Photoelectric Effect, January, 1928, PP 90-100.

7. Bridgman, P. W.
Photoelectric Effect and Thermionic Emission; a Correction and an Extension, May, 1928, PP 862-866.

8. Bubb, F. W.
Direction of Ejection of Electrons by Polarized X-Rays, February, 1924, PP 137-143.

9. Chaffee, M. A.
Angular Distribution of Photoelectrons Ejected by Polarized Ultraviolet Light in Potassium Vapour, May 15, 1931, PP 1233-1237.

10. Dixon, E. H.
Some Photoelectric and Thermionic Properties of Rhodium, January 1, 1931, PP 60-69.

11. Du Bridge, L. A.
Photoelectric of thorough Outgassed Platinum, March, 1927, PP 451-465.

12. Dunn, H. K.
Changes in the Photoelectric Threshold of Mercury, May, 1927, PP 693-700.

13. Erich, Max.
A New Photoelectric Effect in Alkali Cells, May 1, 1930, PP 1059-1065.

14. Farmley, T. J.
Photoelectric Threshold of Single Bismuth Crystals, November, 1927, PP 656-663.

15. Foote, P. D. and Mohler, F. L.
Photoelectric Ionization of Caesium Vapour, August, 1925, PP 195-207.

16. Fowler, R. H.
Analyses of Photoelectric Sensitivity Curves for Clean Metals at Various Temperatures, July 1, 1931, PP 45-56.

17. Frenkel, J.
Some Remarks on the Theory of the Photoelectric Effect, July 15, 1931, PP 309-320.

18. Fry, T. C. and Ives, H. E.
Voltage-Current Relations in Central Cathode Photoelectric Cells, July, 1928, PP 44-56.

19. Geiger, P. H.
Spectro-Photoelectric Effect in Argentite, November, 1923, PP 461-469.

20. Goetz, A.
Photoelectric Effect of Molten Tin and Two of its Alotropic Modifications, March, 1928, PP 373-385.

21. Hales, W. B.
Critical Photoelectric Potential of Clean Mercury and the Influnce of Gases and of the Circulation of the Mercury upon it, December, 1928, PP 950-960.

22. Hall, H. and Oppenheimer, J. R.
Relativistic Theory of the Photoelectric Effect, July 1, 1931, PP 57-79.

23. Hammond, H. E.
E. M. F., Resistance, and Capacitance Phenomenon in Photo-Voltaic Cells Containing Grignard Reagents, April 15, 1930, PP 998-1007.

24. Hornbeck, J. W.
Photoelectric Response of Potassium at Low Temperatures, December, 1924, PP 631-638.

25. Huxford, W. S.
Effect of Electric Fields on the Emission of Photoelectrons from Oxide Cathodes, August 1, 1931, PP 379-395.

26. Ives, H. E., Olpin, A. R., and Johnsrud, A. L.
Distribution in Direction of Photoelectrons from Alkali Metal Surfaces, July, 1928, PP 57-80.

27. Ives, H. E. and Olpin, A. R.
Maximum Excursion of the Photoelectric Long Wave Limit of the Alkali Metals, July 1, 1929, PP 117-128.

28. Ives, H. E. and Stilwell, G. R.
Photoelectric Emission as a Function of Composition in Sodium-Potassium Alloys, February, 1927, PP 252-261.

29. Jones, R. B.
Photoelectric Threshold of a Doubly Evaporated Film, July 15, 1929, PP 227-232.

30. Kazda, C. B.
Photoelectric Threshold for Mercury, November, 1925, PP 643-654.

31. Kunz, J. and Williams, E. H.
Photoelectric Effect of Caesium Vapour, November, 1923, PP 456-460.

32. Koller, L. R.
Photoelectric Emission from Thin Films of Caesium, December 1, 1930, PP1639-1647.

33. Kurrelmeyer, B.
Photoelectric Conductivity of Sulfur, December, 1927, PP 893-910.

34. Lawrence, E. O., and Edlepsen, J. Q.
Photoionization of Potassium Vapour, October 1, 1929, PP 1056-1060

35. Lawrence, E. O., and Edlepsen, N. E.
Photoionization of the Vapours of Caesium and Rubidium, July 15, 1929, PP 233-242.

36. Lawrence, E. O. and Linford, L. B.
Effect of Intense Electric Fields of the Photoelectric Properties of Metals, August,1, 1930, PP 482-497.

37. Linder, E. G.
Photoelectric Effect and Surface Structure in Zinc Single Crystals, November, 1927, PP 649-655.

38. Loughridge, D. H.
Direction of Photoelectron Emission. October, 1929, PP 488-498.

39. Loughridge, D. H.
Direction of Ejection of Photoelectrons Produced by X-Rays, December, 1925, PP 697-700.

40. Martin, M. J.
The Photoelectric and Thermionic Properties of Molybdenum, June, 1929, PP 991-997.

41. Mohler, F. L.
Photoionization of a Gas by a Discharge in the same Gas, July, 1926, PP 46-56.

42. Mohler, F. L., and Foote, P. D.,and Chenault, R. L.
Photoionization and Relative Absorption Probabilities in Caesium Vapour, January, 1926, PP 37-50.

43. Morris, L. W.
Certain Photoelectric Properties of Gold, May 15, 1931, PP 1263-1268.

44. Nielsen, J. R.
The Influence of Temperature upon the Photoelectric Effect,
January, 1935, PP 30-40.

45. Pauling, L.
Photoionization in Liquids and Crystals and the Dependence of the Frequency of X-Ray Absorption Edges on Chemical Constitution,
September 15, 1932, PP 954-967.

46. Piersol, R. J.
Photoelectric Conduction in Selenium, November, 1937, PP 664-671.

47. Piersol, R. J.
Symmetry of Incident and Emergent Photoelectronic Velocities,
February, 1924, PP 144-152.

48. Roller, D., Jordan, W. H., and Woodward, O. B.
Some Photoelectric Properties of Mercury Films,
August 1, 1931, PP 396-400.

49. Roller, D.
Photoelectric Behaviour of Solid and Liquid Mercury,
August 15, 1931, PP 738-744.

50. Szczeniowski, S. E.
Spacial Distribution of Photoelectrons, February 17, 1930,
PP 347-374.

51. Tucker, F. B.
Photoelectric Emission from Platinum; Effect of Heat Treatment,
December, 1928, PP 774-781.

52. Van Den Akker, J. A. and Watson, E. C.
Application of the Geiger-Muller Ion Counter to the Study of the Space Distribution of X-Ray Photoelectrons,
June 15, 1931, PP 1631-1638.

53. Warner, A. H.
Variation of Photoelectric Effect with Temperature and Determination of the Long Wavelength Limit for Tungsten,
May, 1928, PP 813-822.

54. Winch, R. P.
Photoelectric Properties of Silver, May 15, 1931, PP 1205-1213.

55. Winch, R. P.
Photoelectric Properties of Thin Unbacked Gold Films, July 15, 1931, PP 321-324.

56. Woodruff, A. E.
Photoelectric Emission from Platinum, November, 1925, PP 655-670.

57. Watson, E. C.
Space Distribution of the Photoelectrons Ejected by X-Rays, May, 1928, PP 726-741.

58. Watson, E. C.
Velocity and Number of the Photoelectrons Ejected by X-Rays as a Function of the Angle of Emission, October, 1927, PP 488-493.

VI Physical Review Supplement, The

1. Compton, A. H.
The Corpuscular Properties of Light, July, 1929, PP 74-89.

2. Mohler, F. L.
Recombination and Photoionization, October, 1929, PP 218-227.