

SOME MEASUREMENTS OF A PHOTOELECTRIC DENSITOMETER

by

ROSS HARRIS ANDERSON

B. S., Kansas State College of  
Agriculture and Applied Science, 1930

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A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

KANSAS STATE COLLEGE  
OF AGRICULTURE AND APPLIED SCIENCE

1935

## TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION .....	2
STATEMENT OF PROBLEM .....	3
DESCRIPTION OF DENSITOMETER .....	4
DEFINITION OF DENSITY .....	12
EXPLANATION OF THE THEORY OF PHOTOELECTRIC EFFECT ...	15
TESTING THE PHOTOELECTRIC CELL FOR ITS FATIGUE .....	22
TESTING THE PHOTOELECTRIC CELL FOR ITS SENSITIVENESS TO DIFFERENT WAVE LENGTHS .....	26
MEASURING THE EFFECT OF ULTRA-VIOLET LIGHT ON PUTMAN DYE .....	28
MEASURING THE CONCENTRATION OF A SOLUTION BY MEANS OF THE DENSITOMETER .....	31
PENETRATING POWER OF X-RAYS THROUGH METALS .....	35
MEASUREMENTS OF THE RELATIVE INTENSITY OF THE VARIOUS LINES OF A SPECTRUM .....	42
TESTING THE DENSITIES OF FILMS EXPOSED TO ULTRA-VIOLET LIGHT .....	44
OTHER SUGGESTED TESTS .....	54
SUMMARY .....	55
ACKNOWLEDGMENTS .....	58
BIBLIOGRAPHY .....	59

## INTRODUCTION

A review of the development of scientific measurements and measuring instruments indicates a constant attempt for greater improvement, an improvement, whereby instruments and apparatus will be easier to manipulate, where data can be collected easier, and where a very small amount of error will be involved.

This development is revealed in the constantly improved methods involved in the measurement of the velocity of light.

Galileo failed completely when he attempted to detect an interval of time for light to travel from one hill to another.

Roemer obtained a close approximation of its velocity in his famed observations taken of the satellite of Jupiter as it was eclipsed by the planet. By noting the period of the eclipses from opposite positions on the earth's orbit he made a fair computation of the velocity of light.

Greater accuracy in this measurement was obtained by Fizeau, Foucault, and later worked out with a very small amount of error (12).

In the field of photometry there has been a decided change from the very crude methods of measurement in which the eye played an important part, to more accurate and more

efficient methods of measurements. It was from this study that measurements of density, or densitometry, developed. Its development has been slow and since measurements all had to be done through the judgment by the eye, large errors have resulted.

With the development of the photoelectric cell a new method of measurement by the use of light has been made possible. This method indicates the intensity of radiant energy which is transmitted to the cell while the earlier photometric method depended upon the eye of the individual to detect different degrees of light intensity. Photoelectricity marks a new era in the study of light transmission. Its uses in densitometry are presented here.

#### STATEMENT OF PROBLEM

Examination of previous work in the study of transmission and absorption of light suggested the use of a densitometer involving the application of the photoelectric cell.

The measurement of light transmission and absorption through both solid and liquid media has been measured by photometric methods but the presence of error has been large.

It was suggested that a densitometer be constructed which involved the application of the photoelectric cell, that a number of measurements of the coefficient of absorption and transmission of light through different media be



made, and that other applications of the densitometer be tested.

#### DESCRIPTION OF DENSITOMETER

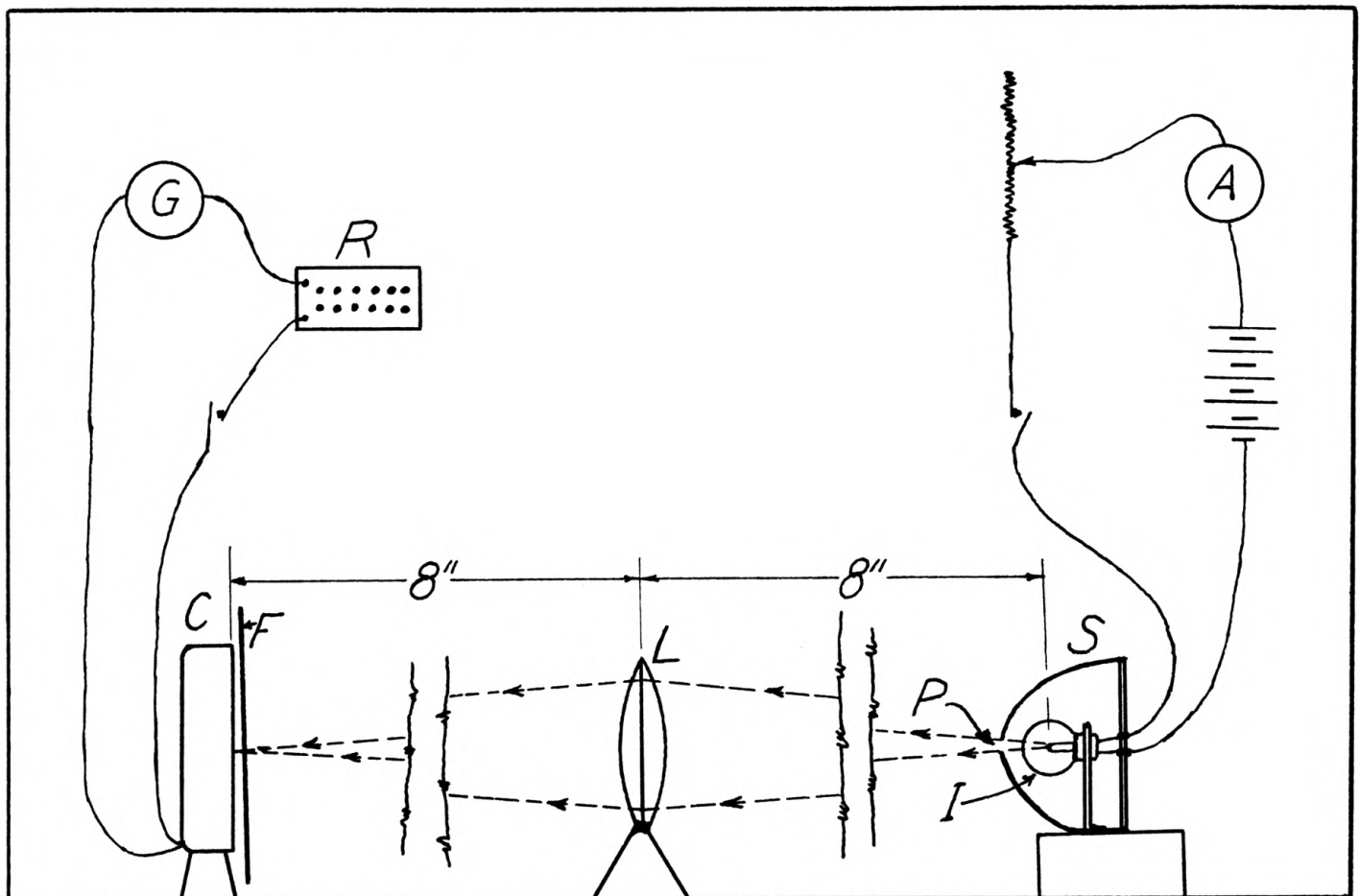
A thirty-two candle power automobile lamp was used in the densitometer as a light source. It was enclosed in a bullet-shaped brass shell with openings for ventilation and a pin-hole opening in the front for emitting a beam of light to the cell. In order to direct this beam of light through a definite portion of the media examined, and to eliminate as much scattering by diffusion as possible, a condensing lens was placed between the pin-hole and the photoelectric cell in such a position as to make the pin-hole and cell at conjugate foci. By bringing the light to a focus on the cell or near the cell makes it easier to eliminate any stray light. Most stray light is eliminated by placing a dark paper cover with a small punch-hole in it directly over the face of the cell so that the punch-hole comes directly in line with the converging beam. There was also a dark paper box placed over the densitometer to exclude all foreign light which might affect a galvanometer reading.

Five lead storage batteries, an ammeter, a carbon plate rheostat, and a knife switch were placed in series with the lamp. Thus the current could be kept constant at

some desired amount and make the light source a constant factor.

The media to be tested were placed in front of the photoelectric cell and held in a constant position. They could be moved by means of a micrometer screw from a traveling microscope which made it possible to adjust the media so that any portion of it could be placed in the line of the beam of light. A sensitive galvanometer was connected in series with the photoelectric cell. Readings were taken through a telescope on a circular scale placed 50 centimeters from the galvanometer mirror. A deflection of 1 millimeter on the scale was equivalent to 9.8 microamperes. A calibrated resistance box was placed in series with the galvanometer which made it possible to keep all of the readings within the range of the scale. The galvanometer used was of the De Arsonval table type. Its readings were a linear function of the electromotive force generated by the photoelectric cell. Its action was deadbeat thus making it possible to make rapid as well as accurate readings.

A diagram of the densitometer is shown in Figure 1, and Plates I and II show photographs of the instrument and set up, respectively.



### KEY

- G*-Galvanometer — reflecting scale type
- R*-Std resistance box
- C*-Photronic cell
- F*-Film
- L*-Lens
- S*-Shield for light
- P*-Opening for light beam
- I*-Auto light bulb
- A*-Ammeter

Fig. 1. A diagrammatic drawing of the densitometer apparatus.

**PLATE I**

**Photoelectric densitometer.**

*PLATE I*

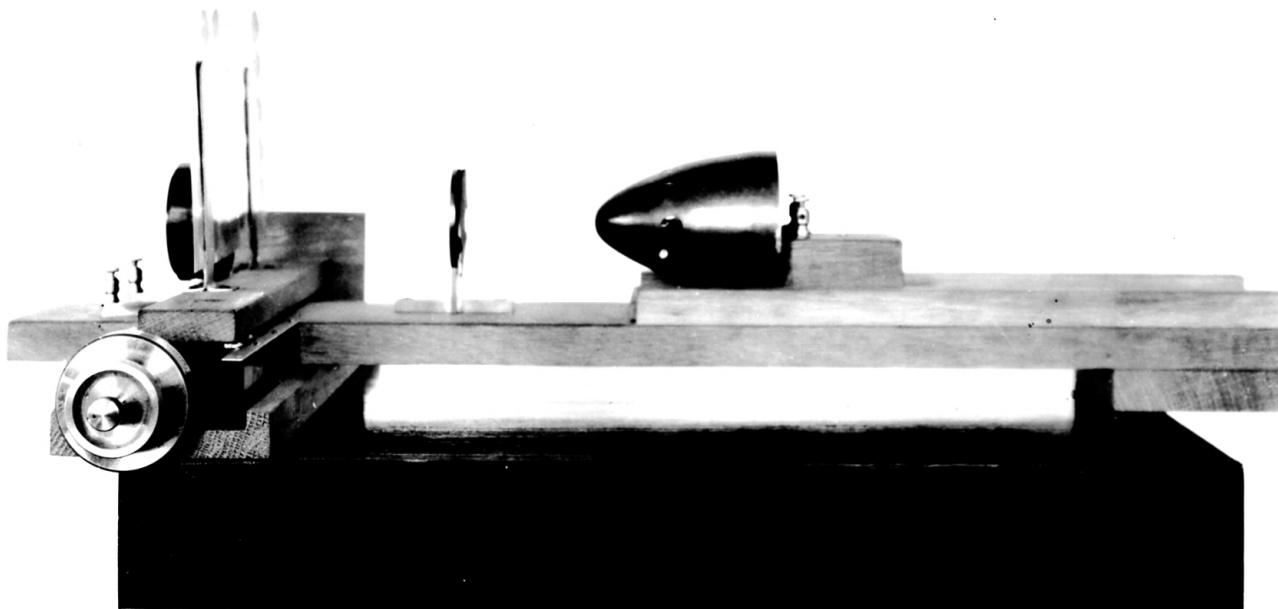
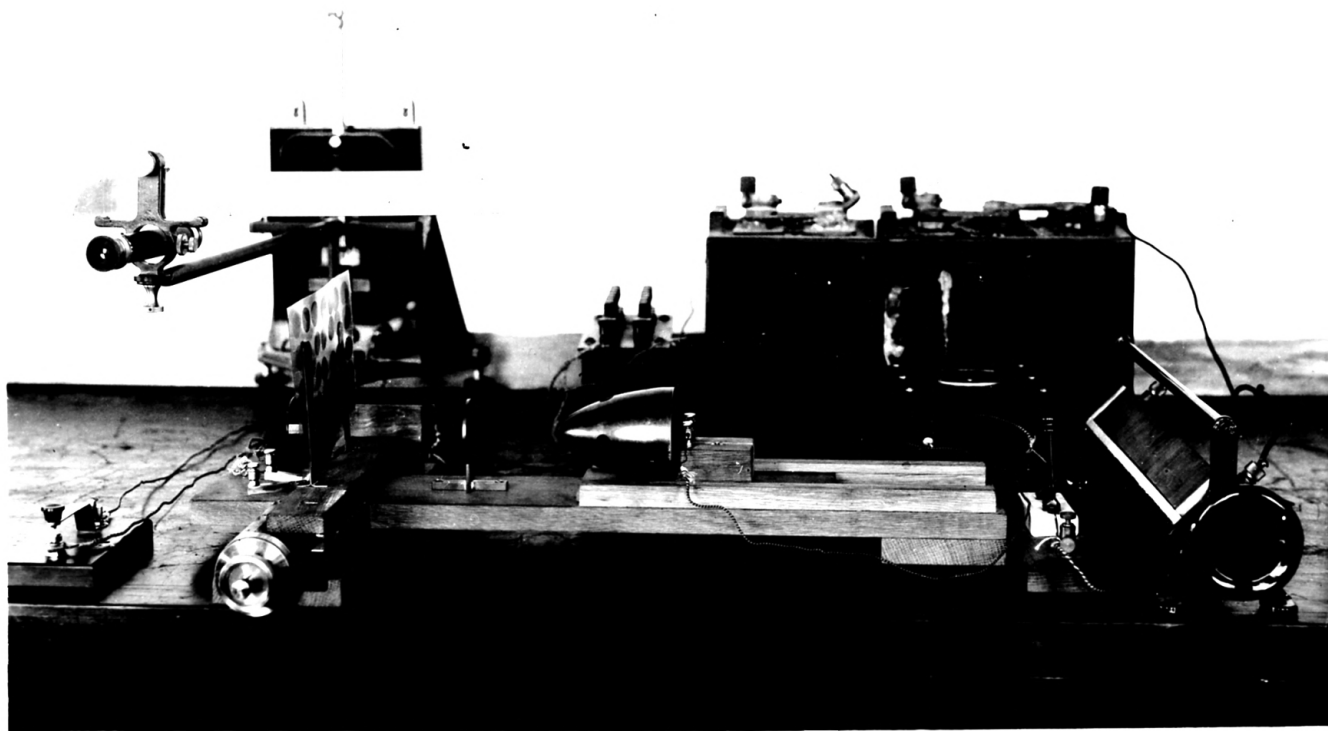


PLATE II

Densitometer set up

# PLATE II





One of the earliest pieces of work in measuring optical density was that of Hurter and Driffield, according to Neblette (7). Their work consisted in determining the densities of photographic films and plotting the density of the films against the time of exposure. Their light source for exposing the films was fairly constant but their densitometer consisted merely of a Bunsen photometer of the grease spot type. After a balance was made by equal illumination of the grease spot, the silver deposit to be measured was inserted in the path of one of the beams of light and the grease spot indicator again shifted until a balance is secured. The difference between the first and last readings is a measure of the opacity of the silver deposit.

Some other methods to determine the density were used. Instead of varying the distance between the light source one of the beams of light could be polarized. Or, one of the beams of light may be made weaker by the use of some absorption material placed in its path.

Hurter and Driffield were the first to introduce the idea of optical density. The optical density of a certain medium expressed mathematically was

$$k = \frac{\log_{10} I - \log_{10} I_x}{mx} \quad (a)$$

where  $k$  is the coefficient of density,  $I$  the incident light,  $I_x$  the transmitted light,  $m$  the concentration and  $x$  the

thickness of the medium. It is noted that according to Hurter and Driffeld density is the logarithm of the opacity or the negative logarithm of the transmitted light.

By plotting a logarithmetric curve of the opacity they found what is termed the characteristic curve of films. This curve is shown in Figure 2.

#### DEFINITION OF DENSITY

The term "density" or "opacity" as used here represents a logarithmic ratio between the incident light and the transmitted light.

Mathematically, the density of a certain substance of unit thickness is the logarithm of the intensity of the incident light divided by the intensity of the transmitted light (7).

$$k = \log_{10} \frac{I}{I_t}$$

If  $I$  is the intensity of the incident light and  $I_t$  is the intensity of the transmitted light then

$$\text{transparency} = \frac{I_t}{I}$$

$$\text{and density} = \frac{I}{I_t}$$

where both the incident and transmitted light intensities are expressed in some practical unit such as the foot candle.

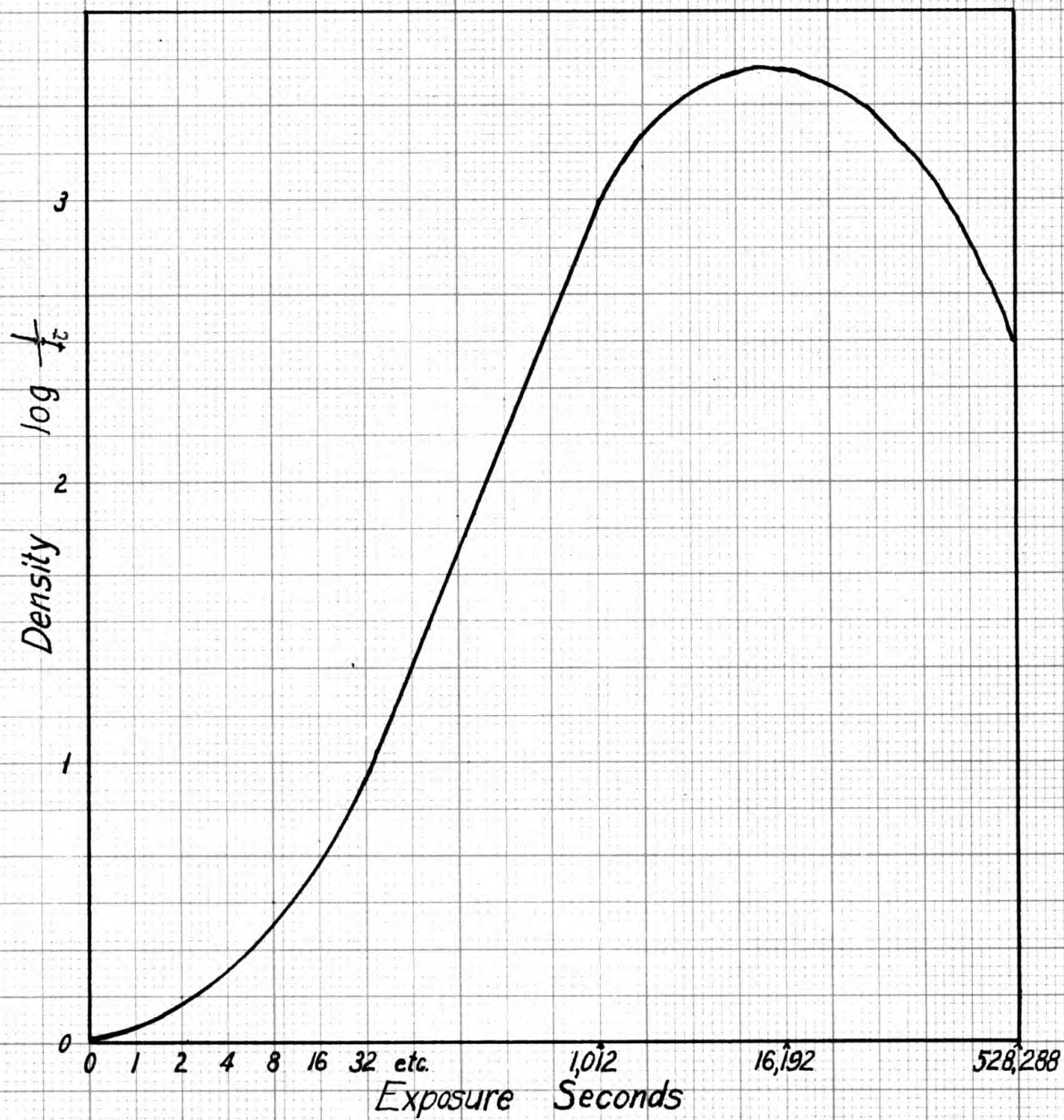


Fig. 2. The "characteristic" curve obtained by Hurter and Drifffield.

Density, when taken over a wide range of values, is a logarithmic function instead of a linear function (7).

If the absorption coefficient of a particular substance is represented by  $k$ , under the assumption that each molecule of the substance has a particular absorption or transmission effect, then

$$I_t = \frac{1}{I^k}$$

and if  $x$  is the thickness of the medium then

$$I_t = \frac{1}{I^{kx}}$$

and if  $m$  is the number of molecules per unit volume of the concentration then

$$I_t = \frac{1}{I^{kmx}} \quad (b)$$

or changing to logarithms

$$\log I_t = -kmx \log I$$

$$kmx = \log I - \log I_t$$

$$k = \frac{\log I - \log I_t}{mx}$$

Here  $k$  is the density of the medium.

If  $k$  is the coefficient of absorption of a certain medium of thickness  $x$  and concentration  $m$ , then  $k'$  is the coefficient of absorption of the same medium of thickness  $x'$  and concentration  $m$ .

The relationship between  $k$  and  $k'$  is

$$\frac{k}{k'} = \frac{\frac{\log I - \log I_t}{mx}}{\frac{\log I - \log I_t'}{mx'}}$$

$$\text{or } \frac{k}{k'} = \frac{x' (\log I - \log I_t)}{x (\log I - \log I_t')}$$

$$\text{or } \frac{k}{k'} = \frac{x' \log (I/I_t)}{x \log (I/I_t')}$$

$$\text{or } k' = k \times \log (I/I_t') - x' \log (I/I_t)$$

#### EXPLANATION OF THE THEORY OF PHOTOELECTRIC EFFECT

In order to measure light intensities or intensities of illumination, it was suggested that the photoelectric cell be employed to determine the transmission through the medium. Light is a form of energy. Whether it is propagated in the form of waves or moves as quanta it possesses a quantity of energy which if placed under a certain condition will produce a certain result. Now when this energy, whether it be visible or invisible, strikes the sensitive surface of any metal such as we find in the photoelectric cell it discharges electrons from the atoms of this surface. A sufficient amount of energy must impinge this surface before an electron will be discharged. According to Slater and Frank (10) if  $\nu$  is the energy in one quantum and the



frequency of the energy radiated, then

$$\epsilon = h\nu \text{ ergs} \quad (c)$$

where  $h$  is considered as a universal constant and spoken of as Planck's constant. From the general formula where  $V$  is the velocity,  $\nu$  the frequency, and  $\lambda$  the wave length we have

$$V = \nu\lambda \quad \text{or} \quad \nu = V/\lambda \quad (d)$$

which also gives the frequency.

From these formulas two empirical laws can be stated: First, the number of electrons released per unit time at a photoelectric surface is directly proportional to the intensity of the incident light. And second, the maximum energy of electrons released at a photoelectric surface is independent of the intensity of the incident light, but is directly proportional to the frequency of the light.

The quantum necessary to release an electron is very small being of the order of about one millionth of an erg. Part of each quantum received by an electron from the radiation of light or other forms of radiant energy is used in pulling the electron away from the surface. The rest of the energy is used to determine the speed of the electron. This surface attraction is so great for some metals that in order for the electrons to be pulled away from their respective atoms a larger quantum is necessary.

According to the previous formula, the energy in one

quantum varies with the frequency so in order to get a larger quantum a higher frequency must be used. Such frequencies as those of the ultra-violet and X-rays are used for this purpose. Each metal that is used for photoelectric effect has a sharply defined characteristic minimum frequency to which it will respond. If electrons are to be torn from the metal, then it is necessary to increase the frequency above the characteristic frequency.

According to Einstein's photoelectric equation the energy required to overcome the surface attraction of the metal for the electron is one quantum and may be stated,

$$W = h\nu - \frac{1}{2}mv^2 \quad (e)$$

where  $\frac{1}{2}mv^2$  is the kinetic energy of the electron,  $v$  its velocity,  $m$  its mass, and  $W$  the energy required to overcome the surface attraction of the metal surface for the electron.

The Weston Photronic cell used in this densitometer is a dry photo-voltaic cell. Although the methods of its manufacture are still unknown to the public some information regarding its construction and operation is published in our literature (9). This cell is of the iron-selenium type and is both sensitive and permanent. Its photo-active parts consist of iron selenide or iron coated with a thin film of silver. It has a rating of approximately 1.4 microamperes per foot candle with a surface of 1.7 square inches. This would give it about 120 microamperes per lumen. It is not



damaged by exposure to stray illumination even when short-circuited. Having once reached equilibrium under a given illumination it will remain constant for a very long period of time. Its color curve is similar to that of the eye but is shifted slightly toward the red end of the spectrum with respect to visual sensation. This curve with its relative visibility curve is shown in Figure 3.

The current output of the cell varies with the illumination on the face of the cell and also with the external resistance which is connected in the circuit. When this external resistance is low the output is linear. This linear response is the same up to high intensities of light even to that of direct sunlight whose intensity of illumination is from 10,000 to 15,000 foot candles.

The total current generated in the cell is a function of the radiant flux only, and is proportional to it. This current divides between an internal conducting path in the cell, and the external circuit if it has one, according to the laws of parallel circuits. The internal resistance of the cell is not a constant, but varies with the illumination or radiant flux, and also upon the leakage current through it. The cell resistance acts as a shunt to the external circuit. The current and resistances are related in accordance with the following equation:

$$I = \frac{E i_0 r}{R + r} \quad (f)$$

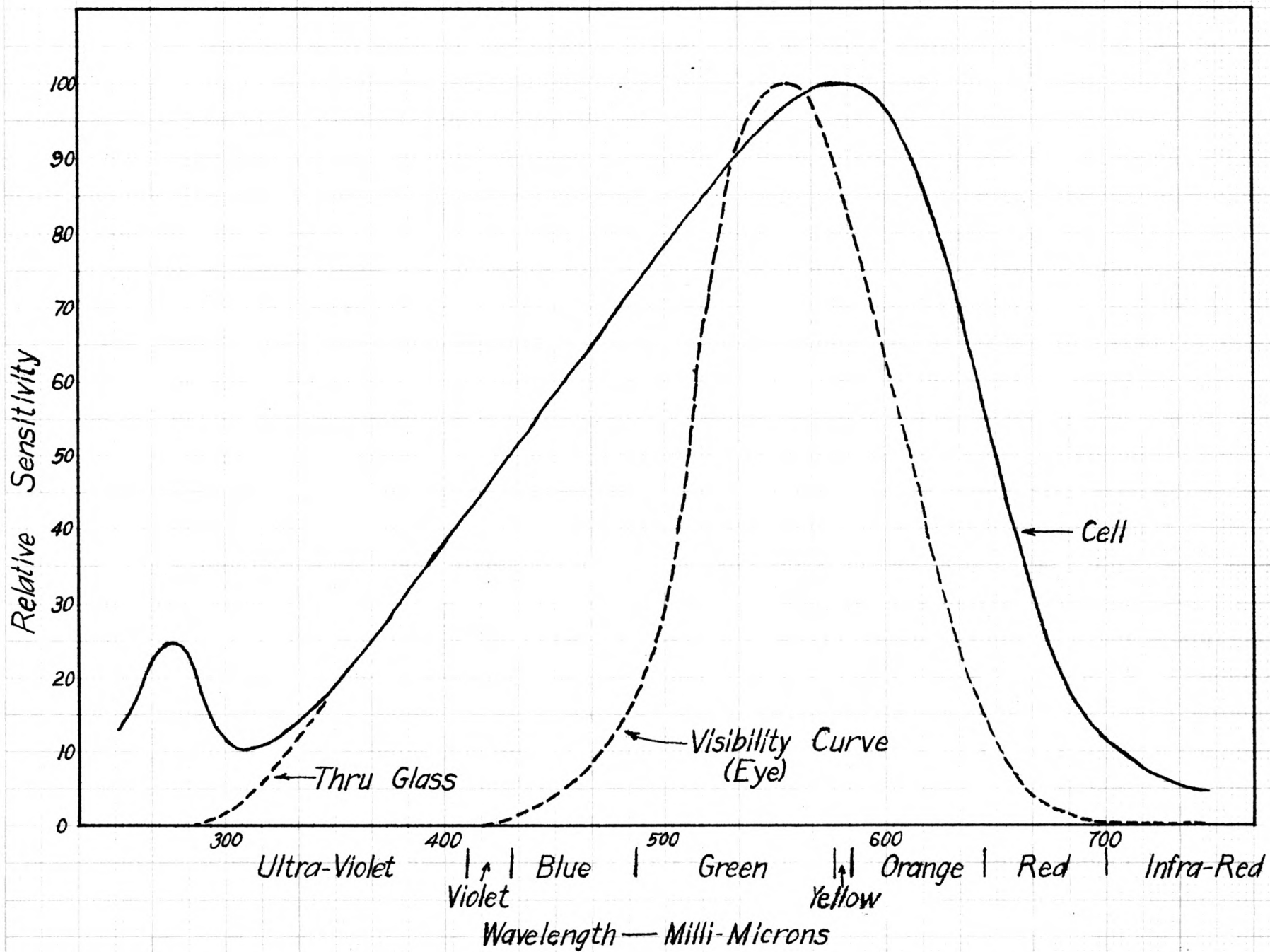


Fig. 3. Spectral sensitivity of Weston Photronic photoelectric cell.

where,  $I$  = external current output in microamperes

$E$  = illumination on cell in foot candles

$i_0$  = total current generated per unit illumination

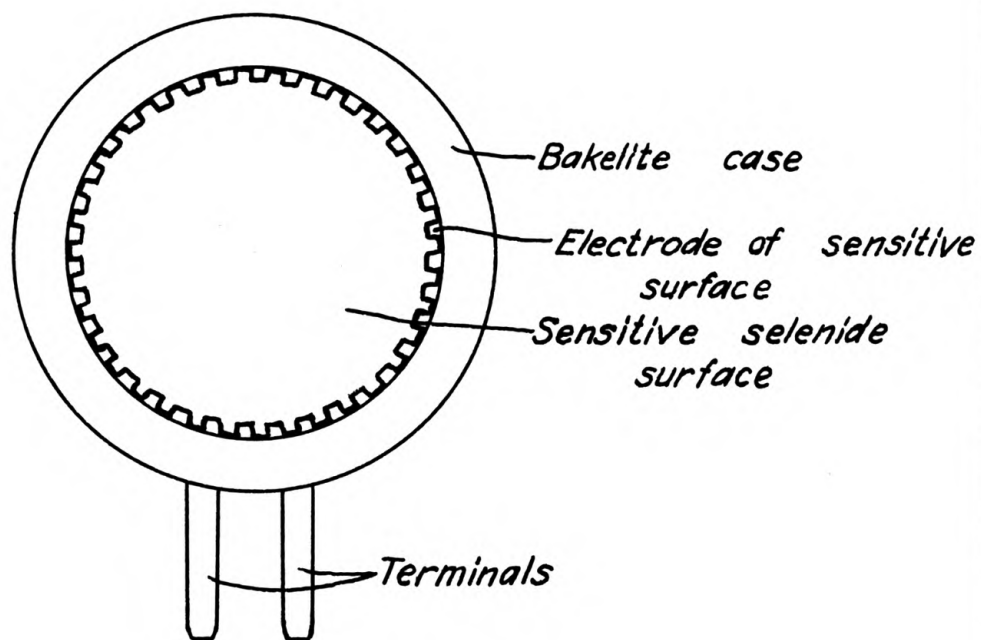
$r$  = internal resistance of cell for illumination  $E$   
and external resistance  $R$

$R$  = external resistance

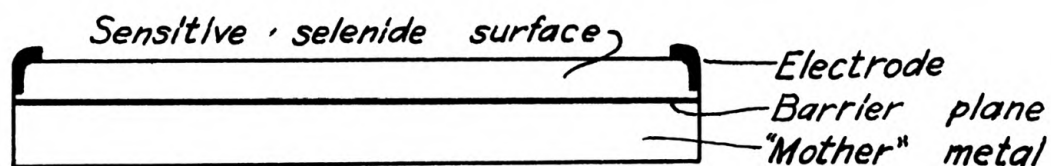
The equivalent circuit is shown in Figure 4. The condenser  $C$  represents the capacitance between the sensitive surfaces in the cell and is in parallel with the internal resistance  $r$  for currents generated by pulsating light.

Changes in temperature have very little effect upon the current generated in the cell, but the internal resistance of the cell is greatly affected by changes in temperature which in turn would affect the current output in external circuits having relative high resistances. This also affects the voltage and for this reason it is better to use the current characteristics of the cell for measuring purposes rather than voltage or resistance, unless the temperature is practically constant. The current characteristics of the cell were used entirely throughout the investigations with the densitometer by means of a low resistant galvanometer shunt.

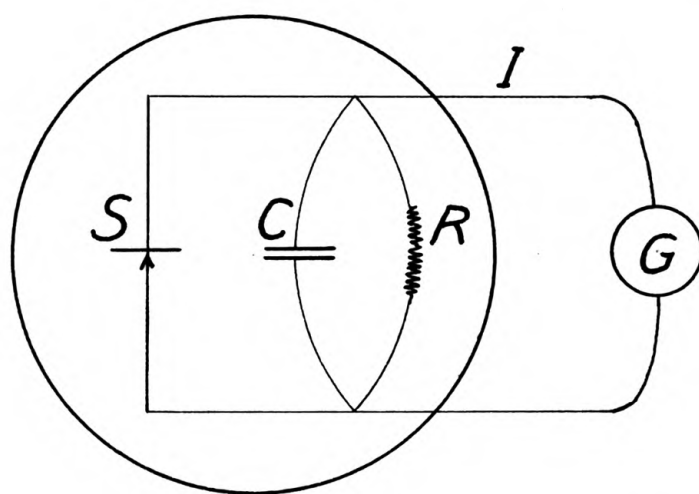
The cell should not be used or exposed to temperatures higher than  $50^{\circ}\text{C}$ . as changes in its sensitivity would result if this temperature is exceeded. If the cell is exposed to



(A) Face of Photoelectric Cell



(B) Horizontal Cross Section of Cell



**KEY**

*S*-Photoelectric surface in contact

*C*-Condenser

*R*-Internal resistance unit

*I*-External current

*G*-Galvanometer

(C.) Diagrammatic Wiring of Cell

Fig. 4. Construction of the Weston Photronic cell.

radiation containing a very high degree of infra-red or heat rays, its temperature might be raised above the "heat limit" and damage the cell.

The cell has an irregularity called "fatigue." This is due to exposure and if a very sensitive measurement is to be taken the cell ought to be free from light for a few moments before the measurement is taken.

#### TESTING THE PHOTOELECTRIC CELL FOR ITS FATIGUE

The cell was exposed to the direct beam of light for a short period of time and then allowed to regain its original sensitivity by resting. After each rest period the cell was again subjected to the light and each time the deflection on the galvanometer read the same.

Another test was made by using a constant absorption medium in front of the cell. In this test different areas of the cell's face were exposed by varying the size of a slit placed in the beam of light. The slit was one centimeter long and readings were taken with openings varying from one-tenth millimeter to 2 millimeters in width. These openings were regulated with a micrometer screw. The current was kept constant at 4 amperes and the light conditions of the room also kept constant.

Table 1 shows the results obtained from five different trials while each trial included 20 different sizes of open-



Table 1. Photoelectric cell response for varying areas of illumination.

Width of slit (mm.):	Deflection in centimeters					
	Trial 1:	Trial 2:	Trial 3:	Trial 4:	Trial 5:	Averages
0.1	1.1	1.1	1.1	1.1	1.2	1.1
0.2	2.4	2.7	2.7	2.7	3.1	2.7
0.3	4.9	5.3	5.5	5.5	5.6	5.4
0.4	7.3	7.6	8.0	8.0	8.3	7.8
0.5	9.4	10.4	11.0	11.2	11.2	10.7
0.6	12.3	13.1	14.4	14.2	14.3	13.7
0.7	15.7	16.3	17.4	17.5	17.7	17.0
0.8	18.7	19.1	20.3	20.6	21.0	20.0
0.9	20.8	21.4	22.3	22.7	23.3	22.2
1.0	22.1	22.5	23.8	24.1	25.1	23.5
1.1	23.1	23.1	24.3	24.8	25.6	24.2
1.2	23.3	23.4	25.0	25.3	26.0	24.6
1.3	24.0	23.5	25.2	25.7	26.5	24.9
1.4	24.1	23.6	25.4	25.7	26.7	25.1
1.5	24.1	24.0	25.4	25.7	26.7	25.2
1.6	24.1	24.5	25.4	25.7	26.7	25.3
1.7	24.1	24.5	25.4	25.8	26.7	25.3
1.8	24.1	24.5	25.4	25.8	26.7	25.3
1.9	24.1	24.5	25.4	25.8	26.7	25.3
2.0	24.1	24.5	25.4	25.8	26.7	25.3

ings. The table also shows a mean or average deflection of all trials made. Figure 5 represents the deflection plotted against size of opening.

Since the spot of light directed on the slit was an image of the filament of the light source it would not have constant intensity throughout but would vary with the intensity of a particular portion of the source. This factor accounts for the fact that the deflection does not increase in proportion to the area of the opening. After the opening became one and one-half millimeters wide the whole spot of light could enter and any further increase in width would cause no change in the amount of deflection on the galvanometer scale.

The most interesting and unanticipated results of this test showed that there was a continued rise in the deflection for most of the succeeding trials although the area of the opening remained the same.

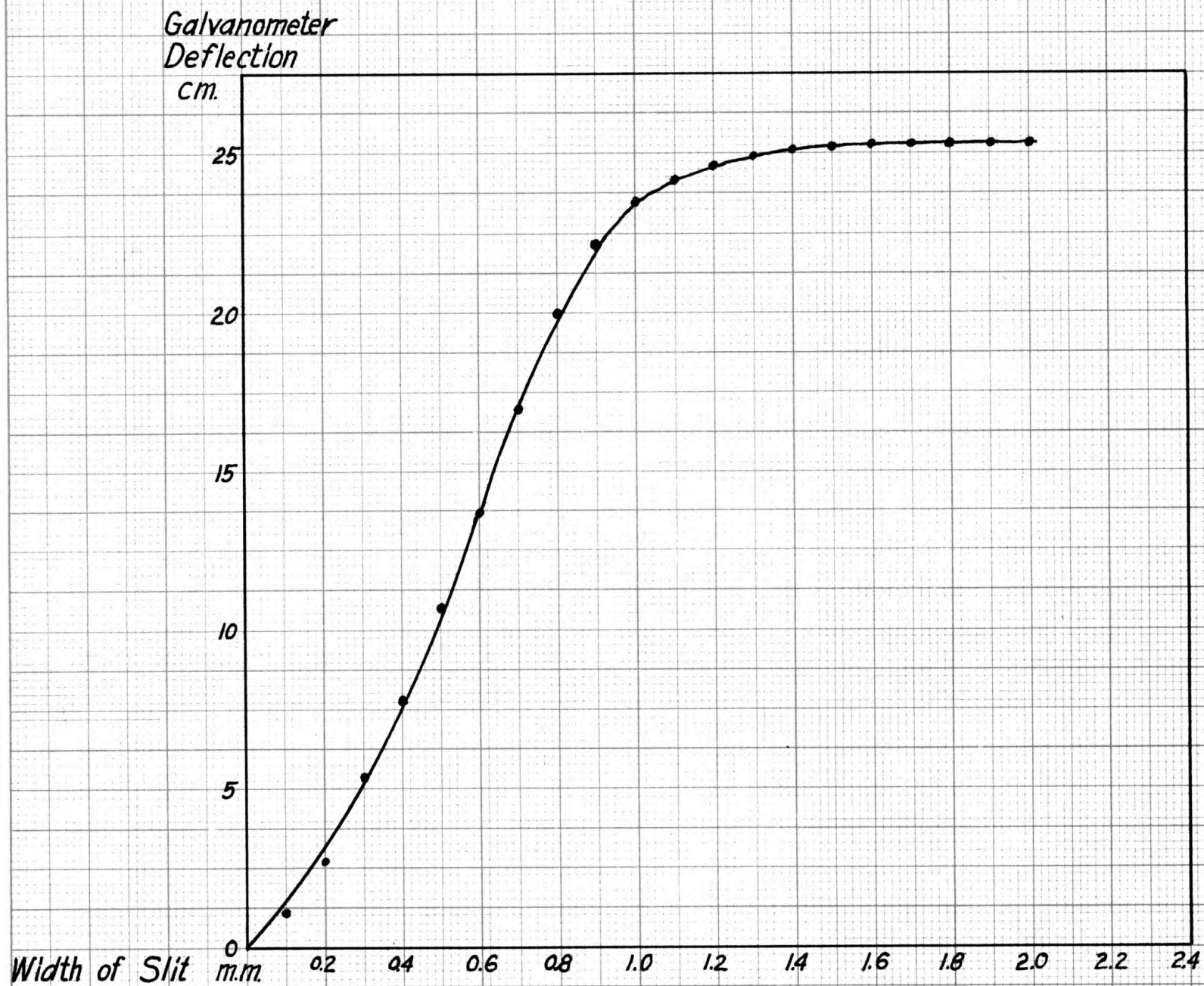
The cause of the gradual increase of deflection on the whole can be accounted for by the fatigue of the cell. From the theory of the cell once the "surface pressure" holding the electrons in their positions is broken some heat is generated (4). This accumulation of heat assists the radiant energy falling on the surface and causes an accumulative photoelectric reaction which gives the same results as would be obtained if the intensity of illumination were in-



**Figure 5**

**Cell sensitivity to various apertures to illumination.**

2. 100/100

*Fig. 5*

creased.

#### TESTING THE PHOTOELECTRIC CELL FOR ITS SENSITIVENESS TO DIFFERENT WAVE LENGTHS

This test was made to show the sensitivity of the photoelectric cell to light transmitted through different colored media. These results were obtained by using the direct rays of the sunlight as a light source since it contained all the visible wave lengths. The sky was clear and the observations were taken between one and two o'clock when the intensity of the sunlight was nearly uniform.

A summary of the results, Table 2, shows the relative transmission intensities of varied thicknesses of blue, green, and red cellophane. Blue showed the greatest intensity of transmission. Red cellophane transmitted a greater intensity of illumination than green. When the thickness of the cellophane was doubled the intensity of transmitted light did not diminish to one-half. In the test with the blue cellophane doubling the thickness would decrease the intensity one-third, while if the thickness of the green cellophane was doubled the transmission intensity was decreased about one-sixth. This shows that for different colors the coefficient of absorption and thickness show a different relationship.

It must be considered that with a certain color, blue for example, that the first thickness absorbs most all the

Table 2. Response of cell to various wave lengths of light.

Media	:E.M.F. through :55 ohms :	: I = P : 55 :	: E.M.F. of cell : open circuit :	: Power : output : (watts)
Atmosphere (direct sunlight)	0.31475	0.00571	0.33970	0.00194
Green cellophane 1 thickness	0.25032	0.00477	0.27940	0.00124
Green cellophane 2 thicknesses	0.21200	0.00385	0.23753	0.00091
Red cellophane 1 thickness	0.25282	0.00459	0.27036	0.00124
Blue cellophane 1 thickness	0.29350	0.00534	0.30600	0.00163
Blue cellophane 2 thicknesses	0.18960	0.00344	0.29161	0.00100
Blue cellophane 4 thicknesses	0.12179	0.00221	0.26346	0.00058

colors except the blue. If the blue rays that have penetrated the first thickness are taken as the maximum it is found that over half of this intensity will penetrate the next layer. This shows that the transmission intensity is not a direct function of the thickness but is a function which depends on a certain constant for each different color.

It was also found that one thickness of any of the three colors used would not absorb half of the light intensity which could be obtained without the colored medium. One thickness of the green cellophane absorbed about 20 per cent of the sun's intensity. One thickness of the blue cellophane absorbed about 7 per cent of the sun's intensity.

Since all three of these colors are prominent in the sensitive curve of the photoelectric cell these results are therefore the corresponding transmission intensities for each of the colors used.

#### MEASURING THE EFFECT OF ULTRA-VIOLET LIGHT ON PUTMAN DYE

A 10 per cent solution of Putman dye was placed in a shallow pan and exposed to the ultra-violet light to determine the ability it possessed to retain its color under this bleaching influence. The pan of solution was placed 24 inches from the mercury vapor lamp and left for intervals of 30 minutes each.



At the end of each period of 30 minutes the dye was made up to its original volume by adding water. A portion of the solution was placed in a small rectangular glass container with parallel sides and placed in the beam of light in front of the face of the photoelectric cell. The light penetrated the solution and the transmitted intensity which affected the photoelectric cell was recorded by the measured electromotive force indicated by a potentiometer. Table 3 gives the results of the effect of bleaching on Putman dye and Figure 6 shows the bleaching curve for this particular dye.

Table 3. Changes of Putman dye due to bleaching.

Time of exposure	Voltage recorded
0 minutes	0.10955
30 minutes	.11255
60 minutes	.11315
90 minutes	.11492
120 minutes	.11552
150 minutes	.11723
180 minutes	.12057
210 minutes	.12310

The curve shows that in general the bleaching effect is almost a direct function of time. Bleaching takes place a little more rapidly at first, then diminishes up to about two hours and for the next hour or more it is bleached directly proportional to the time exposed.

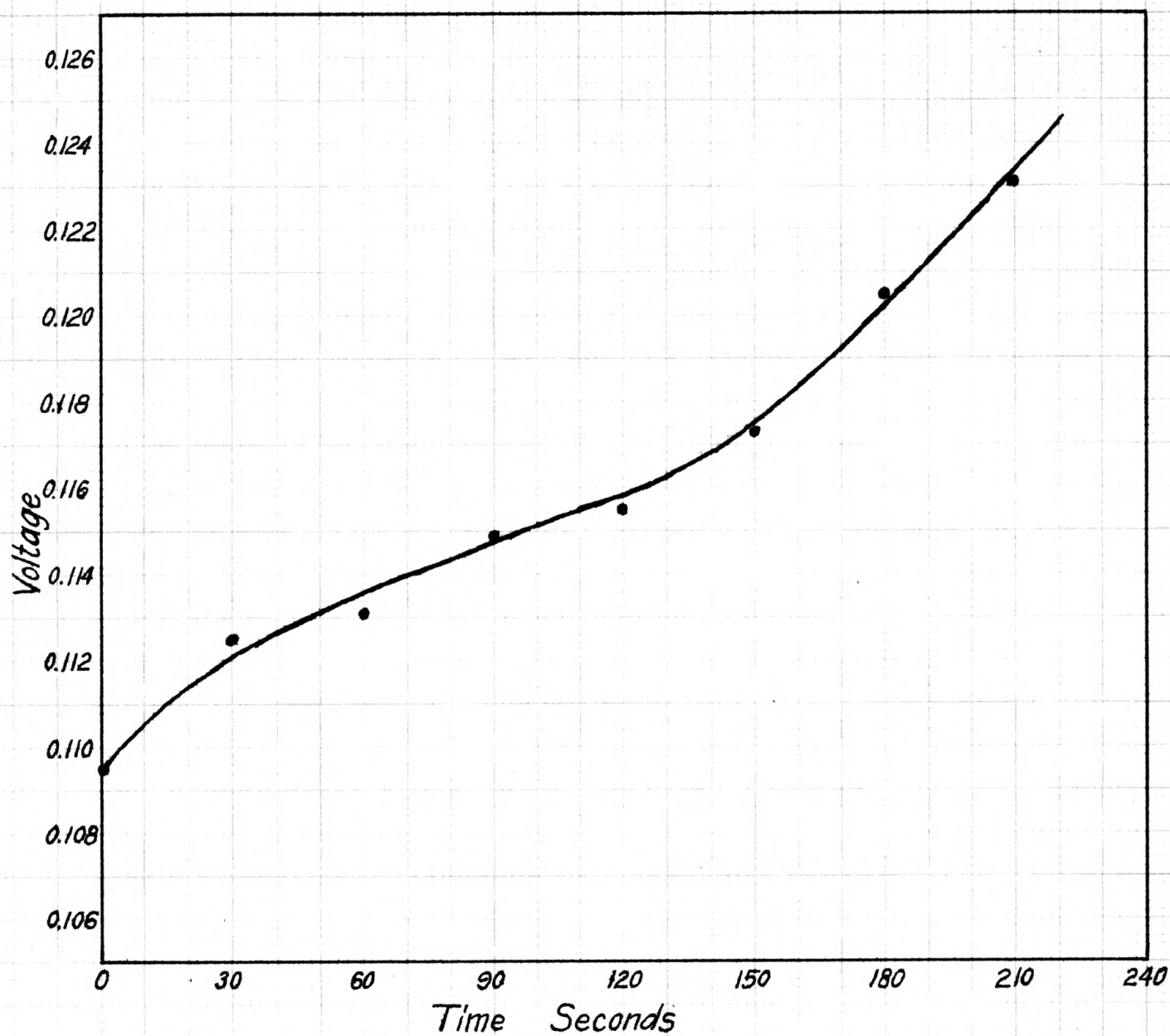


Fig. 6. Bleaching curve for Putman dye.



Some fast dyes like Diamond dye, for example, have a very slow bleaching effect and not until long exposures to intense light will they show any increase in their transparency. The plateau on this curve which occurs between one-half hour and two hours represents a period of fastness where the dye shows a resistance to being bleached.

If the measurements of the liquid are made accurately and the same section of the container examined each time there is little chance of error in this test. The diffusion of the molecules of dye throughout the water would give it an equally distributed absorption effect.

#### MEASURING THE CONCENTRATION OF A SOLUTION BY MEANS OF THE DENSITOMETER

This test was made in order to find out how sensitive the photoelectric cell of the densitometer was in its detection of the densities of diluted dye solutions.

A 1 per cent solution of Putman dye was placed in a small rectangular container with parallel glass sides. This medium was placed in front of the photoelectric cell and a beam of light was passed through it. The response of the photoelectric cell to the intensity of the transmitted light was received by a potentiometer and the voltage recorded.

The dye was then diluted to one-half its original concentration or to 0.5 per cent by making it up to twice its original volume by addition of water. A portion of this

solution was tested for its ability of transmission as in the previous case. The solution was diluted again and again by making a portion of each concentration up to twice its volume. Thus the per cent was halved each time. This process was carried out until a dilution of one part in two-hundred million was reached, or until the cell would no longer give a response which differed from that of tap water.

When the solution had been diluted to one part in thirteen thousand it was impossible to detect it from tap water by direct observation. Table 4 shows the voltages obtained for each dilution. Figure 7 is a curve where concentration is plotted against transmission which is converted into voltage.

It will be noted that at first an increase in transmission or a decrease in absorption is rapid but during the next three dilutions the increase in transmission intensity was slow. Then during the fifth, sixth, and seventh dilutions the rate of increase in transmission intensity was increased again. After the eighth dilution the transmission intensity was increased very slowly until the twenty-second dilution was reached. The transmission intensity of the solution at this stage was the same as that obtained by using tap water.

Table 4. Voltages obtained by transmitted light through different dilutions.

Per cent concentration : Relative voltage of transmission	
1	0.061
$5 \times 10^{-1}$	.114
$2.5 \times 10^{-1}$	.127
$1.25 \times 10^{-1}$	.138
$6.25 \times 10^{-2}$	.151
$3.12 \times 10^{-2}$	.171
$1.56 \times 10^{-2}$	.201
$7.81 \times 10^{-3}$	.232
$3.90 \times 10^{-3}$	.246
$1.95 \times 10^{-3}$	.248
$9.76 \times 10^{-4}$	.249
$4.88 \times 10^{-4}$	.250
$2.44 \times 10^{-4}$	.252
$1.22 \times 10^{-4}$	.252
$6.10 \times 10^{-5}$	.253
$3.05 \times 10^{-5}$	.255
$1.52 \times 10^{-5}$	.256
$7.62 \times 10^{-6}$	.258
$3.81 \times 10^{-6}$	.260
$1.91 \times 10^{-6}$	.263
$9.53 \times 10^{-7}$	.264

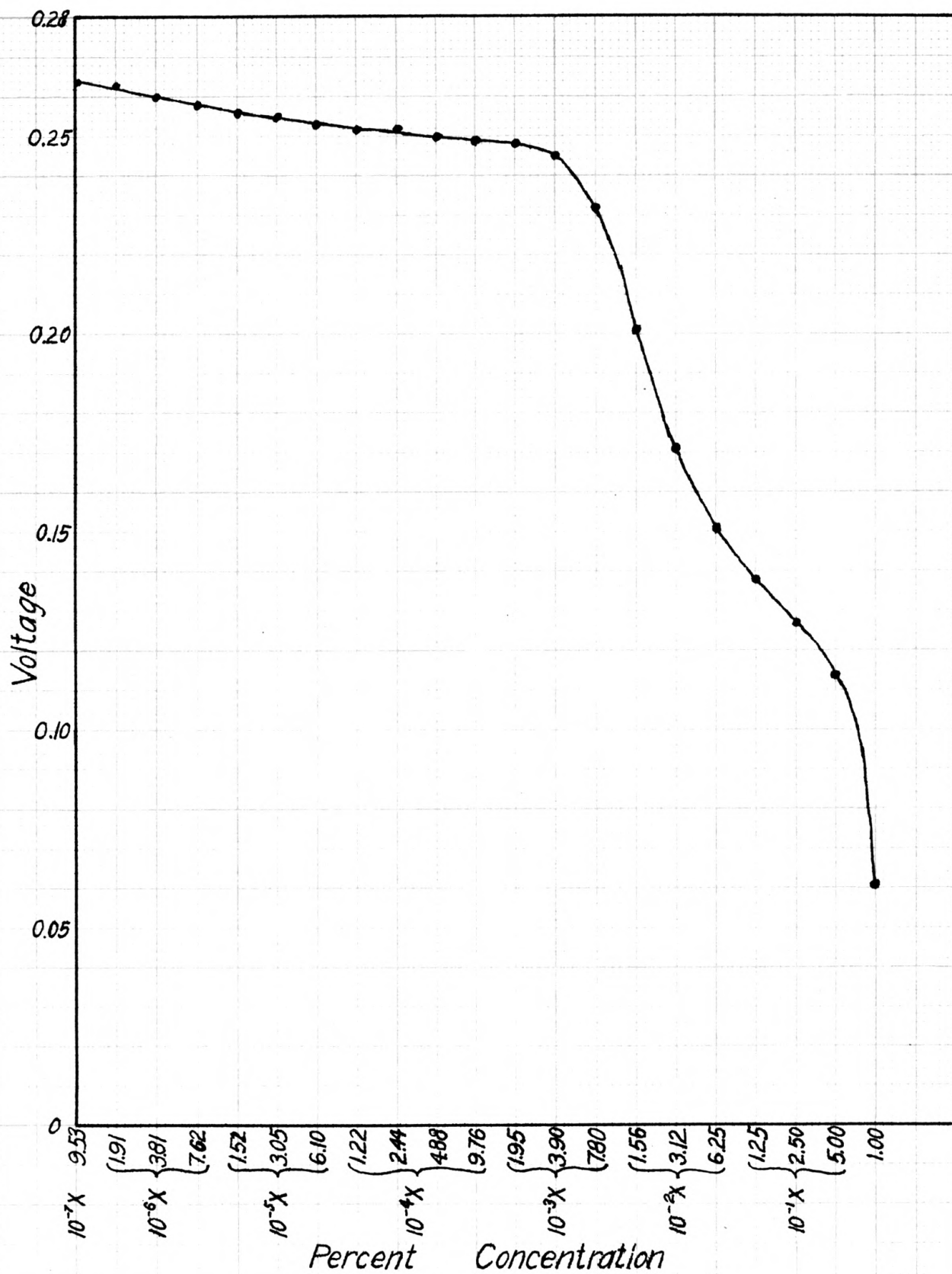


Fig. 7. Relative densities of diluted solutions.

According to equation (b) where  $m$  is the concentration

$$I_t = I_0 e^{-kmx}$$

According to Preston (8)

$$I' = I\alpha^x$$

where  $I'$  is the intensity after transmission,  $I$  is the incident light,  $\alpha$  is a proper fraction and depends upon the nature of the substance, and  $x$  is the thickness.

If we substitute concentration  $m$  for thickness  $x$  the equation will read

$$I' = I\alpha^m$$

which shows that the intensity of the transmitted light is a logarithmic function of the concentration.

The fact that the curve isn't smooth shows that at certain concentrations there must be margins of transmission where a decrease in concentration does not give a similar decrease in photoelectric response. This shows that the intensity of transmission is not a linear function of the concentration.

#### PENETRATING POWER OF X-RAYS THROUGH METALS

It was suggested that the direct rays from the X-ray tube be allowed to strike the sensitive face of the photoelectric cell and find out if this action would produce a galvanometer deflection.

The galvanometer was connected to the photoelectric



cell and the latter placed under the X-ray tube. After covering the cell with dark paper to eliminate any visible rays, the X-rays were applied. A considerable deflection from the galvanometer showed that invisible rays would affect the cell. Applying the X-rays at different times showed that the cell did not become damaged in any way due to the invisible rays.

The response of the cell varied inversely as the square of the distance it was placed from the source of the rays.

Since the behavior of the cell was fairly constant under the influence of invisible rays it was suggested that the cell be shielded and different thicknesses of metals be placed over it. This would involve a new method of finding the penetrating power of the X-rays.

A shield of lead 5 millimeters thick was made which would completely exclude from the cell all diffused or stray rays which might come from any direction and influence the reading on the cell.

Different thicknesses of lead, copper, iron, and aluminum were placed over the cell. The X-rays were applied and the deflection recorded. As was expected the deflection decreased as the thickness of the metal placed over the cell was increased. It was also expected that when a certain thickness was reached, depending on the metal, that the cell would cease to respond. This, however, was not the case.

But on the other hand after a certain thickness was reached the deflection remained the same no matter how great a thickness of metal was placed over the cell. A piece of lead 10 centimeters thick was placed over the cell and still there was a response as great as when 1 centimeter of lead was used.

Table 5 shows the results from experiments with lead and copper. Figures 8, 9, and 10 are curves showing the deflection plotted against thickness. Figures 9 and 10 are results obtained from two different cells.

Why does the cell continue to respond after a maximum thickness of lead is reached?

The response of the cell is immediate so the assumption that the cell responds because heat is transmitted through the metal is therefore void.

This response might be caused by the transformer setting up a small induced current in the circuit of the cell and galvanometer. Since the cell could act as a rectifier and allow electrons to flow unidirectional a deflection might be produced.



Table 5. Intensity of X-ray transmission  
through metals.

Cell 292		:	Cell L 292	
Thickness :	Deflection	:	Thickness :	Deflection
(pb) :	cm.	:	(pb) :	cm.
0.07 (mm.)	9.4		0.07 (mm.)	9.3
0.45	6.6		0.14	6.0
0.55	5.5		0.21	4.7
0.95	4.2		0.28	4.2
1.50	3.5		1.15	3.2
2.00	3.3		2.90	3.1
2.50	3.0		4.60	3.0
3.25	3.0		6.00	2.9
9.00	3.0		8.00	3.0
			12.00	3.0
			18.00	3.0
			26.00	3.0
		:		
			Thickness :	Deflection
			(cu) :	cm.
			0.45 (mm.)	6.6
			0.55	5.5
			0.95	4.2
			1.50	3.5
			2.00	3.3
			2.50	3.0
			3.25	3.0
			9.00	3.0
Zero reading	39.5		Zero reading	27.5

**Figure 8**

**Penetration of X-rays through copper.**

Deflection  
cm.

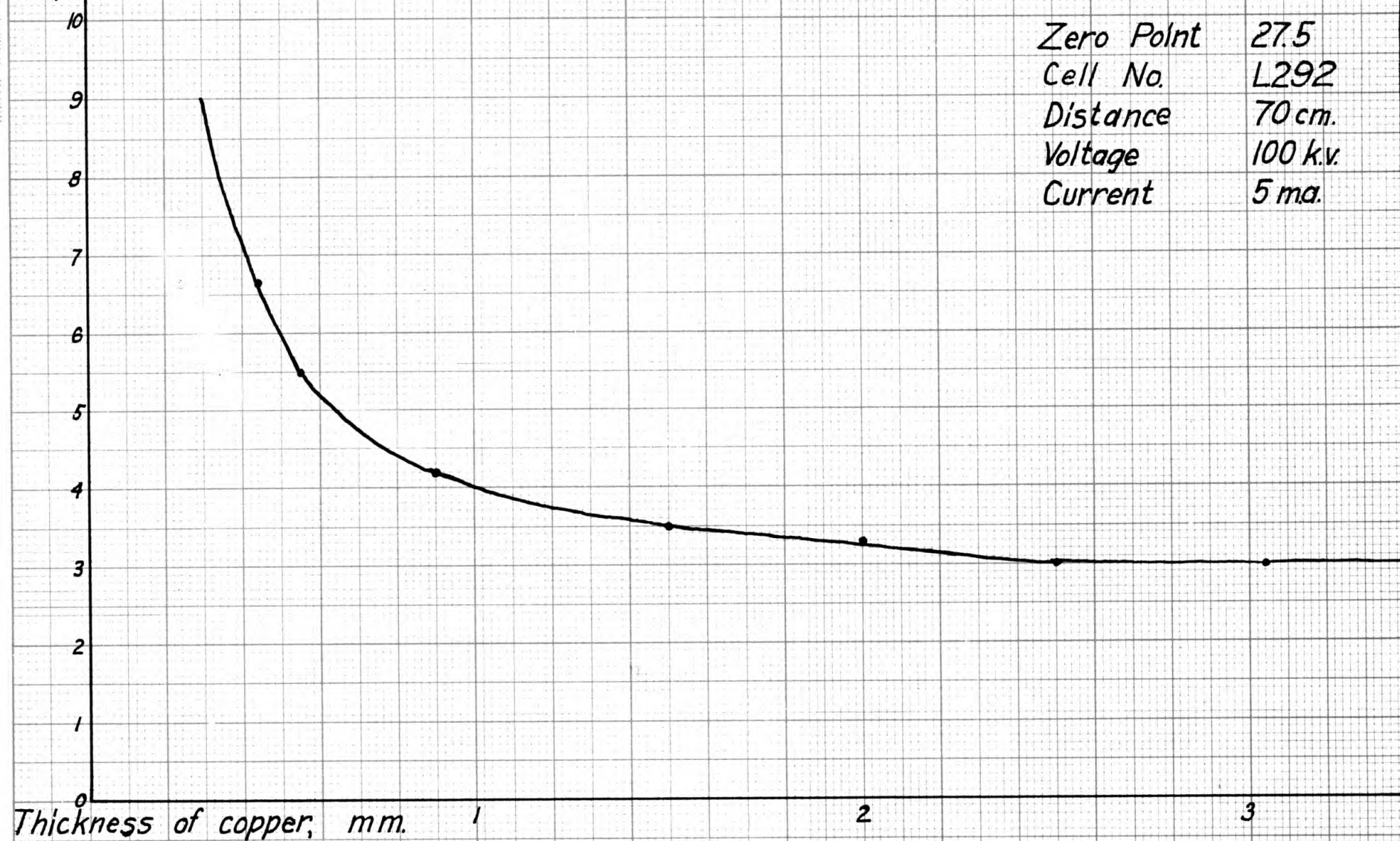


Fig. 8

**Figure 9**

**Penetration of X-rays through lead (cell 292).**

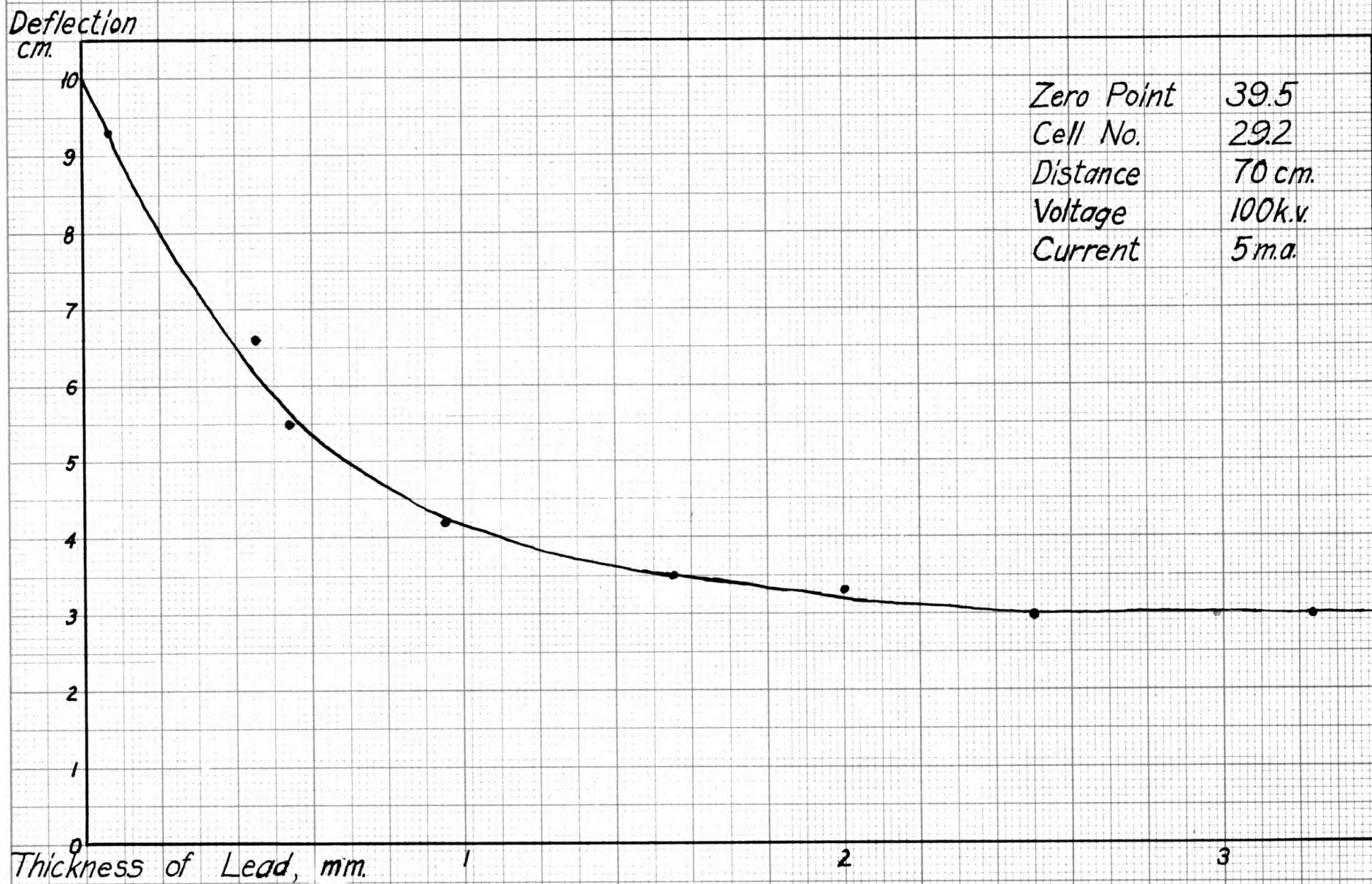


Fig. 9

**Figure 10**

**Penetration of X-rays through lead (cell L292).**



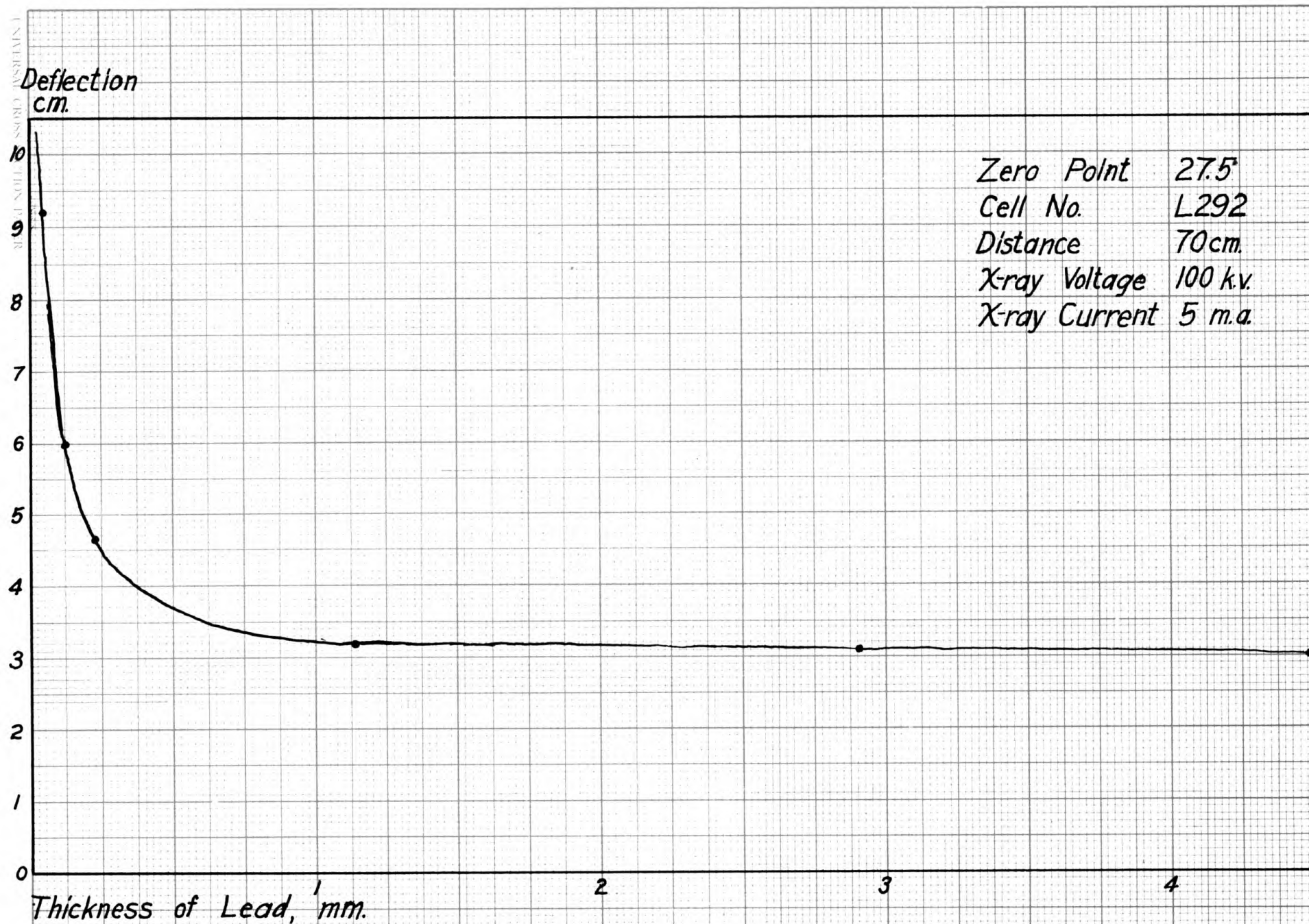


Fig. 10

## MEASUREMENTS OF THE RELATIVE INTENSITY OF THE VARIOUS LINES OF A SPECTRUM

Reference is given here to the lines photographed on a film by a mercury arc after its light had passed through a quartz prism. Their relative intensities will depend upon the ability of the various wave lengths produced to cause photographic fogging of the film.

This test demanded very accurate manipulation of the densitometer and the plates had to be developed exactly alike if any duplicate results were to be obtained. So much chance of error was encountered in developing the plates exactly alike that the tests made show only the relative densities of the most prominent lines in individual plates. With each trial the plates had to be placed with a certain spectral line directly behind a micrometer slit. This slit was about half as long as the line to be measured so error due to a slight change vertically was very small. The width of the micrometer slit was kept constant at one-fourth millimeter.

In order to insure constant illumination through the slit, the latter was kept stationary. The plate however could be moved back and forth until minimum deflection was obtained. This would indicate that the darkest portion of the line was directly behind the slit opening. Since the

darkest portion of the lines is their center it can be concluded that the line is directly behind the slit.

If a reading is to be repeated, the same position can be located by observing the deflection until a minimum is reached and this deflection recorded. Table 6 represents the results obtained from 16 lines of the spectrum. The number of the lines were photographed on the plate through a scale with transparent divisions. With each spectrum that was photographed this scale was photographed adjacent to it for an identification of the lines.

Table 6. Relative intensity of lines in ultra-violet spectrum.

Line number	Deflection mm.	
	Trial I	Trial II
27.4	70	70
25.2	17	17
26.4	32	32
27.9	48	47
28.7	58	57
29.0	201	201
29.5	25	24
30.0	23	23
31.0	15	14
33.2	39	39
36.4	11	10
40.0	8	7
40.1	34	34
43.5	7	6
54.0	6	5
58.0	7	6
Plain film	790	790

The photographic plates were exposed for 2 seconds in the spectograph and placed in the developer for 1 minute. A current of 3.5 amperes supplied the illumination for the densitometer. This could be kept constant by means of a low ranged ammeter.

The range of the results show that for the more transparent lines the data could be repeated with more accuracy than with lines of greater density. No lines below a deflection of 17 indicate exactly the same deflection for the two trials while most all the lines of less density could be repeated with greater accuracy. In the case of line 29 which was the most transparent the data was repeated exactly. With the plain film the repetition was also exact.

Other films were examined which were exposed longer to the ultra-violet spectrum. The results from these indicate the same ranking but show a change in the relative densities. This might be explained on the basis of previous work conducted by Hurter and Driffield who found that an inversion point was obtained by some waves such as the red, sooner than that reached by shorter waves.

#### TESTING THE DENSITIES OF FILMS EXPOSED TO ULTRA-VIOLET LIGHT

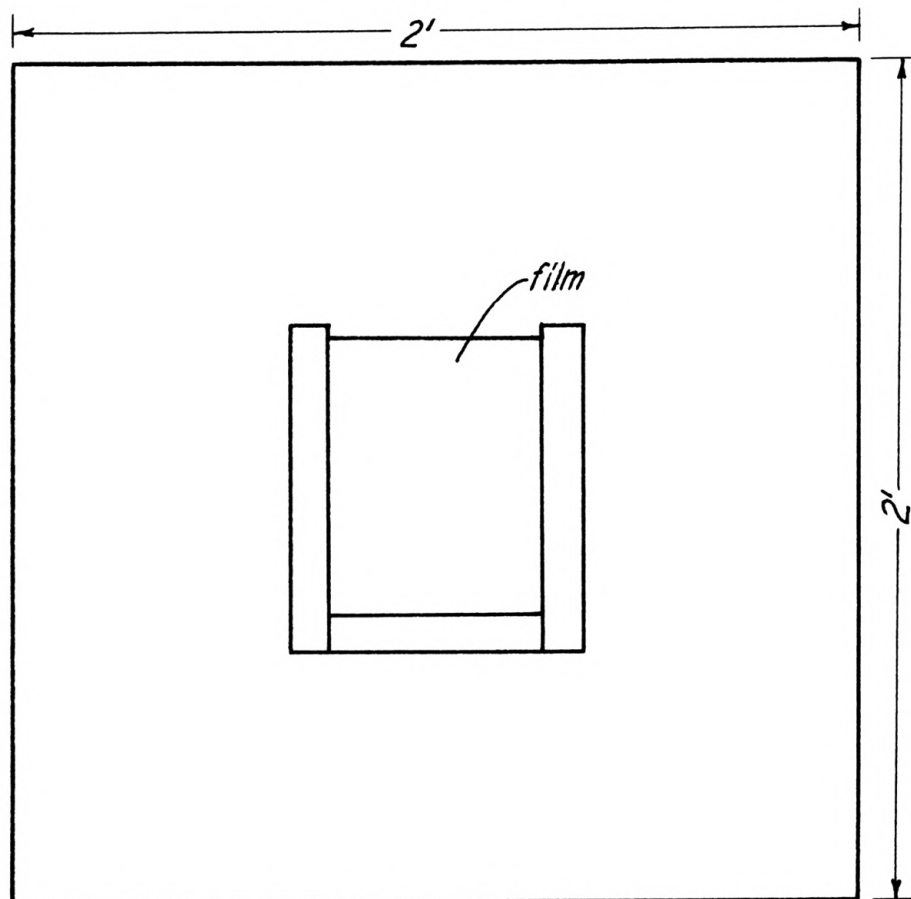
The transmission of light through a developed photographic film or plate can easily be determined by the densitometer. The film was placed against the photoelectric cell



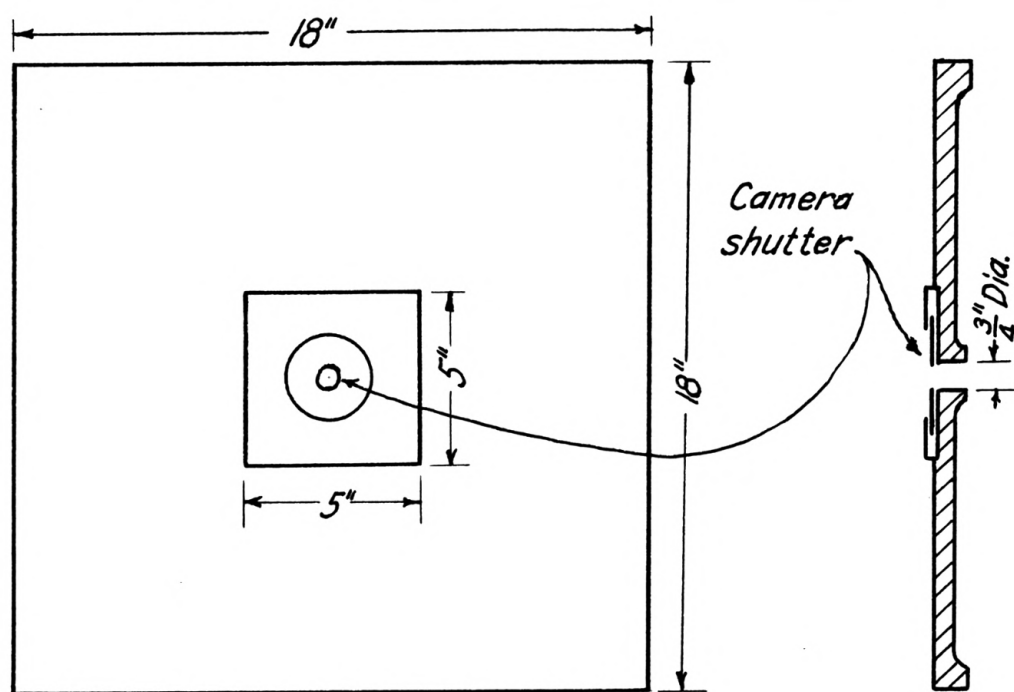
with the portion to be tested directly in line with the beam of light from the light source. It was held in position by holders. The micrometer screw made it possible to move it to various positions desired.

If the films are too dense and only a small amount of light is transmitted the deflection will be too small to show a reasonable amount of accuracy. In this case the light source can be intensified by closing the rheostat and allowing more current through the filament. If there is a resistance in series with the galvanometer this may be reduced in order to produce a greater deflection.

By means of an especially constructed apparatus 35 circular exposures could be made on a 5"x7" film plate. The essential parts of the apparatus are shown in Figure 11. Part (a) is a square board 2'x2' with guides to hold the film. Part (b) is a smaller board  $1\frac{1}{2}' \times 1\frac{1}{2}'$  raised by means of edge strips so as to clear the film. These edge strips are faced on the lower side with black felt to prevent any light from entering around the edges. This part can move over part (a) and allow the opening O to expose any portion of the film. The opening O is three-fourths of an inch in diameter and is closed by means of a camera shutter S which has a constant shutter opening of three-fourths of an inch. In order to prevent lapping of exposures the apparatus was checked off by means of horizontal lines. By keeping (b)



(A) Film Holder



(B) Shutter

Fig. 11. Apparatus for exposing the films.



stationary and moving (a) or by keeping (a) stationary and moving (b) with reference to the horizontal lines regularly spaced exposures can be made.

When exposures are made close up to the light, part (b) is kept stationary. This keeps the position of the opening constant in relation to the light. This however is not necessary when exposures are made at longer distances since the light will have approximately the same intensity for a small change of lateral position.

The shutter S taken from a camera will produce the following intervals:  $1/100$ ,  $1/75$ ,  $1/50$ ,  $1/25$ ,  $1/10$ ,  $1/5$ ,  $1/2$ , and 1 second. If longer intervals for exposure are desired a stop watch may be used.

Exposures were made with both the filtered and unfiltered mercury arc at 115 volts and in each case both the interval of time and the distance were varied. These negatives were developed as nearly the same as possible and each exposed section tested with the densitometer for its ability to transmit light. Table 7 shows the results obtained in three particular instances. Figures 12, 13, and 14 are the curves of the results where time of exposure is plotted against deflection.

In general the results obtained by using the mercury arc are similar to those obtained by Hurter and Driffield when light similar to sunlight was used. According to

Table 7. Relation between the time a film is exposed to ultra-violet light, and its density.

Light 60 inches from film :			Light 26 feet from film		
:Deflection:Deflection:			:Deflection:		
Time : (mm.)	: (mm.)	:	: (mm.)	:Log of	
25th of:without	:with	:Time	:without	:deflection	
a sec. :filter	:filter	:(sec.):	:filter	: (mm.)	
1/4	220	38	1/100	188	2.2741
1/3	107	15	1/75	191	2.2810
1/2	78	17	1/50	190	2.2787
1	30	12	1/25	168	2.2253
2	15	10	1/10	178	2.2504
3	34	11	1/5	78	1.8921
4	17	11	1/2	78	1.8921
5	10	9	1	85	1.9294
6	8	11	2	100	2.0000
7	7	16	3	89	1.9493
8	19	13	4	64	1.8062
9	10	12	5	77	1.8865
10	10	12	6	86	1.9345
11	10	14	7	86	1.9345
12	10	15	8	83	1.9191
13	19	15	9	53	1.7243
14	9	16	10	58	1.7634
15	9	15	11	60	1.7781
16	12	17	12	60	1.7781
17	17	15	13	56	1.7482
18	14	14	14	48	1.6812
19	12	16	15	44	1.6434
20	15	17	16	50	1.6989
21	20	18	17	65	1.8129
22	27	12	18	64	1.8062
23	26	12	19	56	1.7482
24	26	16	20	45	1.6532
25	25	16	21	48	1.6812
26	32	18	22	60	1.7781
			23	67	1.8261
			30	62	1.7924
			60	72	1.8573
			120	71	1.8512
			180	77	1.8865
			240	100	2.0000

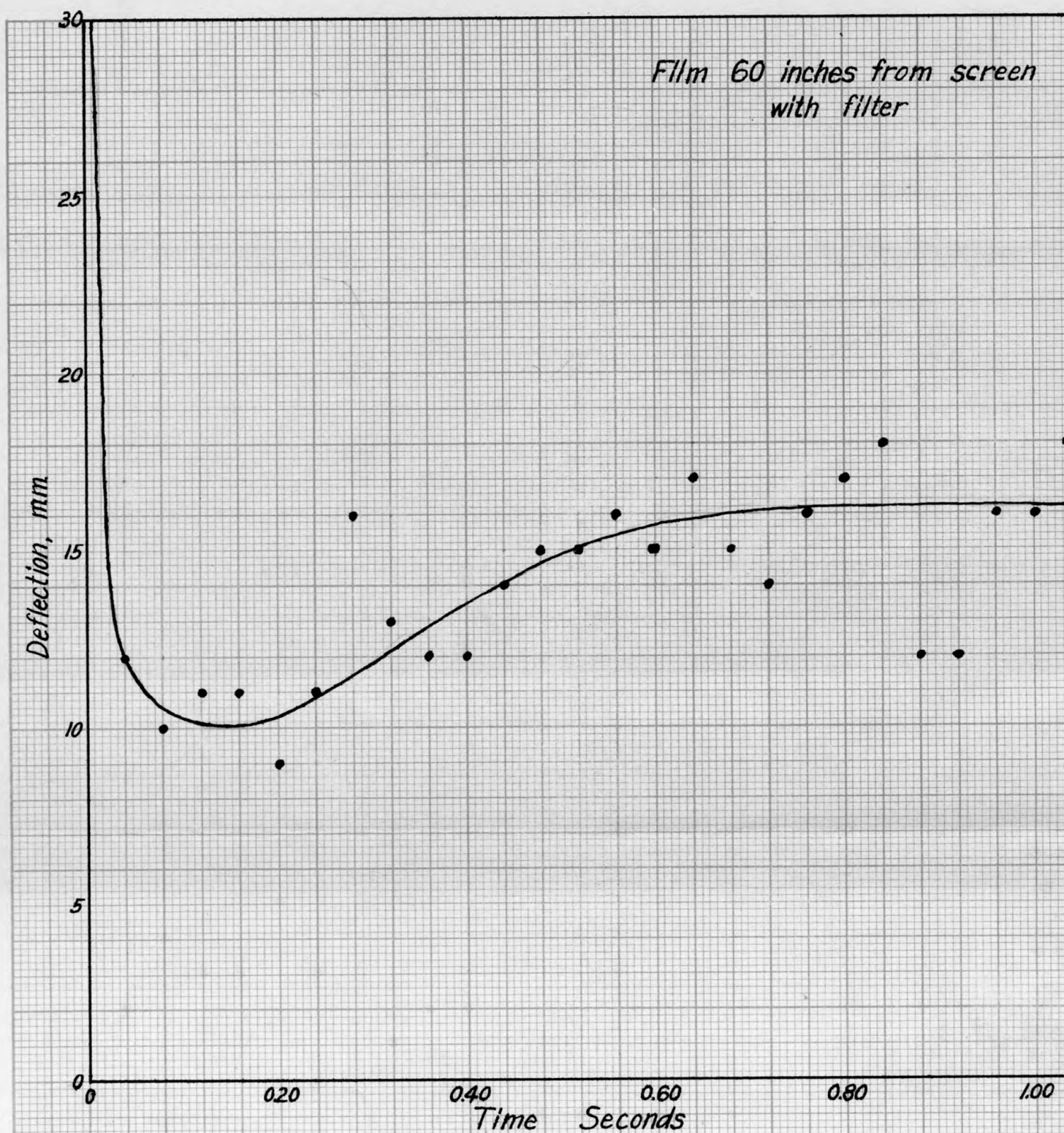


Fig. 12. Relative densities of films exposed to filtered mercury arc lamp.



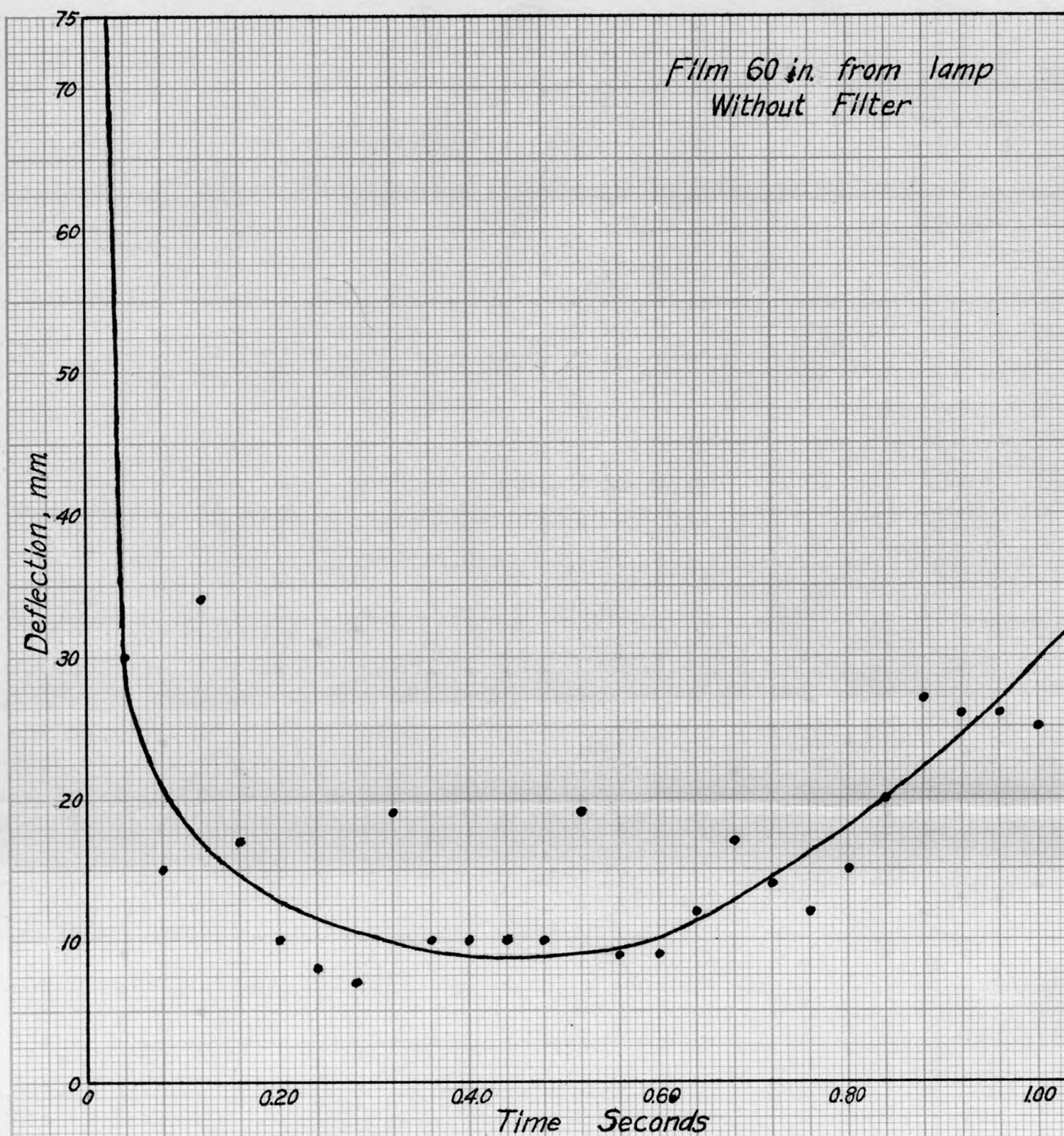


Fig. 13. Relative densities of films exposed to un-filtered mercury arc lamp (60 inches).

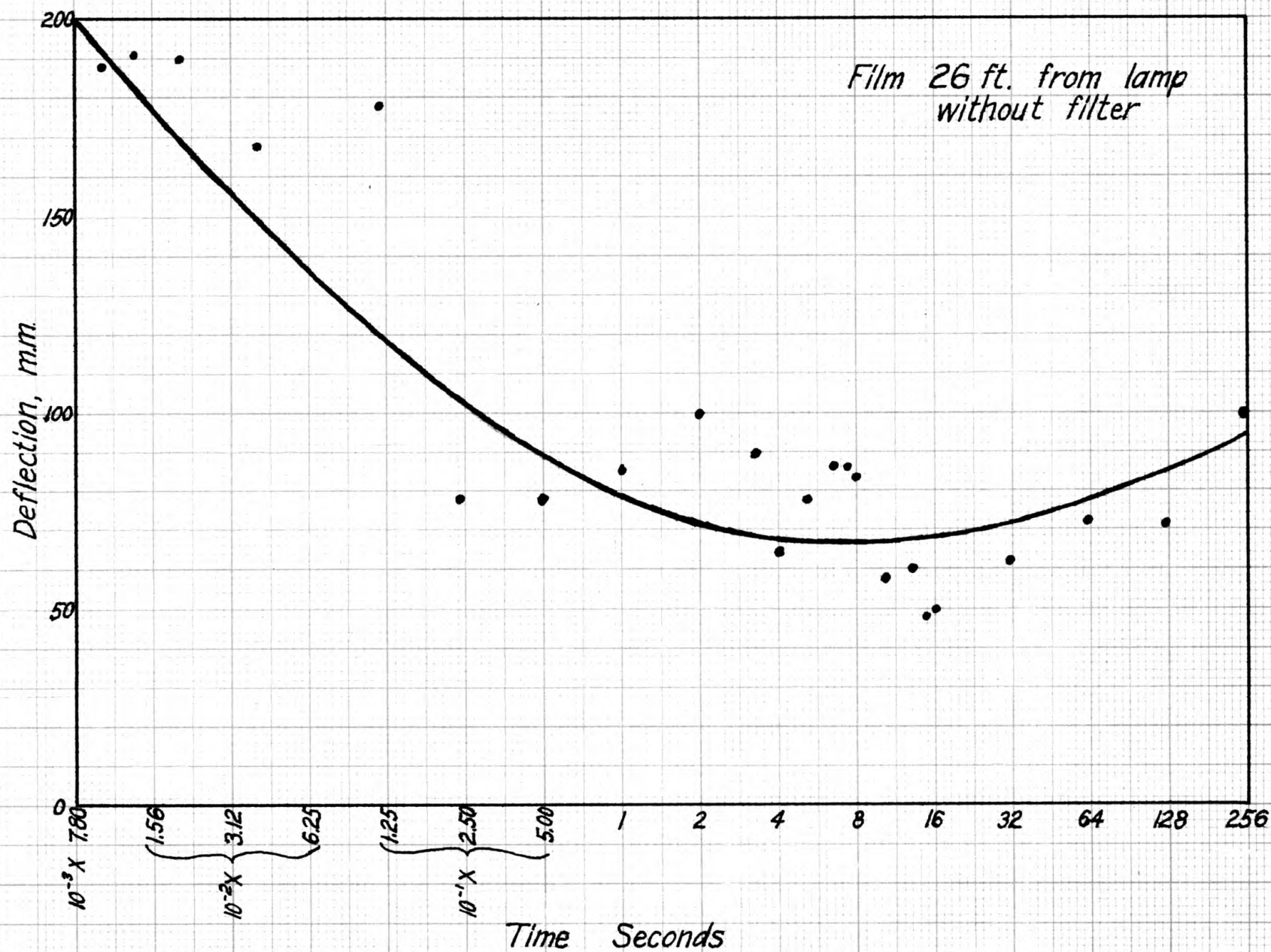


Fig. 14 (a). Relative densities of films exposed to unfiltered mercury arc lamp (26 feet).



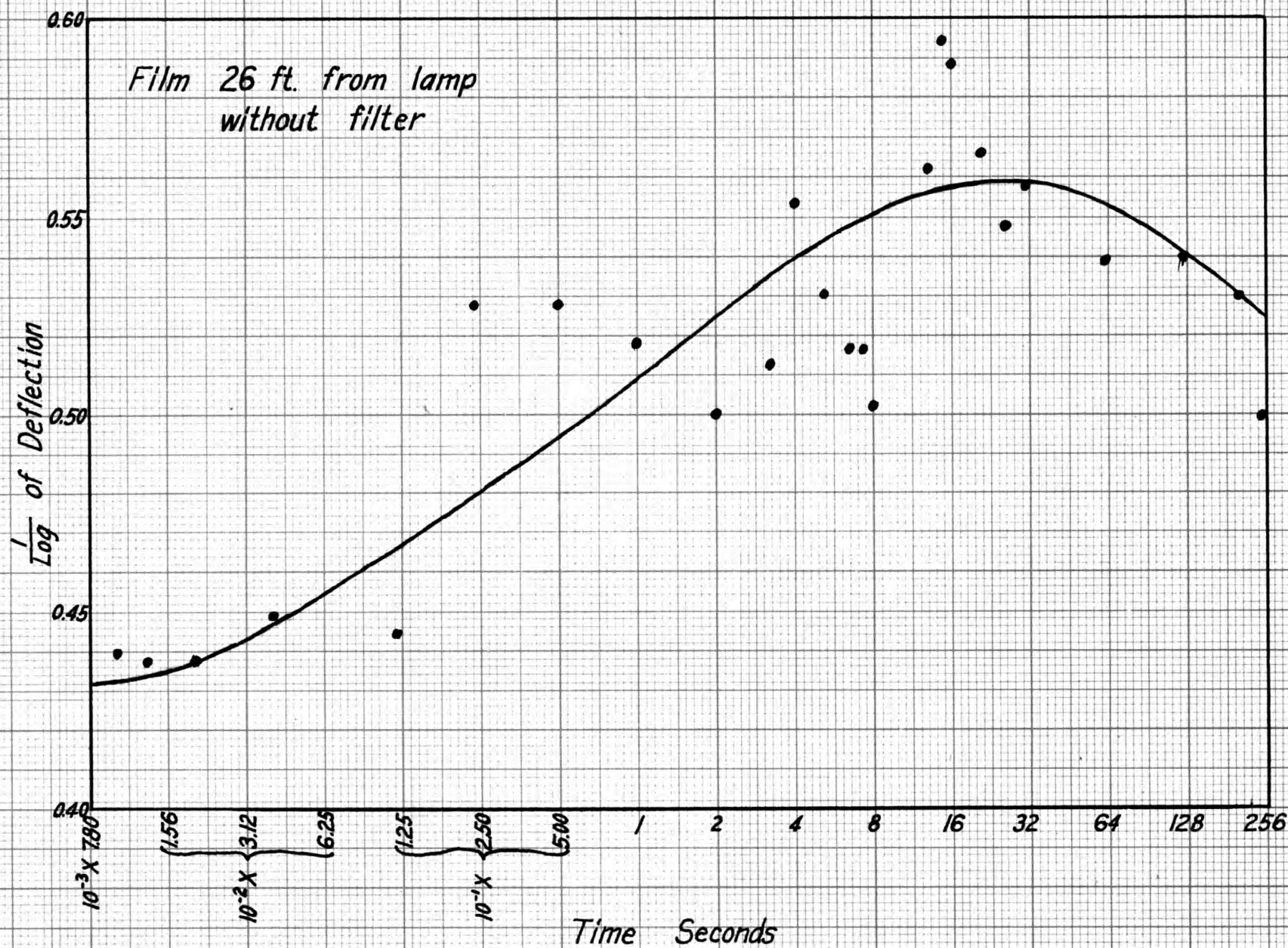


Fig. 14 (b). A "characteristic curve" for mercury arc light.



Derr (3) when the effect of increasing exposure is studied, it is seen that beyond a certain point, varying with the kind of plate used, increase of exposure fails to bring an increase of density. This point shows a period of over-exposure, which may be continued to the point where increase of exposure absolutely fails to produce further increase of density. If the exposure is still further increased, a reversal of the preceding action takes place, and the action of the light is to produce less photographic reaction, so that the image is weaker than before; and thus may be continued to the point of complete reversal, the plate developing as a positive instead of a negative.

In the test made with the filtered light, where only the ultra-violet light was allowed to strike the film, the reversal came at about one-half of a second. In this test as in most all tests observed, the fogging of the film was very rapid at first up to about one-fifth of a second and from here on the fogging was slow. Figure 12 shows the curve with time of exposure plotted against deflection.

A similar test to the one above was made but this time without the filter. In this case the reversal was reached at about one-fifth of a second as shown in Figure 13. In this case the trough of reversal is more abrupt than when the screen was used. The condition of a positive is reached much sooner also.

Figure 14 (a) shows the results obtained when the film was exposed at a distance of 26 feet. In this case the reversal comes at about 6 seconds which would be expected from the law of inverse squares. Figure 14 (b) is taken from the same data as (a) but here the logarithmic coefficient of absorption is plotted against time of exposure. This curve is similar to that of Figure 1 obtained by Hurter and Driffield and called the "characteristic curve."

According to Neblette (7) no photographic process is, strictly speaking, free from the effects of reversal, but rapid gelatine bromide plates are more subject to the effect than a comparatively insensitive plate such as wet colodium. It has been determined that atmospheric oxidation is probably necessary for reversal but reducing agents either prevent it altogether or retard its appearance.

#### OTHER SUGGESTED TESTS

The densitometer of this type can be used in photographic printing to determine the amount of time a print should be exposed through the negative. One good print taken from a certain negative under observed conditions is used as the basis. Some region of the film such as the average transparent portion is studied with the densitometer. The deflection is recorded and the time of exposure for printing compared with it. Now by means of comparing other

negatives with this one by measuring some of their average transparent portions, the time of exposure for printing can be calculated. This ought to be a solution to economy in printing as well as better prints.

Density and absorption of different kinds of glass such as frosted glass, glass of different colors and glass of different chemical compositions.

Absorption coefficient of textiles, showing the change due to colors and kinds of material.

Stoppage of light due to piling of several thicknesses of a transparent substance and making a comparison to the stoppage of light through the same thickness of material but only one piece.

Penetrating power of X-rays under varying voltages and currents.

#### SUMMARY

Some precautions must be taken in using the densitometer if the results are to show the lowest possible error. It must employ a constant current for its light source, and a current which is easily and accurately controlled. All radiation must strike the same portion of the cell so as to eliminate error due to any possible nonuniformity of its sensitive surface. A fairly sensitive and dead-beat galvanometer must be used in order that the de-

flection mirror may come to "rest" before fatigue or change in current can occur. In order to obtain the most accurate results, the temperature should not show too great a variation during the test, nor should any foreign light be admitted.

The photoelectric densitometer which employs a dry photoelectric cell such as the Weston type is dependable because it will deliver similar responses when a repetition under similar conditions is made. Allowing it to remain at rest for a few moments will bring it back to its sensitive state.

It was found that the intensity of the sunlight through blue cellophane was greater than the intensity through either red or green. Yet red absorbed more of the light than green. The intensity of illumination through two layers of the colored media was more than half of the intensity through one layer. This shows that the first layer absorbed most of the wave lengths except those of its own color, while it transmitted those which could easily be transmitted through the second layer.

This type of densitometer presents a unique method to detect the slightest change in density of a solution. In the measurements made in this work, it was found that when a slight change occurred in a Putman dye solution, due to bleaching or dilution, the densitometer indicated a reasonable change in deflection. It has been found that this



densitometer can detect a dilution of Putman dye of one part in two hundred million while the eye can detect one part in thirteen thousand.

When X-rays fall on the densitometer cell, the galvanometer shows a reasonable deflection. This fact indicates that the cell is responsive to forms of radiant energy other than light. Since this response cannot be literally called photoelectric, it might be classified as radiant intensity response. However, the electrical results produced in the cell are the same as those produced by visible radiation. This gives a new way to determine the penetrating power of X-rays. It is found that when any metal placed over the cell is increased in thickness the response of the cell decreases.

The density of the lines in the ultra-violet spectrum plate shows a corresponding relationship. Each line has its distinctive density if the plate can be exactly duplicated. A longer exposure will produce denser lines but will not change the corresponding densities of them. The photoelectric densitometer presents a rapid and accurate way to measure the densities of all kinds of photographic films. The inversion curve for films exposed to different kinds of radiation can be directly obtained by the densitometer method. It is found that for ultra-violet radiation there are two cycles in the density of the silver salts on the

film.

It might be stated in conclusion that there is a wide range of tests which can be made by the photoelectric densitometer. Suggested and possible tests are very numerous and some are problems which would reveal a quantity of information, present many ideas of research and reveal hidden facts concerning modern theories of light.

#### ACKNOWLEDGMENTS

The author expresses his appreciation to Professor E. K. Chapin, his major instructor, for his instruction and guidance in this work. The author is also indebted to Professor J. O. Hamilton and Karl Martinez for their assistance in photography for this work, and to Professor L. E. Hudiburg for his helpful suggestions in designing apparatus to make this work possible.



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