THEORY AND APPLICATIONS OF THE PHOTOELECTRIC CELL

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PREFACE

With all that recently has been said and written about the numerous spectacular and useful applications of photoelectric tubes, little has been written that will give the layman an elementary acquaintance and knowledge of the theory and applications of the photoelectric cell, which has finally come into its own. So it has been the aim of this thesis to give the layman the fundamental theories of photoelectric phenomena, and to show the unlimited possibilities of the photo-tube from a commercial viewpoint.

Campbell McCord

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THEORY AND APPLICATIONS OF THE PHOTOELECTRIC CELL

CHAPTER I

THEORY

Historical Introduction

Although the photoelectric cell is new to the world of applied physics, its underlying principles have been known for some forty years. And photoelectricity has been the subject of much investigation for a number of years.

The essential fact of photoelectricity is that when light falls upon a metal surface, electrons are emitted. The first investigator in the field, Heinrich Hertz, discovered quite by accident that a spark passed more readily between two electrodes when the electrodes were illuminated by a similar spark. Later, Hallwachs found that under the influence of light a negatively charged plate lost its charge. Succeeding investigators identified this loss of charge with the emission of electrons, and they established the conditions under which it takes place.

Fig. I shows the elements of a photoelectric tube. Light falls upon the metal cathode and causes it to emit electrons. The anode, having a positive potential, (due to the battery), attracts these electrons. This stream of electrons passing from cathode to anode constitutes an electric current, and this current is controlled by the light incident on the plate.

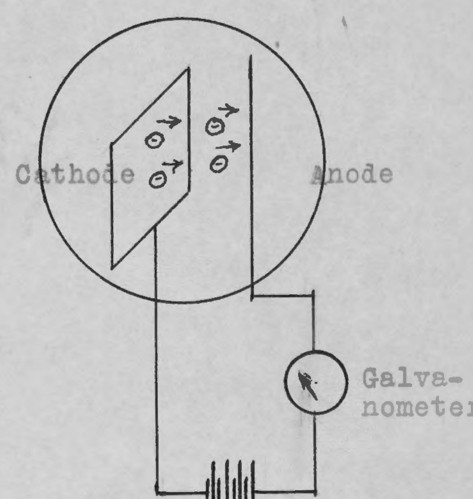
Fundamental Laws

There are three fundamental laws governing photoelectric action, all of them being empirical. They are:

1. The number of electrons released per unit time at a photoelectric surface is directly proportional to the intensity of the incident light.

2. The energy with which the photoelectron is emitted is a linear function of the frequency of the light producing it.

3. This energy is independent of the intensity of the light.

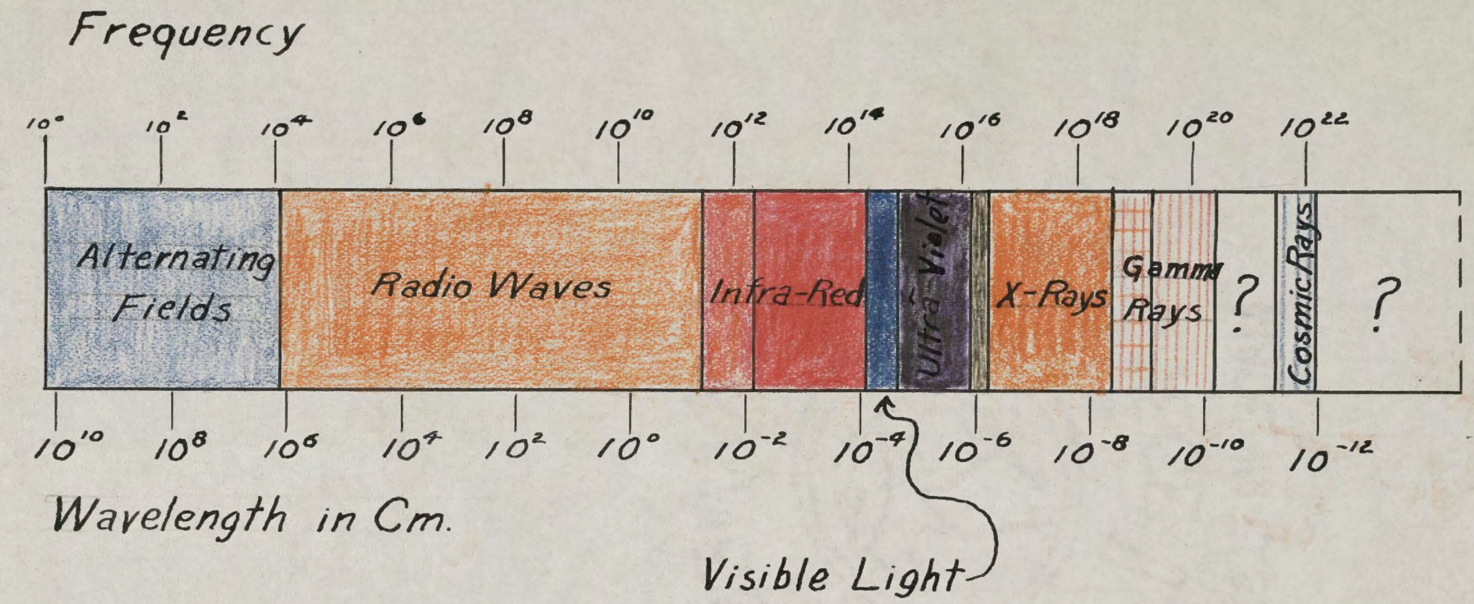


The Photoelectric Tube

Fig. 1

The first law is to be expected, but the last two laws are of a surprising nature. They imply that when the electrons are emitted they possess various velocities, but that there is a definite velocity which is determined by the greatest frequency of the radiation. And no matter how intense the same radiation may become, the highest velocity will not increase. When these three laws are considered together, one's conception of light may receive a jolt.

For this reason, it may be best to get a clear conception of the theory of light, and for that matter, of all radiant energy, before proceeding further.



SPECTRUM OF RADIANT ENERGY

Fig. 2

Radiant Energy

It is important for one to understand something of the spectrum of radiant energy before studying photoelectric phenomena. Radiant energy may be defined as that energy associated with electromagnetic oscillations propagated through space. These radiations have frequencies ranging from almost zero to very high values.

Fig. 2 shows the spectrum of radiant energy. It It will be noticed that some of the different types overlap. First there are the alternating fields. Then comes the radio waves. Next are the infra-red or heat rays. And in between the infra-red and the ultra-violet rays comes visible light. It will be noticed that visible light occupies a very small part of the spectrum of radiant energy. After ultra-violet, and in succession, follow X-rays, gamma rays, and cosmic rays, with a gap ~~a gap~~ in between the last two. The gamma rays are emitted by radioactive materials, while the cosmic rays are celestial oscillations.

The fundamental difference between any of these rays, so far as we know, is in their frequencies. For some reason, which has not been explained yet, this difference in frequency gives the radiant energy different properties.

To the scientist, it is no more wonderful that X-rays will pass through human flesh than it is that visible light will pass through glass; or that the eye is sensitive to certain frequencies known as those of visible light.

The Nature of Light

Newton's corpuscular theory of light explained radiation as a bombardment by minute particles projected at extremely high velocities, in much the same way as the alpha and beta rays are explained today. Now if this theory were right, then two equal beams of light , when superimposed, should always combine to a beam of twice the intensity. But this is not the case. The phenomenon of interference shows that two such beams may do anything from extinguishing themselves to giving a beam of twice the intensity. In other words, they add together in the same way that alternating currents add. That is, the addition depends upon the phase relation. Thus, this phenomena leads us to the wave theory of light.

If light is a wave motion, then there must be something to move. The hypothetical carrier of light has been called the ether. But let us go farther. The phenomenon of polarization shows that light is a transverse wave, that is, the ether atoms move at right angles to the light beams, and not in its direction. In such a transverse motion the ether atom neither approaches nor recedes from the next ether atom. And the only way in which one atom can propagate motion to the next atom is when there are forces acting between the atoms so as to hold them together in their relative positions.

Such bodies are solid bodies. So we might say that transverse waves can exist only in solid bodies. And since the velocity of light is very high, the forces between the ether atoms which transmit the vibrations must be correspondingly great. And consequently, we may say that the ether is a solid body of very high rigidity. At the same time, the ether must be of extremely high tenuity, since all cosmic bodies move through it without meeting any friction. In the revolution of the earth around the sun, either the ether stands still and the earth moves through it, or the earth carries a mass of ether with it. In either case, there would be frictional energy coming from the earth. Incidentally, no such evidence of ether friction has been observed. Which of these two alternatives should we take ?

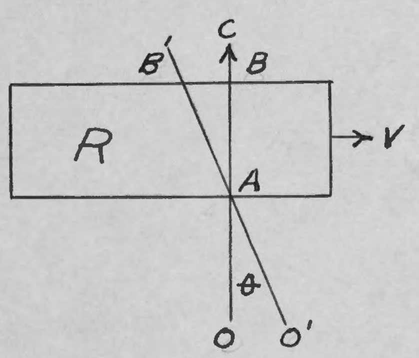


Fig. 3

Suppose R is a train moving at velocity v, and a rifle bullet is shot from O at a velocity c. It strikes the train at A and leaves at B. But while the bullet is going through the train, the point B' moves up to where B formerly was. Thus, for an observer on the train, the bullet would appear to move from A to B', and therefore come from O', from a direction farther forward by angle θ, where tan angle $\theta = \frac{v}{c}$.

Now, instead of the train consider the earth; and instead of the bullet, a beam of light from a fixed star. If the ether stands still, the beam of light would follow the path of OABC. And from the moving earth we could see the fixed star, not as it really is, at O, but at O'. A half year later, when the earth is moving in the opposite direction in its orbit, we would see the star deflected an equal amount in the opposite direction. And during the course of the year, the star would describe a small circle. This is exactly the case, and this phenomenon is called aberration. So we may conclude that the ether stands still and is not carried along by cosmic bodies.

But wait. If the ether stands still and the earth is moving through it, then the velocity of light should be (I80,000 - 20) miles per second when the earth is traveling in the same direction as the light, and the velocity should be (I80,000 + 20) miles per second when the earth is traveling in the opposite direction. If, however, the ether moves with the earth, the velocity of light should be the same in all directions. This is the case, and it has been amply proved by the now famous Michelson-Morley interferometer test. So we may conclude that the ether moves with the earth. This is the opposite conclusion from that given by aberration.

Thus, the conception of the ether is one of those untenable hypotheses which have been made in an attempt to explain some difficulty.

The more it is studied, the more contradictions we get. Lack of courage has kept us from openly abandoning the ether hypothesis. The belief in ether is contradictory to relativity, to theories concerning photoelectric phenomena, and to other theories concerning light. So we may finally say that there is no such thing as ether. Expressed in a more popular phrase, which seems to be meaningless, but is full of meaning, " Ether is nothing."

What, then, is the fallacy in the wave theory of light which led to the conception of ether. The logical error which led to the ether theory was the assumption that a wave must necessarily be a wave <u>motion</u>.

<u>The Einstein Equation and the Quantum Theory of Light</u>

The theory of light that conforms more nearly to facts established in photoelectricity is that known as the quantum theory. In this theory light is regarded as being a torrent of small corpuscles, each containing energy of the amount hf, where h is a constant known as Planck's constant, and f is the frequency of the light. It is self-evident that, if each quantum of light releases a photo-electron, then the photoelectric current will be proportional to the intensity of the light. An equally simple relation follows for the relation between the energy of the photo-electron and the frequency of the light.

The next great step in the theory of light was made by Einstein, for which he recieved the Noble Prize. It was known as the Einstein equation.

Einstein postulated that the whole of the energy of the quantum, hf, disappeared as radiant energy and reappeared as the energy of the photoelectron. Let p equal the work which the electron does in passing through the illuminated surfaces to the space outside. Then the kinetic energy of the electron in the space outside will be equal to the energy of the quantum (hf) minus the work the electron does in passing through the surface. That is,

$$\frac{1}{2} mv^2 = hf - p$$

This is known as the Einstein equation, and it is perhaps the most important single equation in the whole quantum theory.

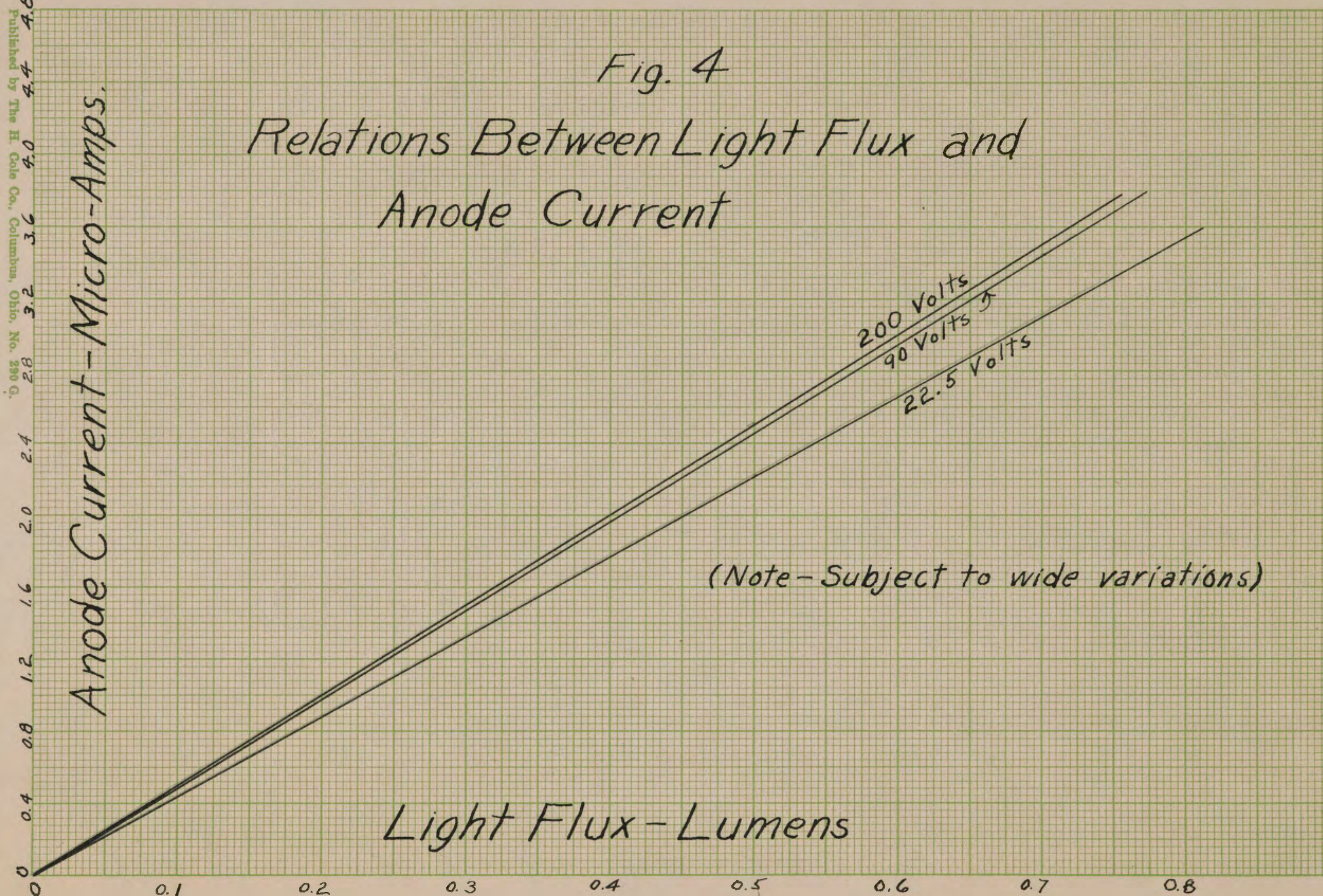


Fig. 4
Relations Between Light Flux and Anode Current

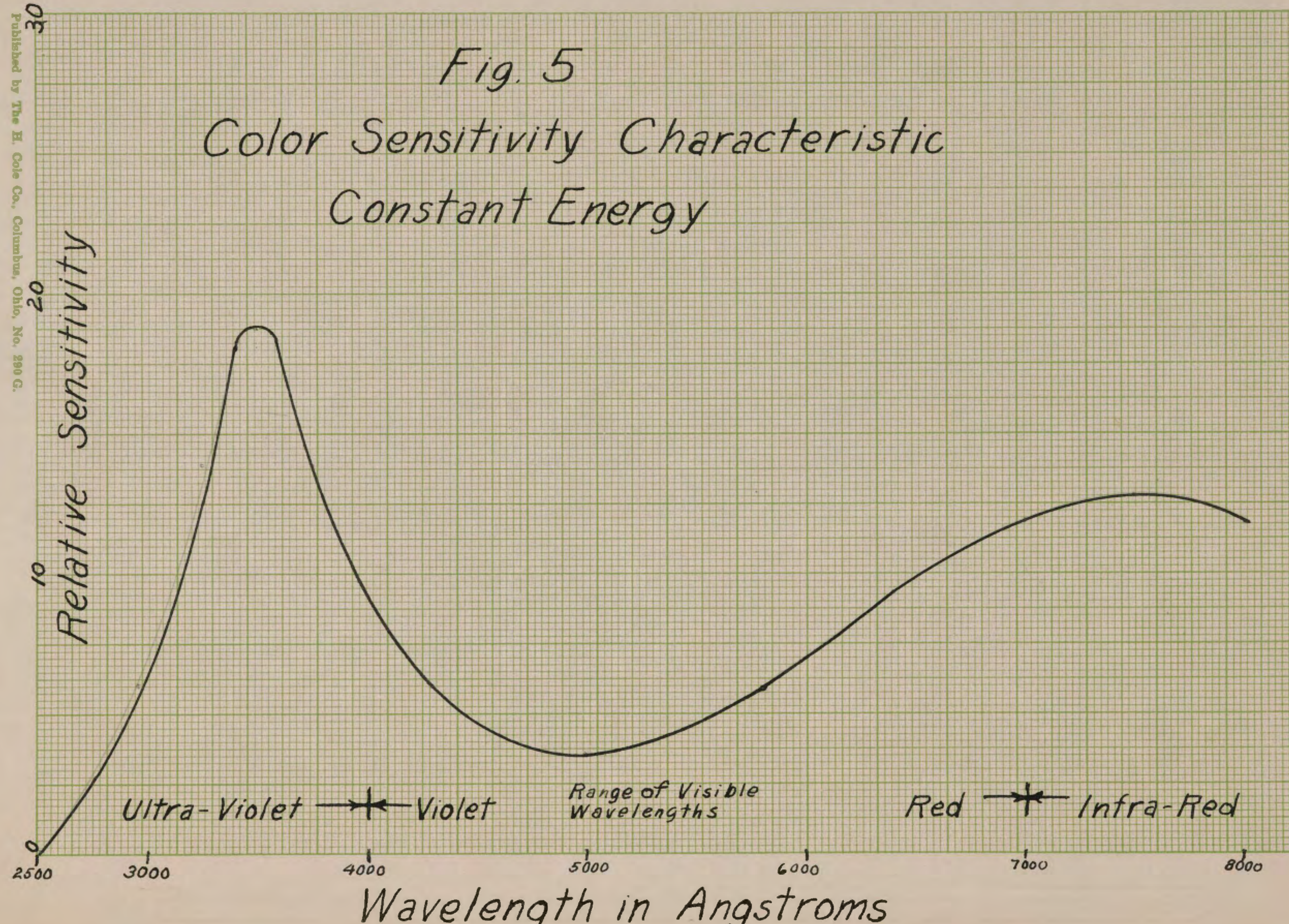


Fig. 5
Color Sensitivity Characteristic
Constant Energy
Relative Sensitivity
0
10
20
30
Ultra-Violet
Violet
Range of Visible Wavelengths
Red
Infra-Red
2500
3000
4000
5000
6000
7000
8000
Wavelength in Angstroms
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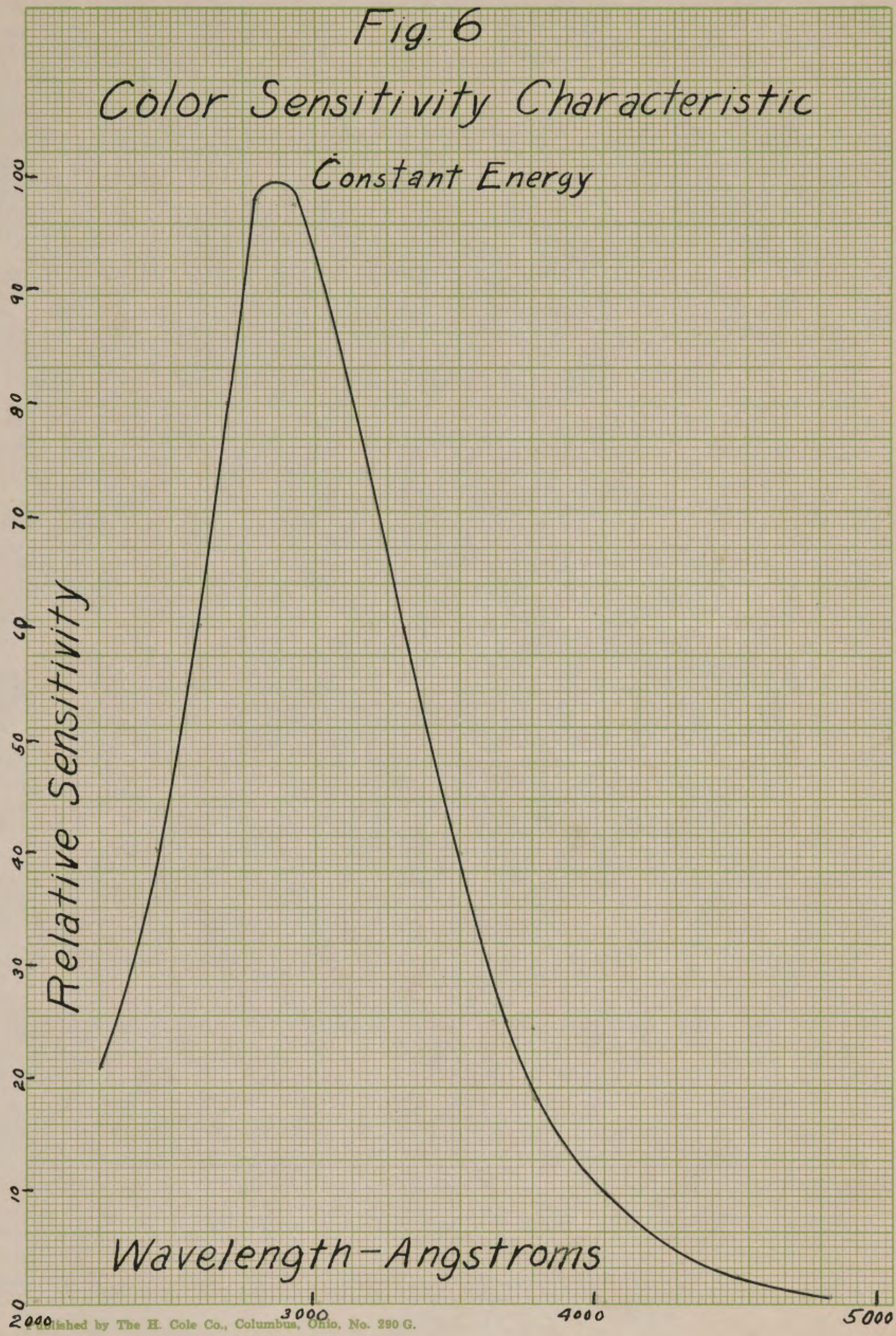
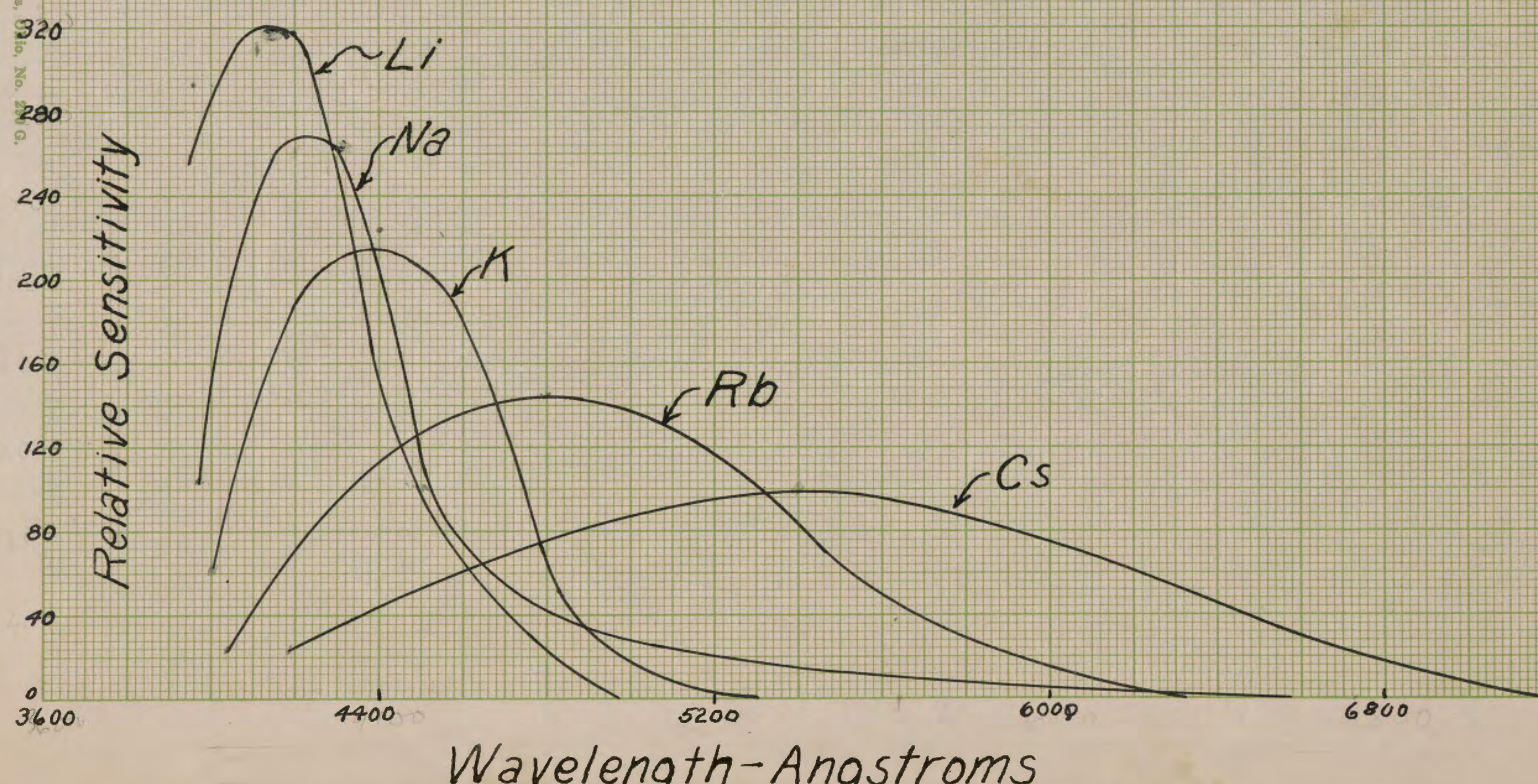


Fig. 6
Color Sensitivity Characteristic
Constant Energy
Relative Sensitivity
Wavelength-Angstroms
0
10
20
30
40
50
60
70
80
90
100
2000
3000
4000
5000
Published by The H. Cole Co., Columbus, Ohio, No. 290 G.

Fig. 7

Color Sensitivity Curves for the Alkali Metals

(Note - Curve for Lithium Is Drawn to 1/5 Scale)



Characteristic Curves

Figs. 4, 5, 6, and 7 are the most important characteristic curves of a photoelectric cell. Fig. 4 shows that the anode current is directly proportional to the light flux incident upon the cell. This agrees with the first law of photoelectricity.

Figs. 5 and 6 illustrate the second and third laws. They show that when the light flux is held constant, the sensitivity,(energy with which the photoelectron is emitted), of the tubes are a function of the frequency. It will be noticed that the maximum sensitivity is independent of the frequency. It depends upon what substance the cathode of the photocell is made of.

Another thing to be noticed is that the sensitivity of the two photo-tubes come to a somewhat abrupt end. This is easily explained by Einstein's equation:

$$\frac{1}{2} mv^2 = hf - p$$

Let f have a value $f = \frac{p}{h}$, then substituting this in the Einstein equation:

$$h\frac{p}{h} - p = 0 = \frac{1}{2} mv^2$$

In other words, when the frequency is given a certain value, the kinetic energy with which the electron is released is just equal to zero, and there will be no photoelectric current. Below this frequency there will be no photoelectric effect at all.

This an important characteristic of any photoelectric cell, and the frequency f_0 is called the threshold frequency. In Fig. 5 the threshold frequency is 8000 angstroms.

Fig. 7 shows the sensitivity ranges of the alkali metals generally used in the photocell, the peaks of these curves appearing the same order as their respective elements appear in the periodic table.

By coating the cathode with the proper elements, the photocell can be made to have a sensitivity curve of almost any desired kind.

The simplest characteristic of a photocell is its volt-ampere characteristics. Fig. 8 shows a family of such curves taken under different conditions of illumination. As the voltage is increased under constant illumination, the current increases gradually to a saturation value, beyond which further increases in voltage cannot increase the current. The saturation current represents the condition where all of the electrons being liberated by the light are being collected by the anode. Increasing the voltage will not increase the current, because there are no more electrons to be caught.

If the light intensity is increased, a new saturation current is obtained at a slightly higher voltage. For most tubes, the saturation current is reached at voltages of less than I00. In order to get a response proportional to the illumination, the photocell should be operated above the knee of its volt-ampere curve.

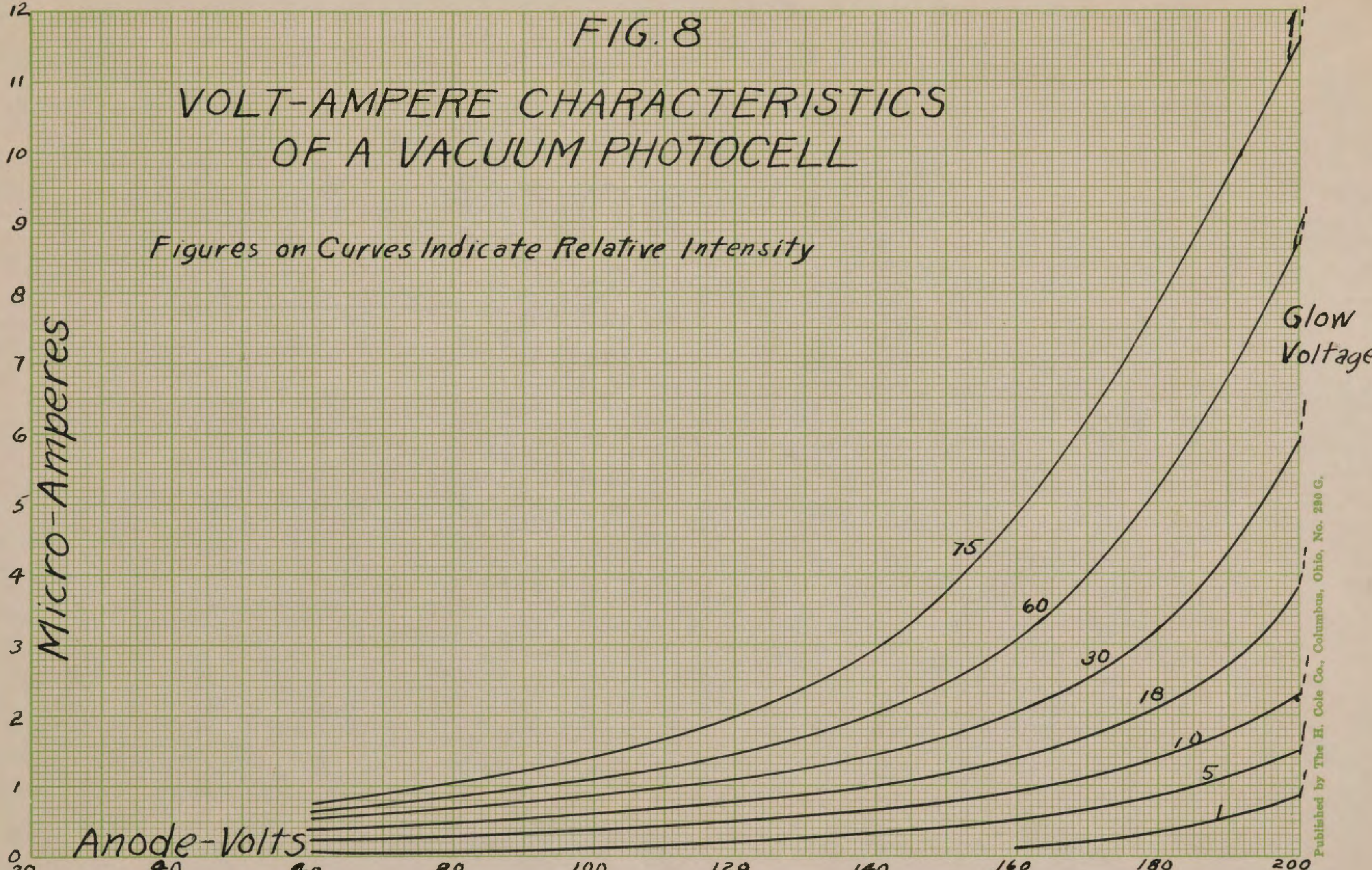
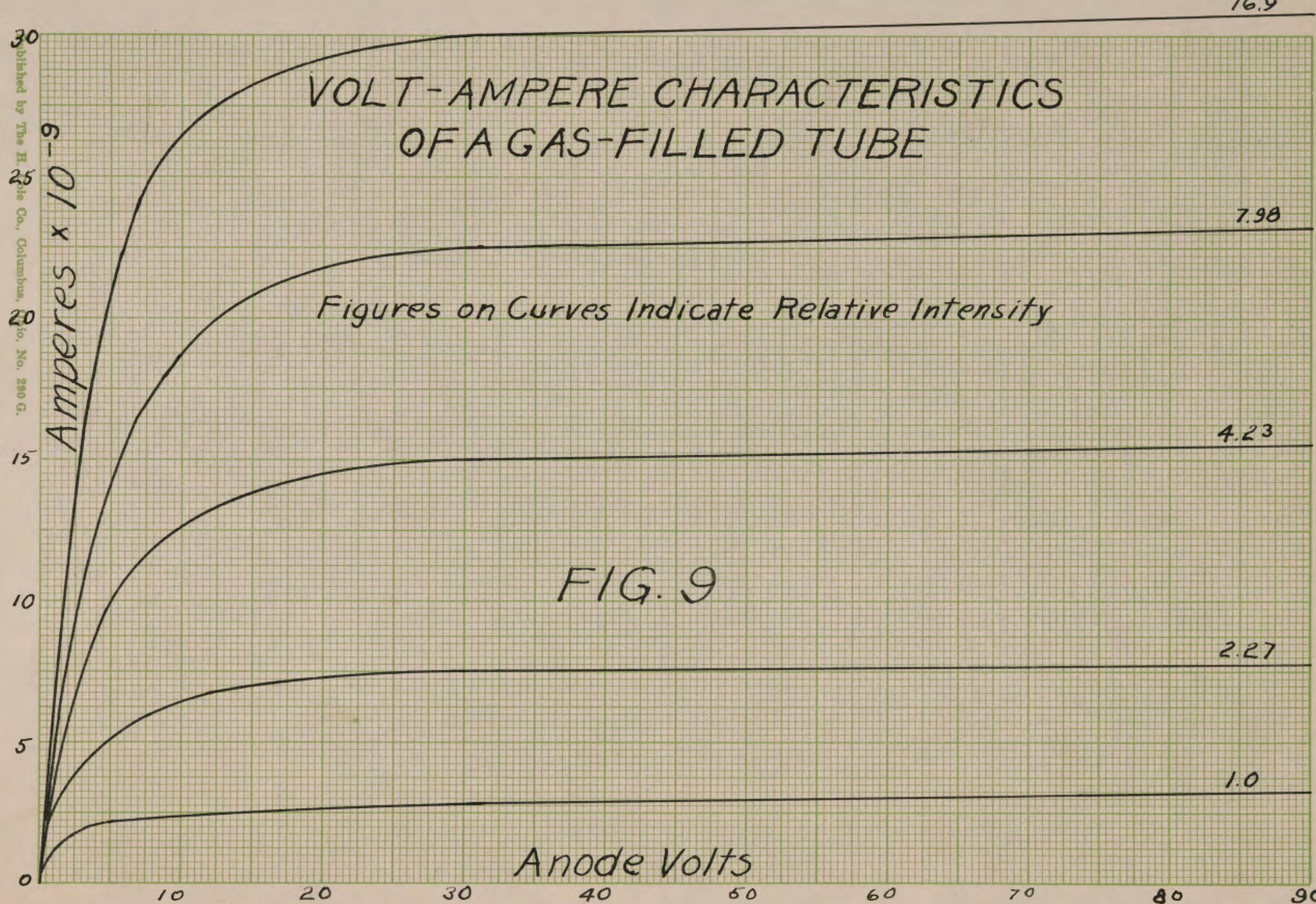


FIG. 8
VOLT-AMPERE CHARACTERISTICS
OF A VACUUM PHOTOCELL
Figures on Curves Indicate Relative Intensity
Micro-Amperes
Anode-Volts
Glow
Voltage
75
60
30
18
10
5
1
0
1
2
3
4
5
6
7
8
9
10
11
12
20
40
60
80
100
120
140
160
180
200


VOLT-AMPERE CHARACTERISTICS
OF A GAS-FILLED TUBE
Figures on Curves Indicate Relative Intensity
FIG. 9
Amperes x 10^{-9}
Anode Volts
16.9
7.98
4.23
2.27
1.0
0
5
10
15
20
25
30
10
20
30
40
50
60
70
80
90

Vacumn and Gas-Filled Tubes

If a little gas is added to a photo-tube, its characteristics are changed radically. The current no longer saturates, but continued to increase as the voltage is increased. This is due to the collisions between the electrons and the gas molecules. When electrons strike gas molecules they break the gas molecules up into electrons and positive ions. This is in effect an increase in current.

The advantage in introducing gas into a phototube, is that the current is greatly increased, sometimes as much as ten-fold. The choice of gases is very limited, as a gas has to be selected which will not react with the cathode material. For this reason, rare gases are used. And argon perhaps is used the most.

Fig. 9 shows the volt-ampere characteristics of a gas-filled tube.

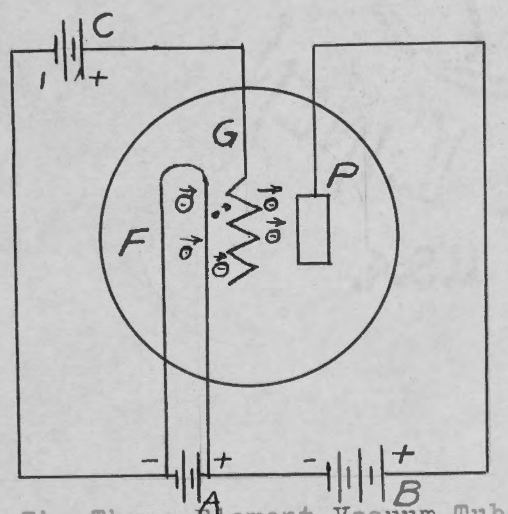
Time Lag

The time required for photoelectric response is extremely small. Measurements have been made which show that the current begins to flow within less than 10^{-9} seconds of the time that the light falls on the cathode. Consequently, vacuum-type tubes give a current which reproduces faithfully any variations in light intensity, with no lag other than that due to the inductance and capacity of the electrical circuit. In gas-filled tubes, there is a slight time lag, this lag increasing with the frequency. At a few hundred cycles this lag is negligible, but at very high frequencies it is quite appreciable. Therefore, the vacuum-type tube is better suited in devices where dynamic response is important.

Amplification

The current set up in the photo-tube alone is so small that there are very few practical applications of the photo-tube which do not involve amplifiers. Some uses, such as that of the talking movies, require that the photocell current be amplified as much as two billion times. To do this, the radio tube has been employed in exactly the same manner as in a radio set.

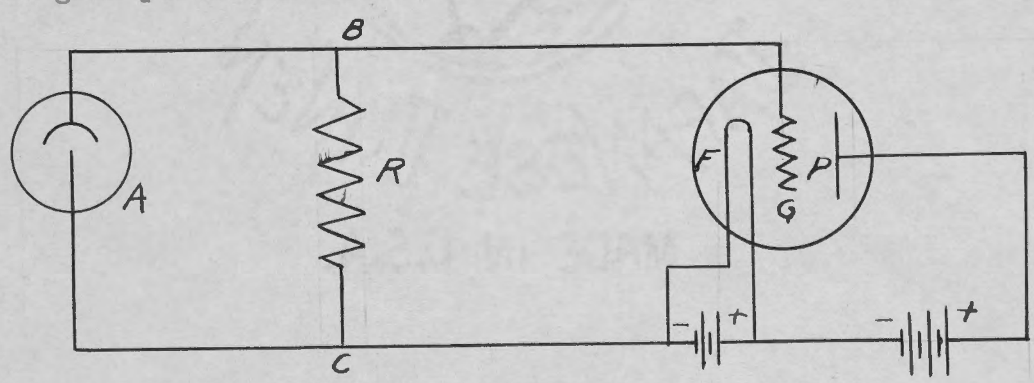
Fig. 10 is a diagram of the three element radio tube. The filament, F, is heated by the battery, A, and electrons are emitted from the filament. Now the plate, P, is maintained at a positive potential through virtue of the battery, B. And since the electrons have a negative charge, they are attracted by the positive plate. As long as the charge on the grid remains positive, the flow of electrons (current) will be a function of the temperature of the filament. If the temperature of the filament is raised high enough, there will be so many electrons in the immediate vicinity of the filament that their combined negative charge will repel any other electrons that try to leave the filament.



The Three Element Vacuum Tube
Fig. 10

This is commonly called space charge. And it means that there is a maximum flow of electrons that can be set up in any given two element tube.

But there are three elements in the tube shown in the figure. And it so happens that if the charge on the third element, the grid, is changed the least bit, the current flowing in the plate circuit will be changed greatly. Suppose the grid is positive with respect to the filament. Then the space charge will be reduced, because the positive grid will help to pull the electrons away from the filament, and send them on their way to the plate. On the other hand, if the grid is given a sufficient negative bias, the flow of electrone will be stopped entirely. Thus, it is seen that the plate current can be controlled much more readily by varying the grid potential.



Resistance Coupled D. C. Amplifier

Fig. 11

Fig. 11 shows what is probably the simplest type of amplifier. It is called the resistance coupled D. C. amplifier. A small current is set up in the photocell circuit ABC. The resistance R is arbitrarily made very high, say IO megohms. This resistance is small compared with the internal resistance of the photo-tube, so it does not appreciably affect the photo current. If a voltmeter were placed across BC, it would measure the IR drop across the resistance. And since the resistance has been made high the drop will be relatively great.

It will be noticed that this drop is applied across the filament and grid of the radio tube. Thus, if the photo current is increased, the IR drop will be increased, and this drop applied to the radio tube, will increase or decrease the plate current (according to which end of the resistance has been connected to the radio tube). If a varying current has been set up in the photo-tube circuit, a somewhat corresponding current, but of much greater amplitude, will be set up in the radio tube. In order to make the response of the plate circuit proportional to the photo current, a potentiometer would have to be placed in the plate circuit. And this potentiometer would have to be adjusted so that when the photo-tube is dark, the plate current would just be reduced to zero.

There are many other types of amplifiers used in practice, but since the subject is outside the scope of this book the writer will let it be suffice to show the fundamental principle of the radio amplifier.

In passing, it may be mentioned that transformer coupling is used mostly in alternating current circuits, because an additional amplification (ranging from 2 to 6) can be obtained through the transformer alone.

CHAPTER II

APPLICATIONS

Sound Movies

The most important application of the photocell, from a commercial viewpoint, is that of producing audible motion pictures. Today, this new industry has almost replaced the silent screen. Some success has been attained by a scheme of projection in which the sound effects are picked up electrically from a phonograph record which is synchronized with the picture sequence. But this method requires the attention of a skilled operator, and may at times become faulty.

The best method is that which makes the use of the photocell. In this method, the sound is reproduced from the film itself, and it is therefore impossible for the sound to get "out of step". There are two distinct types of sound tracks which are used on the films, namely, the variable density and the variable area type. These two types are illustrated in Fig. I2. Fortunately, the same scheme of photoelectric reproduction will serve equally well with either type of sound track.

Fig. I3 illustrates the method used in reproducing the sound. The source of light is from a tungsten filament, and the intensity of the light is held constant. The condensing lens forms an intense rectangle of light upon the narrow slit

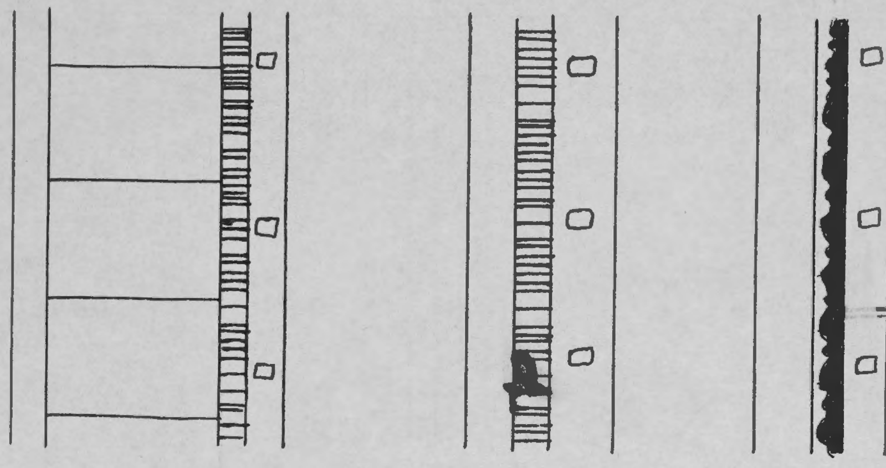


Fig. 12

Portions of Film Illustrating Sound Track of the Variable Density (Left) and Variable Area (Right) Types.

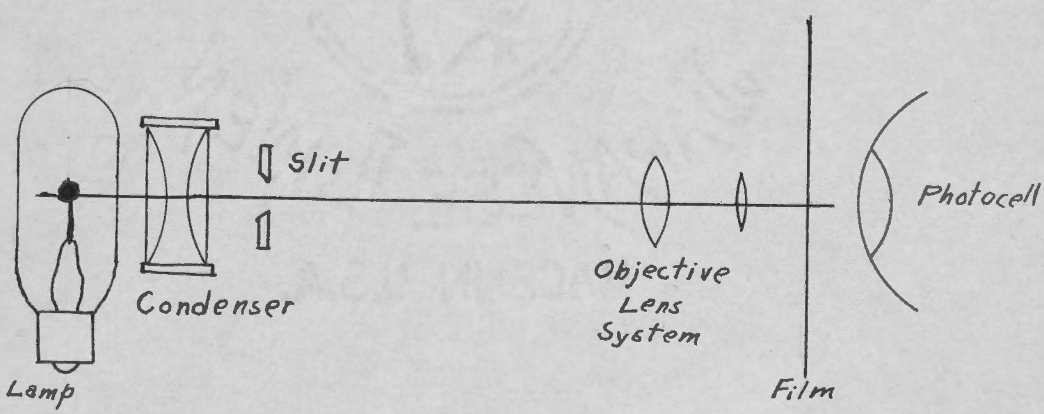


Fig. 13

A Practical Optical System for Reproduction of Sound from Film.

which is placed in the path of the light beam. Although very narrow, the slit is not so narrow that it will produce diffraction. Next, the beam of light passes through a second condensing system which focuses upon the sound track a reduced image of the slit. Now, the quantity of light passing through the sound track of the film will be inversely proportional to the density (or shaded area, as the case may be) of the film at each particular point. Thus, the amount of light that reaches the pho photocell is regulated by the sound track upon the film. And since the current set up in the photocell circuit is proportional to the intensity of the incident light, this current is controlled by the sound track on the film. And lastly, this current is passed through a loud speaker which reproduces the sound by the same manner in which a telephone operates.

The proper width of the narrow beam of light will depend uppn the highest audible frequency that is to be reproduced..Let us assume that frequencies up to 5000 cycles are to be reproduced. And also that the speed of the film is to be I8 inches per second. Then the length of the shortest wave on the track will be $\frac{I8}{5000}$ = 0.0036". If such short modulations are to appear in the photocell circuit, the width of the beam of light must not be more than a small fraction of 0.0036". As a compromise between fidelity and intensity 0.00I" has been adopted as the accepted width.

With such a small rectangle of light playing upon the photocell, the actual current set up in the cell is so small that the power is only about 0.01 microwatt. It requires about 20 watts to operate the average loud speaker in a theater. Therefore, the photocell current must be amplified 2,000,000,000 times before it can operate the loud speaker. And too, the amplification must be linear over a range of frequencies from about 50 to 8000 cycles.

This amplification is usually accomplished by transformer coupling, in much the same manner as in a radio set. For that reason, and for lack of space, the different amplifying circuits will not be dealt with in this book.

Facsimile Transmission

There are two different methods of facsimile transmission. In one method a diaphanous replica of the picture (or subject) to be transmitted must first be made. In transmitting, a small pencil of light is passed through the replica, and this pencil of light advancing over the picture spot by spot until the whole picture has been scanned. And in doing so, the photocell responds to every change in translucency. It is evident that the luminous flux in the cell can be made relatively great, and therefore, amplification does not present the formidable problem that it does in sound movies.

Fig. 14 shows the second method of facsimile transmission. No replica is made here. And the quantity of light striking the photocell is only that which is reflected from each spot on the picture. Evidently, the quantity of light striking the photocell (using the same light source) will be much less when using this method of reflection than it will be when using the first method. The main advantage, though, is that no replica has to be made when the second method is used.

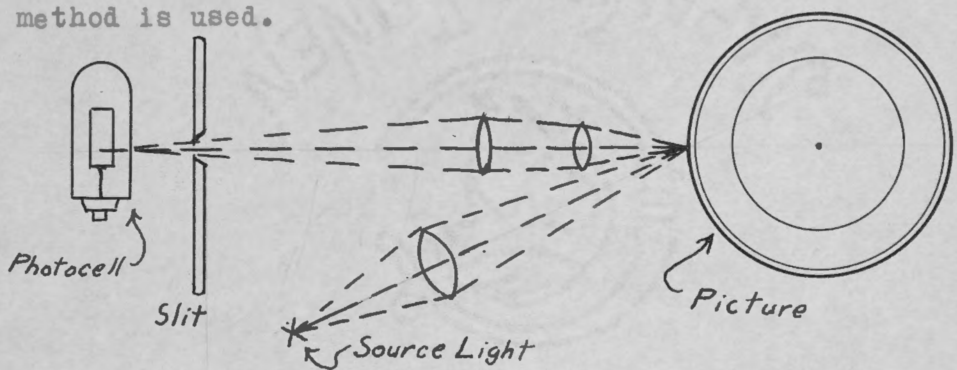


Fig. 14

One Type of Optical System Used in Facsimile Transmission.

Television

Television would be impossible if it were not for the photocell. In a way, television is an enormously accelerated picture transmission. The pictures are transmitted in much the same way as in facsimile transmission, except that several pictures are made a second.

If the picture to be transmitted contains the same number of picture elements as are used in facsimile transmission, and the scanning should be completed in $\frac{1}{16}$ of a second, then the picture frequencies would be impossibly high.

That is to say, the transmitting carrier frequency would be more than 100,000 cycles.

Rapid scanning in itself presents a formidable problem. In the future, the cathode ray tube, or some other device, may be used to serve the purpose best. But at present, the Nipkow disk is perhaps the most common device used. This

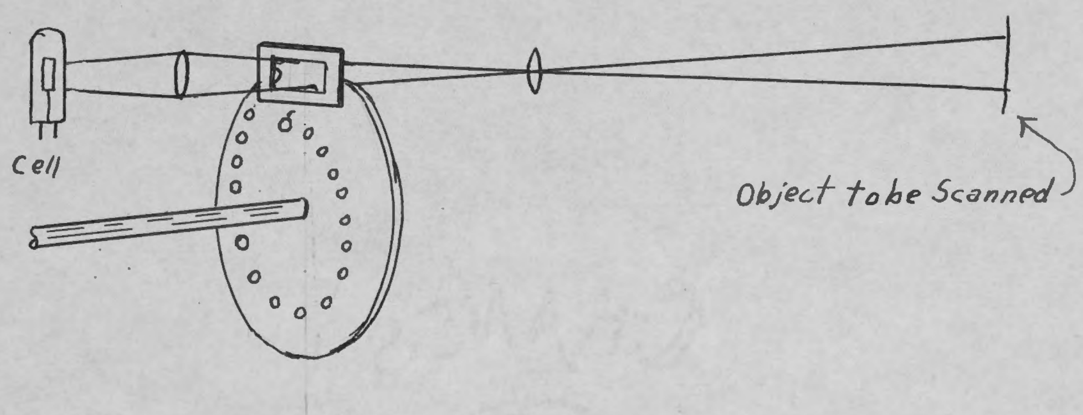


Fig. 15

The Nipkow Disk As Used In One Method Of Scanning.

method of scanning is illustrated in Fig. 15. When the disk is rotated, each hole describes a path under the image once per revolution. As one hole finishes its path, the next succeeding hole begins its path. In this way, the whole image is gone over one spot at a time. And the photocell responds to the light coming from each successive spot.

When one considers that for an 80-line picture, only 1/6400 of the total light flux enters the photo-sensitive device, and that each element affects the photocell for only 1/102,400 of a second, it seems that the problem of television is almost hopeless. But from reports gathered from reliable sources, the writer believes that television will prove itself to be of value commercially within the next few years.

<u>Contactless Relays</u>

The contactless relay perhaps has more varied uses than any other photoelectric device. The photocell is hooked up with a sensitive relay, in such a way that the relay can be made either to open or to close when light falls upon the photocell.

An unlimited number of uses can be made of the photoelectric relay. It can be used in counting articles, people, or vehicles passing a certain point; it can be used for the turning on and off of sign lights by the gradual transition between day and night; or it can be used in any case where it is desired to have a switch open or close when a fixed beam of light is broken. Some of these varied uses are listed on the following few pages.

Several photoelectric drinking fountains have been installed, wherein the water is turned on by intercepting a beam of light which is focused on a photocell.

The Toledo Scale Company has equipped some of its scales with a photocell mounted behind a slot in the scale dial. It is "eclipsed" when the desired weight has been fed into the scale hopper.

A car-dumping installation at Waukegan, Ill., is equipped with a relay set which warns the operator of the car when the car is near the end of the track.

McGraw-Hill has installed photoelectric

McGraw-Hill has installed photoelectric counters on its folding machines which count the number of sheets handled.

The DeVilbiss Company of Toledo, Ohio, uses a photoelectric device in the spraying of lumber with paint. The whole thing is done automatically. The spraying is done in an enclosed booth. When a board enters the booth, the sprays are turned on, coating both sides uniformly at one time. And when the board leaves the booth, the photoelectric relay cuts off the spray guns.

N. Ryan Company's ready-mixed concrete plant in Brooklyn, N. Y., uses a relay set to weigh cement automatically. The source of light passes over the scale beam. And when the beam rises, it cuts off the source of light, and the relay in turn, stops the pouring of cement.

A photocell installation on the Korn Dam, Evitts Creek, Pa., not only weighs the concrete, but it records weight of sand, weight of rock, weight of cement, weight of water, and time of mix.

W. L. Enfield, of Cleveland, Ohio, rigged up a photocell camera to guard his laboratory. When the intruders entered, they were greeted with a loud explosion, and their pictures were automatically taken.

The Arcturus Radio Tube Company has patented an automatic control for airport lighting on runways. This device might be used to advantage where the cost of keeping the lights on all night is prohibitive. The pilot of an airplane spots the single beacon. Directing his own searchlight at the searchlight on the ground, the light from the airplane strikes a photocell, and the flood lights are automatically turned on.

At the Canisius College Seismic Observatory in Buffalo, N. Y., a photocell has been attached to the recording mechanism of a Galitzin seismograph. The cell keeps continual watch on the galvanometer light beam, and gives warning of an approaching earthquake.

Color Analysis and Comparison

The photocell is inherently suited for the matching of colors. The auxiliary equipment is essentially the same as used in standard color matching devices, except that the photocell is substituted for the human eye.

The photocell is an ideal instrument for measurements of the brightness of such ~~faint sources of such~~ faint sources as stars. The dimmest star which can be seen with the naked eye is designated by astronomers as a sixth magnitude star. The amount of light which would reach the unaided eye from such a star would be 5.5×10^{-13} lumens. if this same flux is allowed to fall upon the best photo-tube that cam be produced at present, the resulting current would be 1.1×10^{-16} amperes. But with the best amplifiers available, currents can be detected as low as 0.5×10^{-18} amperes, or 1/20 of the current set up by the flux from a sixth magnitude star. In other words, the photocell, when equipped with the best amplifier available, is 20 times as sensitive as the eye.

Color analysis is not so simple as color matching. As the name implies, a color analyzer is an instrument that automatically draws for permanent record the color curve for any given sample. By means of a flicker disk, the photocell receives alternately monochromatic light reflected first from a standard, then from the sample to be tested. A difference between these results in a pulsating photoelectric current which is amplified sufficiently to operate a motor and move a shutter in the standard light path. A recording pen indicates on a chart the position of the shutter at which the light from the standard equals that from the sample. As the chart is rotated, the monochromatic light is moved through the visible spectrum. In this way, as many points as are desirable may be secured on the curve. And furthermore, the resulting curve is an absolute identification for any particular color. Such a color analyzer is used in the Louvre Museum in Paris. It defines the various curves by using only six points. And the time required to draw each curve is only a few minutes.

General Electric manufactures a color comparator by which a phototube matches the roast of coffee. These comparators are used by several coffee makers.

The Sheldon Electric Corporation has put a photocell colorscope on the market. It is used for color matching and color measurement.

Communication Over Light Beams

One of the most interesting accomplishments made possible by the photocell is that of communication over a directed beam of light. Dr. Bellamy Taylor, of General Electric, has done much work toward perfecting this means of communication. The beam of light may be modified by several different methods. It may be said here that experiments have been carried on using infra-red radiations. The advantage here is that infra-red radiations penetrate fog, smoke, and dust better than radiations of shorter wavelength.

Mechanical Reading

A novel illustration of the use of the photocell is that of mechanical reading. A light chopper with five concentric circles of holes, each circle being perforated with a different number of holes, divides the light source into five beams of different frequencies. This light passes over the different letters on a printed page, then is reflected to a photocell, which, in turn, operates a telephone. Thus, each letter will set up a different tone in the circuit. And with a lot of practice, a blind person can learn to read in this fashion.

Timing Devices

Excellent use may be made of the photocell as a timing device, that is, it may be used to supply the impulse that stops the timer. For instance, in timing runners on a track team, the tape may be replaced by a beam of light. This beam of light would be directed toward the photocell. Such a device would not only measure the winner's time, but it would also measure the other runners' times. Such timing instruments have been developed, and it is claimed they are accurate to less than 0.01 second.

The passage of a star over a given meridian may be accurately determined by means of the photocell. The cell is placed behind the collimator slit of an astronomical telescope, and a hair line is focused at the middle of the slit. When the image of a star reaches ane edge of the slit, the photoelectric current is used to produce a musical note. And when the image coincides exactly with the slit, the musical note is interrupted. This is a very accurate method of timing stars.

A similar method is to be used at the Chicago World's Fair in June, 1933. When the Fair opens, its lighting circuits will be switched on by light from the star Arcturus, gathered in the great Yerkes telescope, focussed on a photocell, and amplified for transmission to relay switches at Chicago. The light to be used left Arcturus 40 years before, at the time of the Chicago World's Fair of 1893.

One can readily see that the swings of the pendulum in a precision clock can be recorded without in any way introducing a retarding torque to the pendulum.

Photocell Integrators

The photocell has been applied as an integrator or computer of irregular areas, by Dr. T. S. Gray of Massachussetts Institute of Technology. The method of first cutting out the space below the graph or curve to be measured is utilezed. Light is then allowed to shine through this opening, and the ratio of the light passing through this hole to that light which will pass through a unit area, gives the area of the irregular graph.

L.R. Koller of General Electric has developed an integrating unit consisting of a photocell in series with a battery and hydrogen voltameter. The total amount of light emitted by any given source over any period of time may be determined by measuring the volume of hydrogen liberated.

Dividing Machine

The interferometer is used in connection with the photocell as an exceedingly accurate dividing machine. Thus, in making such things as diffraction gratings, the photocell automatically stpps the advancement of the cutter when it has advanced a given number of wavelengths of light.

Photoelectric Recorder

General Electric has put on the market a photoelectric recorder. This instrument produces a continuous record of any quantity for which an indicating instrument is available. This is accomplished by an optical system and a photo-tube circuit which causes a high-torque recording element to continuously follow and record the readings of the high-sensitivity element.

Automatic Titration

The photocell is used in some chemical laboratories for automatic titration. The method to be used should be obvious to any student of chemistry. A source of light is passed through the liquid, and when the color of the liquid changes, the photocell current is also changed, and this in turn, automatically controls the titration.

Semagraph

Buford L. Green, of Charlotte, N. C., has invented an apparatus called the Semagraph, which causes typewriter copy to operate a linotype. The typewritten matter is fed to the linotype, and it is scanned by a photoelectric cell. And the current set up in the cell operates the linotype keyboard.

Temperature Control

The photocell, in conjunction with a grid glow tube and a thermocouple, has been employed in a device to keep electric ovens at a given temperature. The photocell is used in this device to read a meter. That is to say, there is a source of light which passes through an aperture in the meter to the photocell. When the needlepoint on the meter is in front of this aperture, the source of light is cut off, and the photoelectric relay set is operated.

Control of Illumination

A vehicular tunnel in Paris uses photocells to keep the light intensity inside the tunnel at a value near to that of the intensity on the outside. If the inside of the tunnel is either darker or brighter than on the outside, then drivers may be confused. Thus, at night, only a few of the lights are turned on, while on a bright day, all of the lights are turned on. For other degrees of brightness on the outside, different numbers of lights are turned on. This use suggests the need of a like use for accustoming one's eyesight to the inside of a theater as one enters.

Miscellaneous

The photocell has been used for automatic inspection of surfaces. This is accomplished by recording the intensity or quality of light reflected from the given surface.

Another use is that of checking small departures in sizes of articles. This method is described by Robbins, B. S. T. J., 7, 708, 1928.

Photocells have been employed for the photometry of ultra-violet rays, that is, for measuring the intensity of ultra-violet radiations.

Walter Howey, New York City, has invented an electric-eye engraver, which will make newspaper halftones in a few minutes, without the use of acids.

The Scientific Crime Detection Laboratory of Northwestern University uses photocell in connection with ultra-violet rays to detect stains that otherwise could not be found.

The photoelectric cell can be used to detect counterfeits. That is to say, it can be used to show whether a "doubtful" stock certificate is printed on the same grade of paper as a certificate which is known to be good.

Watt-hour meters may be calibrated by using the photocell in connection with a neon lamp. This method is is described by Aroff and Young, in The Electric Journal, 36, 255, 1929.

An article by Arnold in Radio Engineering, 9, 30, 1929, describes a method of automatically controlling furnace temperatures by means of the photocell and a thermocouple.

The photocell is used as a safety device in smoke detection and fire prevention. For smoke detection the source of light is directed toward the space to be protected. When there is too much smoke, the quantity of light reaching the photocell is diminished, and this in turn, sounds a warning. In fire prevention the sourceof light may either be directed toward the spot to be protected, or it may be directed where the fire is likely to occur. The spurious radiation from a starting fire can be used to sound an alarm, or operate a fire extinguisher.

High frequency currents may be measured by measuring the intensity of a tungsten filament put in the high frequency circuit. It is assumed here that the brightness of the lamp depends upon the effective current.

Christian Paulson, of Western Electric Company, has patented a device employing the photocell which gauges material by comparing it with a standard sample.

Professor Floyd Firestone, of the University of Michigan, has perfected a photocell inspector which detects flaws less than one ten-thousandth of an inch in size.

The ship Mauretania was navigated by observations of the invisible sun taken with the new MacNeil infra-red sextant. Photocells, a thermocouple, and thermionic tubes are used in this device--the photocell detecting the infra-red rays from the sun.

CHAPTER III

THE FUTURE OF THE PHOTOCELL

It is of interest to wonder what the photocell may hold in store for the future. It is impossible to say what the vast amount of research work being done will reveal in the future, but some guesses can be made as to what special lines this research work will lead to.

It might seem that since most metals are particularly photo-sensitive to the ultra-violet, that radiations of this wavelength will be used in the future in preference to those of visible light. But there are several disadvantages to the ultra-violet. First, the quartz mercury arc is the only practical source of ultra-violet, and this source is too expensive and not as easy to handle. Second, the optical system of the devices used would have to be made of materials translucent to ultra-violet rays. For example, in sound movies the lens would have to be made of quartz, and a different type of film would have to be made. Third, ultra-violet rays are harmful to the eyes, thus necessitating special precautionary measures.

It has been found by experiment that the ideal photocell must be one which has maximum sensitivity at 30,000 angstroms. It has also been estimated that the ideal photocell in an evacuated glass bulb should have a sensitivity corresponding to 66 milliamperes per lumen, a value 2000 times as high as that obtained in our best vacumn cells of today. Whether this limit will be closely approached is a thing hard to predict. But it is practically certain that much improvement in the design of the photocell is yet to be made.

The fact that photocells can be made with maximum sensitivities at almost any part of the visible, ultra-violet, or near infra-red spectrum leads us to believe that many new devices involving color will be invented. The transmitting and receiving of television in natural colors has already been accomplished with a limited degree of success. And in the future, the writer sees no reason why there should not be nocturnal television. That is to say the pictures to be transmitted would be detected by the infra-red, or heat rays, that they put out. And in this way, the pictures could be taken in the dark.

Many other predictions could be made as to the future of the photocell, but the writer will leave that up to the reader to predict.

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DEFINITIONS

Some photometric terms often used in photoelectricity are given below for reference.

Luminous Flux is the rate of passage of radiant energy evaluated by reference to the luminous sensation produced by it.

Lumen--The unit of luminous flux is the lumen. It is equal to the flux emitted in a unit solid angle by a uniform point source of one international candle.

Luminous Intensity--The luminous intensity of a point source in any direction is the luminous flux per unit solid angle emitted by that source in that direction.

International Candle--The unit of luminous intensity is the international candle.

Illumination--The illumination at a point of a surface is the density of the luminous flux incident at that point of the quotient of the incident flux by the area of the surface when the latter is uniformly illuminated.

Angstrom--A minute unit of length equal to one ten-thousandth of a micron or one hundred-millionth of a centimeter, a term often used in expressing the wavelength of light.

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a matter sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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