Photoelectricity, the Means of Television

The "Electric Eye" and the Principle of its Operation

By JOHN P. ARNOLD

SINCE the recent art of visual communication—the electrical transmission and reception of, not only "still" pictures, but also of the images of objects in motion—has been demonstrated experimentally and successfully applied to many practical uses (such as the commercial service of sending photographs by land wire and cable, the broadcasting of weather maps by radio, and the television transmissions in this country and England) much descriptive writing has found its way into print, mainly expressed in awe and with fanciful predictions for the future; but very little has been told of the scientific principles on which these systems are founded.

Many branches of human knowledge have been levied upon to furnish the appliances of this art: for picture transmission is a group achievement, the product of many workers in varied fields of thought, in which individual genius has played only a contributary part. Chemistry, mechanics, electricity, and more specifically telephony, optics and photoelectricity, have aided in its development; and it is only through the study of these sciences that we may expect to find the answers to problems for which we have no present solution.

Photoelectricity is probably the least familiar of the above-named subjects and, as it deals with the light-sensitive cell, which has the same great importance in this form of communication as the "thermionic" vacuum tube in radio broadcasting, the theoretical and practical aspects of this science and the general facts regarding cells are considered here.

THE PHOTOELECTRIC EFFECT

The photoelectric cell itself is a converter of light intensities into electric currents which may be amplified and employed in accordance with ordinary electrical practice. The conversion of light into extremely minute electrical impulses is brought about by what is known as the photoelectric effect. This effect is due to the fact that an *insulated metallic conductor loses negative electricity when illuminated.* The loss of negative electricity is caused by the emission of electrons from the conducting surface. Moreover, the quantity of electrons emitted varies with the intensity of the light which influences the action. Thus, stated in the form of a rule, we say that *the photoelectric effect is proportional to the intensity of the illumination and to the time during which it acts.*

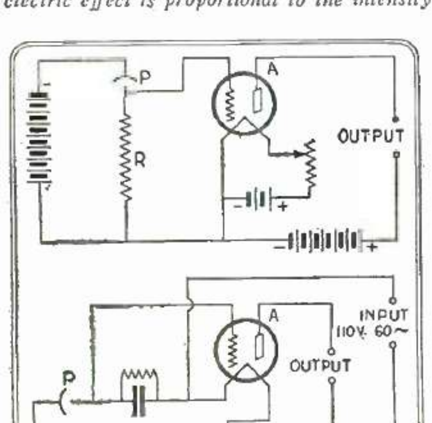

Fig. 2. Two methods of connecting a photoelectric cell in the grid circuit of an amplifier tube, which is necessary in advance of a mechanical relay. One draws its current from a battery, and the other from the lighting mains.

This proportionality between the intensity

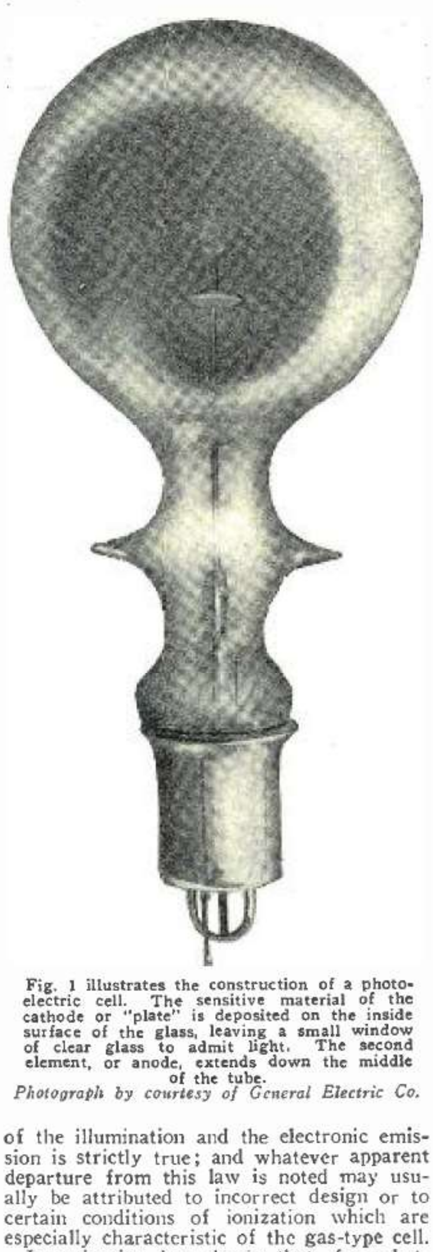

Fig. 1 illustrates the construction of a photoelectric cell. The sensitive material of the cathode or "plate" is deposited on the inside surface of the glass, leaving a small window of clear glass to admit light. The second element, or anode, extends down the middle of the tube.
Photograph by courtesy of General Electric Co.

of the illumination and the electronic emission is strictly true; and whatever apparent departure from this law is noted may usually be attributed to incorrect design or to certain conditions of ionization which are especially characteristic of the gas-type cell.

Investigation has shown that, for whatever metal is used as a conductor, there is a definite wavelength at which the photoelectric effect takes place. The minimum frequency required to produce this phenomena shifts continuously toward the red end of the spectrum as the light-sensitive material is made more electro-positive. (See RADIO NEWS for June, 1927, page 1422.) As the "alkaline" metals (sodium, potassium, lithium, caesium and rubidium) respond to radiations in the visible part of the spectrum, these substances are used in cells for visual communication.

The loss of electrons which a photoelectric body undergoes when illuminated may be observed to take place either in a vacuum or in gases. This has led to the development of two general types of cells, both using for the conductor or plate one of the alkaline metals in the form of a hydride (a compound of the metal with hydrogen), which is more sensitive than the pure metal. They differ mainly that in one the plate is placed in a highly-evacuated tube; while in the other it is contained in an inert gas, such as argon at low pressure. In the construction of such cells great care is taken to prevent oxidization of the plate and, for this and other reasons, they are more thoroughly exhausted than the ordinary vacuum tube.

CONSTRUCTION OF THE CELL

To illustrate more clearly photoelectric action, it is useful to describe the modern cell. The PJ-1 and PJ-5, gas-filled and vacuum types respectively, are taken as examples. These cells are 5¾ inches long and the glass tube has a maximum diameter of 2¼ inches. The light-sensitive material is deposited on a silvered surface, on the inside of the tube, with a connection leading out through the glass. The only other element is the anode, or filament, which has a lead also brought out of the tube. A small aperture of clear glass allows light to fall on the plate. When a potential is applied and the plate illuminated, a current flows from the latter to the filament. Fig. 1 shows the typical cell; but others vary in size, shape and design.

Two methods of connecting cells to the input of the familiar three-element tube, using either a direct or an alternating potential across the terminals of the cell, are shown in Fig. 2. Either the gas-filled or the vacuum types may be used with these circuits; the essential difference being that the gas-filled cell, because of ionization, passes a greater current. In the diagrams P indicates the conventional symbol for the cell. In order to minimize the effect of tube leakage, the value of R lies between one and ten megohms. Theoretically, however, the higher the resistance used, the more sensitive the circuit will be.

Fig. 3 is a graph showing the current-voltage characteristic curves of a gas-type cell with direct current applied across its terminals. These curves were taken at the distances indicated from the source of illumination, which was a 250-watt Mazda lamp.

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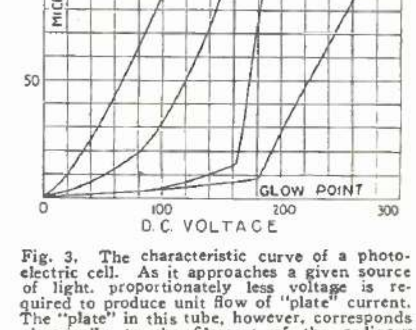

Fig. 3. The characteristic curve of a photoelectric cell. As it approaches a given source of light, proportionately less voltage is required to produce unit flow of "plate" current. The "plate" in this tube, however, corresponds electrically to the filament of the ordinary tube.

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the relay, this act setting in motion a new electrified steel mill in Pittsburgh, Pa. This same action was shown to the visitors at the Radio World's Fair, with the exception that the motor and lights were in the Theatre of Wonders.

TRANSMISSION OF PHOTOGRAPHS

An exhibit that attracted great attention was the reception of photographs by radio with receiving apparatus that can be attached to an ordinary radio receiver in place of the loud speaker. The apparatus, which is shown in the accompanying illustrations and which was developed by A. G. Cooley, is said to be of such simple construction that it can be built by an amateur. The photographs are received on sensitized paper, which is placed around a cylinder. The picture is built up line by line.

The Radio Corporation of America demonstrated a similar system with the exception that the transmitted photograph or sketch could be enlarged to many times the size of the original. The printing of the picture is controlled by a relay regulating a flow of hot and cold compressed air.

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In operation these cells will glow under excessive potential and while glowing, of course, are not sensitive to light variations. Efficient operation is secured somewhat below this point. If the rated voltages of the cell are exceeded, its life is considerably shortened. The manufacturers of the above-described cells specify that they should not be operated at a temperature above 30° Centigrade, which is 86° Fahrenheit.

To those familiar with the action of the thermionic tube, the application of the photoelectric cell to visual communication is not hard to understand. The current through the cell rises and falls with the varying intensities of the light directed on the plate. This current may be made to influence the grid of a sensitive vacuum tube, as shown in the circuit diagrams; and the output of the latter is fed into an amplifier.

PRACTICAL DIFFICULTIES

This description of the way of handling the output of cells sounds simple enough on paper; but the fact of the matter is that difficulty is often experienced in designing amplifiers which will give an adequate response to the extremely minute impulses involved and to the rapid fluctuations necessary to transmit pictures or, especially, scenes of motion. This provides radio experimenters with a problem which is definitely within their province to solve, in addition to those questions of static elimination and fluctuations of signal strength, which must be answered before radio will become a practical channel for such communication.

It is fortunate for the progress of visual communication that the photoelectric cell, although it has some disadvantages, is a device of great speed and precision. Cells of the better type are capable of translating extremely rapid fluctuations of light and shade without appreciable lag or "hang-over," for the emission of electrons is practically instantaneous.

Individual cells of the same type vary widely in their characteristics, as do radio tubes; and when two or more cells are used together, often the case in television systems, it becomes necessary to balance their outputs by means of resistors. Cells after some use show evidence of *fatigue;* that is, a deterioration of the photoelectric surface, often due to leakage currents which flow when the cell is not exposed to light. This difficulty regarding "dark currents" is, however, eliminated by careful design.

The thought will arise that cells may be more sensitive to certain light frequencies than to others; this is a fact. The cells we have discussed show a maximum sensitivity in the blue-violet part of the spectrum, while yellow-green elicits the greatest response from the average eye.

In conclusion it may be mentioned that the photoelectric effect has been produced with other than the metallic elements. Crystalline substances and many inorganic compounds respond to the action of light, but these facts, while interesting, are of no service in communication work and need no further consideration here. (A discussion of this subject will be found on page 32 of RADIO NEWS for July, 1927.)

Does Voltage Indicate Merit?

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statistics, in use between 600,000 and 700,000 "B" power units which were designed for use with the original 60-milliampere tube. As by far the greater percentage of these units have been in service for a length of time close to the normal life of the tube, some data on this subject should be at present of interest to the readers of RADIO NEWS.

Though the 60-milliampere rectifiers cannot, as a rule, be used to replace a 125-milliampere rectifier, there are a great many instances in which several worth-while advantages are to be had by the use of the 125-milliampere tube as a replacement unit for the smaller one.

The first of these is increased output. In gaseous-conduction rectifiers the voltage drop across the tubes is very nearly a constant; about 120 volts for the 60-milliampere tube and 90 volts for the 125-milliampere tube, regardless of the load current. As the majority of power units originally designed for use with the former type tube were of the lower-voltage type previously referred to, there is generally an advantage to be gained by increasing their output. Most such power units have a maximum voltage output in the neighborhood of 150 volts at 40 milliamperes.

By the use of the 125-milliampere tube, the output is increased to about 180 volts and 40 milliamperes or sufficient to operate a 171-type tube at full plate voltage, while supplying sufficient current for the great majority of radio receivers.

CONDENSER SAFETY MARGIN

Perhaps it may be thought that this higher output voltage will damage the filter condensers in the power unit. Such is, however, not the case, as the condensers of all reliable power units are made to withstand voltages very much higher than the normal operating voltage; an increase of thirty volts is quite insignificant.

The manufacturer, in the design of the condensers for his power unit, must, in fact, provide against the possibility of the device being operated without load; as this would result if the power unit were turned on without being connected to a radio receiver, or if the filament switch of the receiver were turned off while the "B" unit remained in operation. In this case, the voltage across the filter condensers might well be two or more times the normal operating voltage. It will be seen that the slight increase in voltage due to the use of a 125-