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Courtesy General Electric Co.

A PHOTOELECTRIC RELAY UNIT SHOWING THE "ELECTRIC EYE" OR PHOTOTUBE AT RIGHT AND AMPLIFIER AND RELAY AT LEFT.

Theory and Uses of Photoelectric Tubes

Dewey Classification 535.3

VOL. 13, No. 5

Courtesy Westinghouse E. & M. Co.

COMMERCIAL MODEL OF A WESTINGHOUSE PHOTOTUBE RELAY UNIT SHOWING THE LIGHT SENSITIVE TUBE (RIGHT) AND VACUUM TUBE AMPLIFIER (LEFT).

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THEORY AND USES OF PHOTOELECTRIC TUBES

DEFINITION

In its broadest sense photoelectricity covers two phenomena, namely,

(1) The release of radiant energy when electrons strike particles of matter.

(2) The release of electrons when radiant energy falls on particles of matter.

It concerns, therefore, a transfer from electricity to light, or a transfer from light to electricity.

TYPES OF PHOTOELECTRIC PHENOMENA

Under the first type is the ordinary arc lamp, in which an electric current causes gases to become incandescent, producing radiant energy in the form of visible light waves.

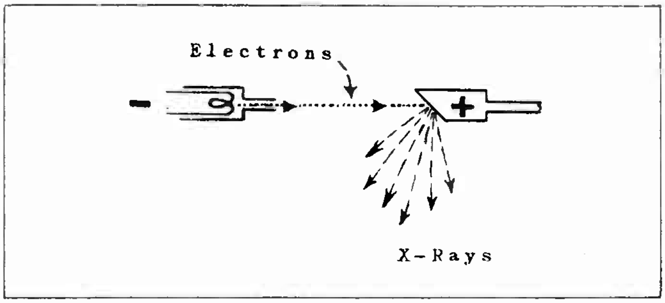

Fig. 1 - PRINCIPLE OF COOLIDGE X-RAY TUBE.

Also under the first type we note the Coolidge X-ray tube, which is simply illustrated in Fig. 1. Here we have a flow of electrons from a filament, the electrons being condensed by a sheath into a fine cathode ray. These electrons attain a tremendous velocity due to the attractive force of the high positive charge on the anode, which is called the "target" for the electron stream. The energy of the electrons in motion is communicated to the molecules of tungsten at the target surface, and these convert the energy into a form of radiation which we call X-rays.

The reverse effect is the emission of electrons from molecules of matter when radiant energy falls on them. This effect was originally discovered by Hallwachs. He found that if a body is negatively charged it will lose that charge when subjected to ultra-violet light. On the other hand, if the body is positively charged it will not be affected by the ultra-violet light. If a negatively charged body loses its charge under the influence of light it follows from the electron theory that we should be able to collect those charges under certain conditions by placing near it a positively charged body. This compares with the ordinary vacuum tube used for radio purposes, in which a positively charged plate is used to collect the electrons given off by the incandescent cathode. In Fig. 2 is shown the energy paths concerned with the Hallwachs effect.

Theoretically at least we could accomplish a double transfer, as shown in Fig. 3. Here we have radiant energy in the form of ultra-violet light directed onto a negatively charged metallic body in a vacuum and which gives up electrons; these would be attracted to the

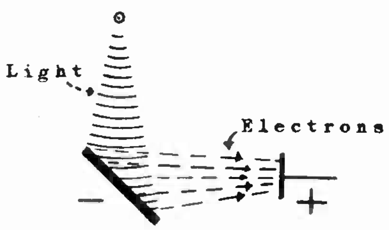

Fig. 2 - PRINCIPLE OF THE HALLWACHS EFFECT.

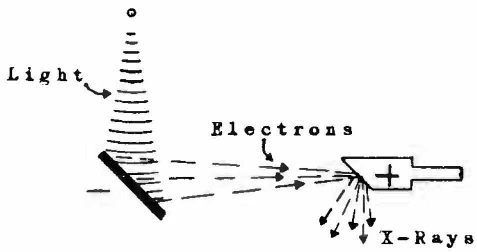

Fig. 3 - THEORETICAL IDEA OF A DOUBLE TRANSFER OF ENERGY.

anode or target. If a sufficient number of electrons could be emitted from the cathode in a given time (not practically possible) X-rays might be radiated from the target due to the energy wrapped up in the bombarding electrons. We observe here a difference in the two forms of radiant energy concerned. Ultra-violet light, while invisible, obeys the well-known optical laws of reflection, refraction and polarization. On the other hand X-rays do not. They do have some properties in common, as we shall see.

IONIZATION OF GASES

In various devices in this branch of science we encounter gases, not only of the non-metallic kind such as oxygen, hydrogen, helium, etc. but also those of the metals themselves, of which the most frequently used is the vapor of mercury, which is normally a fluid. You are familiar with the latter in the wide spread use of mercury vapor lamps, and you find it also in mercury vapor rectifiers.

Gas molecules containing two or more atoms may be dissociated into positive and sometimes negative ions by putting the gas in the line of action of any one of the three paths shown in Fig. 3. In like fashion the single-atom molecules which are electrically neutral are usually made over into positive ions.

Ultra-violet light can ionize mercury vapor by causing the release of one or more electrons from the mercury atom.

Electrons in motion at a sufficient speed may "knock off" other electrons from a gas molecule in their path, leaving positively charged atoms or ions, and sometimes negative ions, depending on the molecular construction.

Furthermore, X-rays also have the ionizing power.

SENSITIVITY TO LIGHT. In a foregoing paragraph we mentioned that Hallwachs, in his experiment, used ultra-violet light. There were natural limitations to this early device on account of the nature of the light. It is easy to see that in a practical way it is much

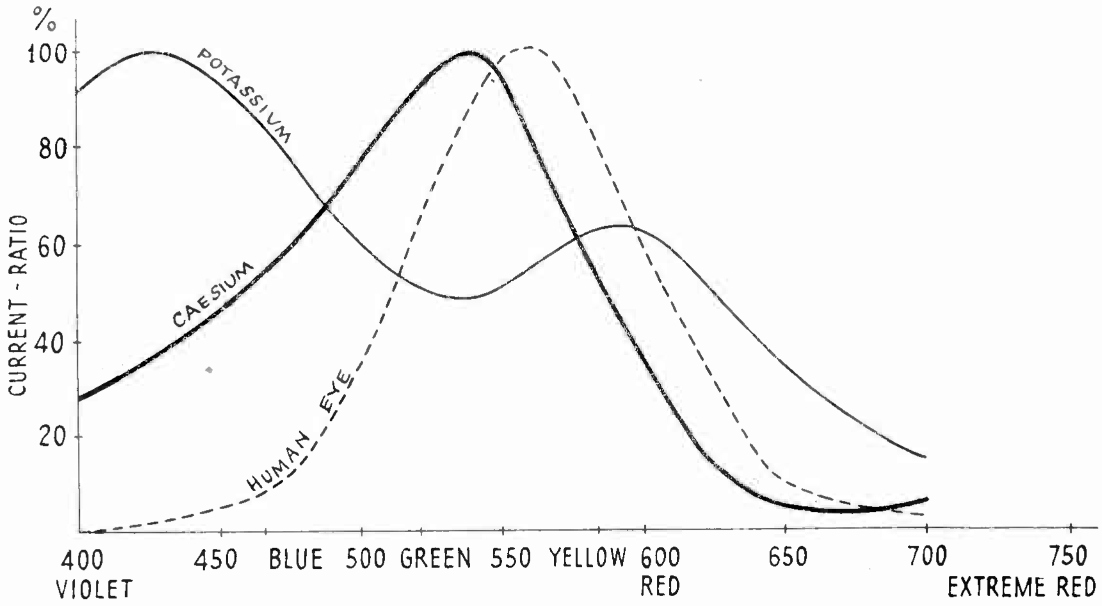

Fig. 4 - CHART SHOWS COMPARATIVE SENSITIVITY OF POTASSIUM, CAESIUM, AND THE HUMAN EYE AT DIFFERENT LIGHT FREQUENCIES.

easier and cheaper to produce and see white or yellow light — which usually contain some ultra-violet, but a much greater percentage of other colors. Thus an ideal material to use would be one that is more sensitive to white light or the same spectrum as the eye.

The discovery that sodium, potassium, caesium and a few other elements were instantly affected by visible light led to intensive development work which brought the photoelectric cell up to its present stage. Although these cells are quite highly developed yet they are not as uniform in performance as the radio tube. Photoelectric cells and radio tubes in general appearance resemble each other and both are classified as "electron discharge devices" although it must be remembered that in the case of the photocell the emission is caused by light while in the thermionic (radio) tube the emission is due to incandescence of the filament or cathode.

An examination of the chart in Fig. 4, which shows the sensitivity of various materials at different light frequencies, indicates that caesium compares favorably with that of the eye. Caesium, however, when used alone is not as sensitive as potassium or copper oxide but it has been found that by coating the caesium on silver oxide its sensitivity is greatly increased and furthermore its frequency characteristic is kept approximately the same as that of the eye.

PRINCIPLES USED IN THE PHOTO-EMISSIVE CELLS

Based on the principles used we have two types of photo-emissive cells or phototubes:

(a) The vacuum type, which consists of a highly evacuated vessel enclosing a positive electrode and a negative electrode, the latter consisting of a surface of such material that it will emit electrons under the influence of radiant energy of the visible or near visible spectrum.

(b) The gas type, which uses the principle of the vacuum type above, with the addition of a certain amount of one or more gases which easily release additional electrons under the forces of collision with electrons emitted from the cathode.

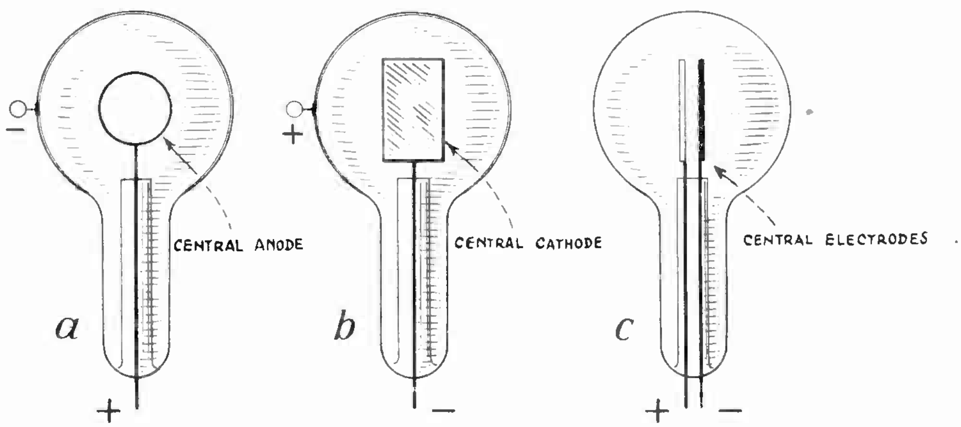

Fig. 5 - PHOTOTUBES ARE CLASSIFIED HERE ACCORDING TO ARRANGEMENT OF THEIR ELECTRODES.

STRUCTURAL FORMS

The three most common forms of phototubes now in use are (a) the central anode, (b) the central cathode, and (c) the central electrodes. In the central anode type the inner surface of the tube is coated with the light sensitive alkali while a rod, used for the anode, is located inside and near the center of the tube. In the central cathode type the inner surface of the tube is coated with a metallic substance and a plate, coated with light sensitive material, is located in the center of the tube. In either case the coating on the inside wall of the tube is connected electrically to a terminal which is brought outside the tube. The third type mentioned or the central electrode tube is now the tube most generally used in sound-on-film movies. It consists of a centrally located rod (anode) with a semi-cylindrical plate (light sensitized cathode) partially surrounding it. Fig. 5 shows the general arrangement of the electrodes.

VACUUM CELL. When the electrodes of a photocell function in a high vacuum it gives them a much different characteristic than when they work in a gas filled medium. When the cathode of a vacuum type cell is subjected to light a certain number of electrons are released and if a high positive potential is applied to the anode all of these electrons will be attracted to and flow toward the anode. On the other hand, if the anode voltage is comparatively low all of the liberated electrons will not be attracted to the anode, but many will continue to remain on the cathode. This characteristic showing the variation in current (electron flow) for a given fixed light intensity, with changes in anode potential is shown in Fig. 6. When the voltage is sufficient to remove all the electrons released by the light, a further increase of voltage should not produce an increase in electron flow. When this condition is reached the current has

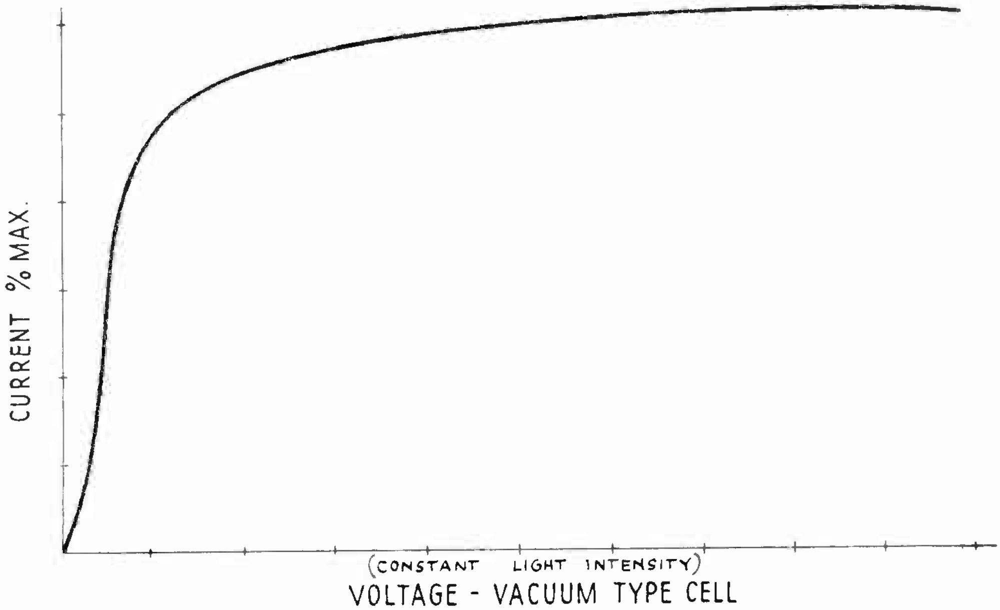

Fig. 6 - CHART SHOWS RELATION BETWEEN CURRENT FLOW AND VOLTAGE CHANGES IN A VACUUM TYPE CELL WITH CONSTANT LIGHT INTENSITY.

reached the saturation value. Of course, if the light intensity is changed the voltage-current curve will be different and the saturation current will increase as the light intensity is increased. Due to imperfect vacuum and rough surfaces on the cathode holding back some electrons there will always be some slight increase in current for an increase in voltage, but this increase becomes so slight that it need not be considered.

EFFECT OF GAS ON CELLS. The action of gas filled cells is much more difficult to understand than the explanation just given for the action of the vacuum type cell. In the first place only gases which do not react chemically with photoelectric material can be used.

Argon, neon and helium answer these qualifications. The normal electron stream in motion will have scattered through it gas molecules which are electrically neutral, and therefore not attracted to either the anode or the cathode. The random motion of the gas molecules through the space of the tube will have no special direction. When an electron collides with a molecule the elastic properties of each may cause them to merely bounce off, their directions and velocities being changed but slightly. If the electron velocity is sufficiently great, however, it may give up some of its energy to the task of freeing another electron from the ties that bound it into the structure of a gas atom. The additional electron joins the stream of electrons originating at the cathode, and more electrons reach the anode than were caused by the light falling on the cathode. The gas atom which was robbed of an electron is no longer neutral, having become a positive ion. This ion is repelled from the anode, and attracted to the cathode, whose charge is of the opposite polarity. During its motion in that direction, it may join another electron and become neutral; or it may approach and reach the cathode at such a velocity that the collision causes an extra agitation of the electrons there, with the consequent increase in the number released. Still another effect occurs when a neutral gas atom combines with an electron to become a negative ion, which is attracted toward the anode.

It all gets very complicated when other variations are considered. Increasing the positive potential on the anode serves to increase the whole effect. It is possible to increase this voltage to a point where the emission from the cathode due to the positive ions present, is as great as or greater than the emission due to the light alone. When this condition is reached the emission of electrons will continue even though the light is cut off. The tube then contains a self-sustaining glow discharge which will continue until the anode potential is lowered appreciably, or until the cathode surface is robbed of its available electrons. In the latter case the tube becomes useless, as it cannot be reactivated like an amplifier tube.

It can be seen that while the gas filled cell is much more sensitive than the vacuum type more care is required to keep it from glowing. The same conditions exist in the gas filled cell as in the vacuum cell insofar as that increasing the light intensity changes the best maximum voltage used. Thus, with greater light intensity a lower voltage must be used to prevent glowing. The graphs of Fig. 7 show this. (The "lumen" is the unit of "luminous flux," which may be defined as the radiant power evaluated according to its visibility). The current sensitivities are graphed for three types of cells made by the Westinghouse E. & M. Co.

Type VA is a vacuum cell having a color-response approximating that of the human eye. Type VB is also a vacuum cell, but having about fifteen times the sensitivity of Type VA, but resembles the latter in that it gives constant output for steady light flux, over a wide range of cell voltages. The gas filled Type GB cell gives increased output up to a limit of about 90 volts. The graph at the right of Fig. 7 shows that the unwanted glow discharge occurs at a voltage which depends on the light flux.

Fig. 8 gives the response per unit energy of the three cells mentioned, with a comparison with the human eye. It will be noted that the GB cell has about five times the response of the VB cell, at the voltages used in taking the data, but that the color response of the two cells is identical.

Referring again to Fig. 7 we see the reason for the greater sensitivity of the gas filled cell. At about 30 volts on the horizontal scale, the VB cell has reached the saturation point for the steady

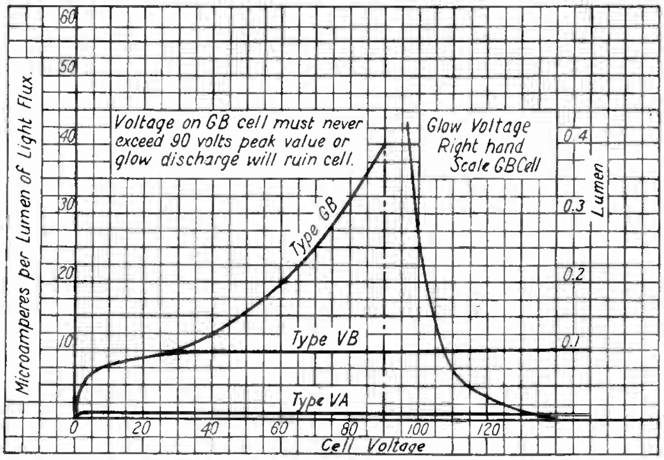

Fig. 7 - TYPICAL CURVES OF AVERAGE CELL OUT-PUT AS A FUNCTION OF APPLIED VOLTAGE AT A LIGHT FLUX OF ONE LUMEN.

light flux condition which determines the electron emission. In the GB cell, however, this voltage is about the point where ionization begins to take effect for that steady light flux, and the current per lumen increases rapidly as the voltage is increased.

In order to limit the cell voltage to a value below that at which glow discharge starts, it is customary to insert a resistor in series with the voltage supply. Its value is such that, as the cell cur-

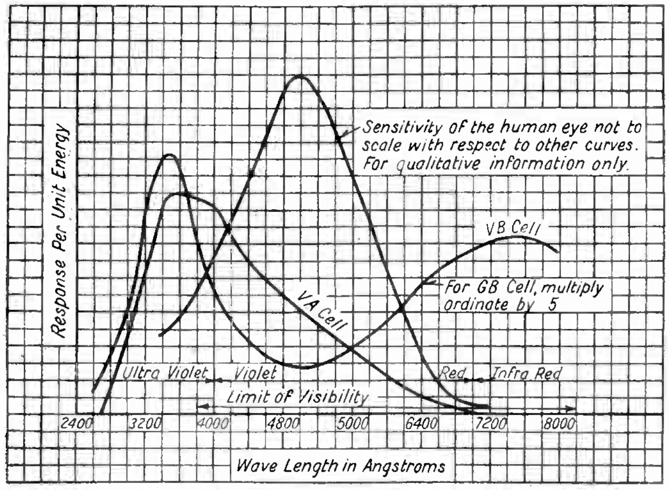

Fig. 8 - COLOR SENSITIVITY OF AVERAGE CELLS OF WESTINGHOUSE TYPES VA, VB AND GB.

rent increases too rapidly near the glow discharge point, the voltage drop across the series resistor will lower the voltage across the cell electrodes. This, of course, reduces the tendency toward a glow discharge. It has a certain disadvantage, in that the average voltage across the electrodes will depend upon the average illumination. What we would like to have is the use of a steady voltage on the electrodes, with the current varying directly as the luminous flux changes. With a resistor in series with the voltage supply, the electrode voltage is no longer constant as the current varies with change in luminous flux. Under this condition there is no longer a nearly linear relation between the illumination and the current, and a slight distortion results.

This disadvantage would not apply to a vacuum type of phototube which is operated above saturation, where a considerable change in electrode voltage makes no appreciable change in current. But then, there is no use in having a protective resistor in the circuit of vacuum phototubes, because the gas in them has been so considerably reduced that no glow discharge could take place except at very extraordinary voltages.

PHOTO-CONDUCTIVE CELLS

The earliest form of photoelectric cell used selenium, but up to very recent times the inherent sluggishness of response limited its usefulness to very few applications. A modern development which is manufactured by the Burgess Battery Company under the name "Radiovisor Bridge" makes use of a unique contact surface and the selenium is carefully treated by a special process. This overcomes much of the slow action of the selenium, and it is claimed to be responsive to variations in light up to a frequency of 10,000 cycles per second. The cell or bridge as it is called consists of two gold electrodes fused into glass. Each electrode is in the shape of a comb, and they are placed with their teeth interlocking, but not touching. The molten selenium is poured over these electrodes in a thin layer and then given a heat treatment to convert it into the chemical form in which it is most sensitive to light. The electrode assembly is then placed in a glass envelope from which air is removed.

The action of this type of cell must not be confused with the photo-emissive cell in which an electronic emission is proportionately caused by light. The property of selenium is such that its resistance to the flow of current is changed by light. The cell resistance decreases when exposed to light, causing more current to flow if the cell is connected across a sufficient voltage. The bridge may be used over a wide range of voltages (10 to 500), the principal difference being that more current flows as the voltage is increased. When dark the resistance is from 1 to 10 megohms. The "bridge" passes appreciably more current than the photo-emissive tubes previously described.

PHOTO-VOLTAIC CELLS

Several oxides of silver and of copper when immersed in solutions of sodium hydroxide become more electropositive when exposed to light. When an electrode having a crystalline cupric oxide surface is associated with an inert electrode of lead, the additional electrochemical potential caused by light makes itself evident as an internal electromotive force which is available for causing current to flow through some external circuit connected across the two electrodes.

The voltage developed in this cell is proportional to the luminous flux to which it is exposed. No external battery is required, which differentiates it from the photo-emissive and the photo-conductive types of cell.

APPLICATION OF PHOTOTUBES IN CIRCUITS

Potassium and caesium cells are very sensitive, but pass such small amount of current that they cannot be used for most commercial purposes unless their output is increased. Since the resistance from

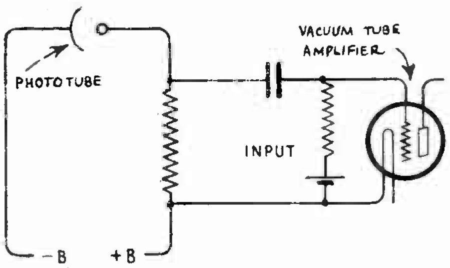

Fig. 9 - ONE METHOD OF COUPLING A PHOTOTUBE TO AN AMPLIFIER TUBE CIRCUIT.

anode to cathode is quite high they are known as high impedance cells. This brings about two requirements. If they are to be used for the production of alternating current of a wide range of frequencies, such as in Sound Pictures and Television, the input impedance of the following amplifier must match that of the phototube. As with any other high impedance circuit, it must be adequately protected by shielding from responding to stray electrostatic and electromagnetic fields which would otherwise introduce random voltages in the signal. These would appear as noise in Sound Pictures, and as flecks of light and shadow in the picture-effect reproduced at a remote Television receiver.

One method of coupling a phototube to an amplifier tube is shown in Fig. 9, where a high resistance is inserted in series with the voltage supply.

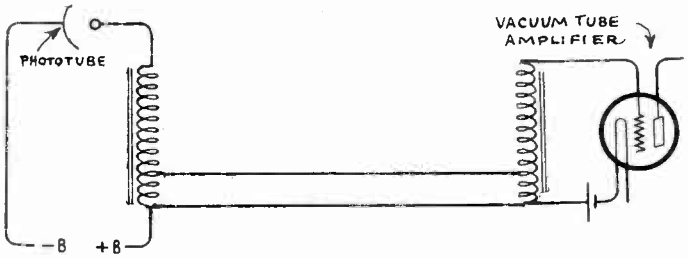

Fig. 10 - AUTOTRANSFORMERS ARE USED HERE TO STEP-DOWN AND STEP-UP THE VOLTAGE.

As the current changes through this resistor due to light variations on the phototube, the varying voltage-drop is applied to the input of the amplifier tube. This system makes it advisable that the first amplifier tube be placed close to the phototube, not only for noise prevention, but also to prevent the capacity of a long cable acting as a shunt at high frequencies.

These troubles are prevented, and convenience of construction improved, by the circuit of Fig. 10, using an autotransformer close to the phototube to step down the voltage. At the desired location of the first amplifier tube a similar autotransformer steps up the voltage which is applied to the grid of the tube. You will note that this satisfies our requirements because (1) the load on the phototube is a high impedance, (2) the input to the amplifier tube is a high impedance, and (3) the connecting circuit has a low impedance not subject to capacity or magnetic effects to any appreciable degree.

<u>INDUSTRIAL USES OF PHOTOTUBES.</u> The articles entitled "Illumination Control" and "Smoke Density" which follow were written by Messrs. W. R. G. Baker, A. S. FitzGerald and J. I. Cornell of the RCA Victor Company and Mr. C. F. Whitney of the General Electric Company, and are given here with illustrations through the courtesy of the publishers of "ELECTRONICS" in which they originally appeared.

Applications of the photocell in the industrial field are for the control of power through the medium of amplifying systems, thyratrons and relays of the light and heavy duty types and, for indicating smoke density, matching colors, counting articles and so on. These topics will be dealt with in the following pages. Thus many devices that were formerly controlled by hand or by clock-work are now controlled by the photocell. For generations light has been considered

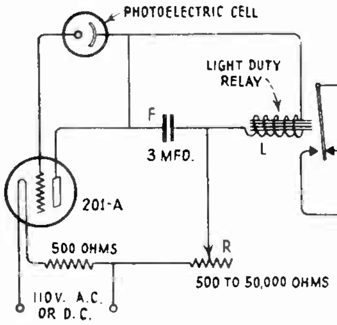

Fig. 11 - A RELAY CIRCUIT WITH PHOTOTUBE AND VACUUM TUBE AMPLIFIER.

only as "something to read by"; of late, however, engineers have begun to realize that beams of light can be put to work. The medium through which light serves for these uses is the surface of an electrode in the phototube which emits electrons under the stimulation of visible or invisible light, as previously explained. These electrons can be used to operate relays and thereby control power of any amount.

A photoelectric cell has the advantage over other devices of being able to operate in periods of unusual darkness during daylight hours which may be caused by a storm for example. Ordinarily during storms apparatus controlled by clock-work would not function. When photocells are used for the switching of incandescent lights used for lighting or for beacons, they are placed in a "window" which faces towards the north so that the direct rays of the sun will not damage the cell. Relays working in conjunction with the light sensitive device make contact when the light shining in the window is less than a certain amount. A typical light-duty relay circuit with photocell and vacuum tube amplifier is shown in Figure 11.

The general scheme for combining several light-duty relays to control many different circuits operated from one light sensitive cell is illustrated in Figure 12. Each relay operates at its own critical current and controls its own heavy duty relay and circuit, although the whole is energized by the same photoelectric cell.

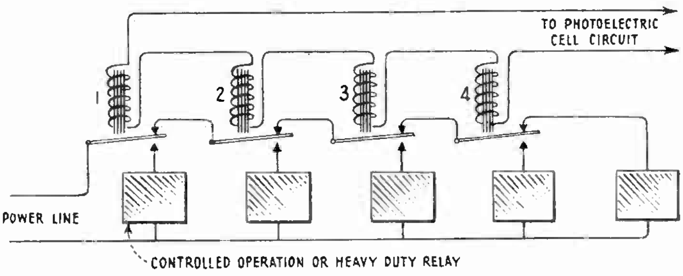

Fig. 12 - AN ARRANGEMENT FOR COMBINING SEVERAL LIGHT-DUTY RELAYS.

A magnetic counting device operated by a photocell is used in many factories at the present time to count the number of articles, such as packages, which pass through a conveyer at a certain point. Any object that is large enough to interrupt a beam of light will operate a photocell, and as a photocell is practically instantaneous in operation, almost any speed may be obtained.

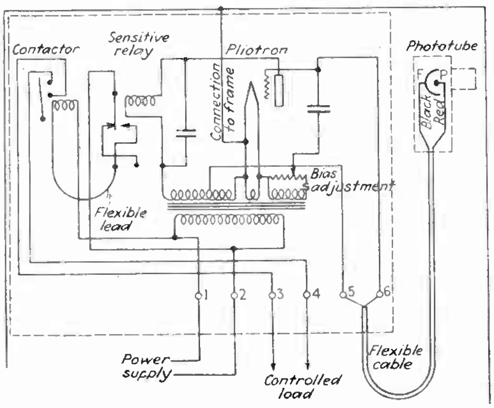

Fig. 13 - CIRCUIT CONNECTIONS OF A LIGHT-OPERATED RELAY.

ILLUMINATION CONTROL. For example, the circuit shown in Figure 13 combines a phototube and triode to form a light-operated relay. The pliotron grid is "biased" negatively by means of a potentiometer across the winding of a transformer and serves to keep the plate current at a low value insufficient to energize a small relay in the plate circuit. A phototube also connects to the grid and a winding of the transformer in such a manner that when light strikes the phototube the grid is made less negative increasing the plate current so that the plate relay is energized. Thus the relay is energized when light strikes the phototube and de-energized when the light is cut off. A contactor capable of controlling usual circuits is operated by the plate relay contacts. By means of normally closed and normally open contacts on the plate relay the contactor may be either energized or de-energized when the light strikes the phototube. The photograph of a commercial unit of this type, illustrated on the front cover, shows the phototube connected to an amplifier and relay unit by means of a flexible cable, thus allowing the phototube to be

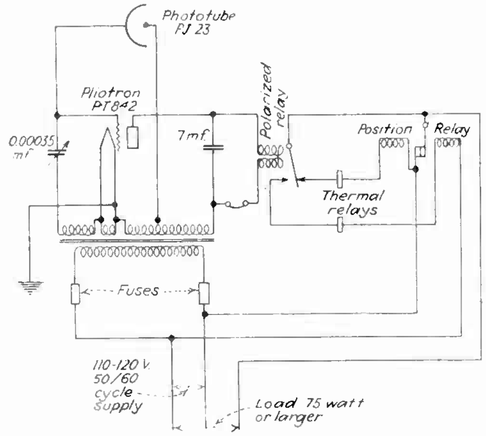

Fig. 14 - THIS CIRCUIT IS ESPECIALLY ADAPTED FOR CONTROL OF ARTIFICIAL ILLUMINATION IN ACCORDANCE WITH DAYLIGHT.

mounted in a variety of positions as required by the application. A modification of the circuit in Figure 13 is shown in Figure 14. Here a phototube and triode are similarly combined, but with special features. The negative bias of the triode is adjusted by means of a variable capacitor which facilitates the setting of the device for operation at a given light intensity. Small thermally operated time-delay relays are interposed between the plate relay and the position

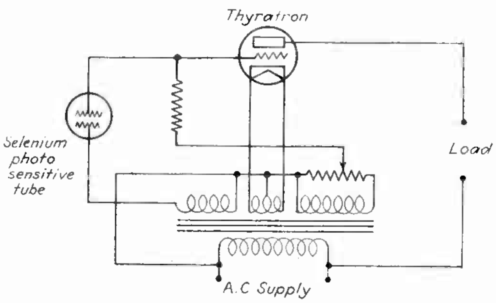

Fig. 15 - A MECHANICAL RELAY IS NOT REQUIRED IN THIS ILLUMINATION CONTROL CIRCUIT.

relay making it necessary for a given change of light to be maintained for several seconds before the position relay is operated. This circuit is particularly adapted for the control of artificial illumination in accordance with daylight. It has been used for street light and sign control. Such apparatus will automatically turn lights "on" and "off."

The circuit in Figure 15 combines a thyratron and a selenium photo-sensitive tube. It provides for illumination control by means of an "on" and "off" relay which is sensitive to light and capable of controlling a large contactor or load directly without the use of a sensitive mechanical relay. When no light falls on the selenium tube the thyratron has positive bias, but when the selenium tube is exposed to sufficient light, this bias is overcome and the thyratron ceases to pass current.

The practicability of the photoelectric cell for regulating traffic lights is being given serious consideration. The Westinghouse Elec-

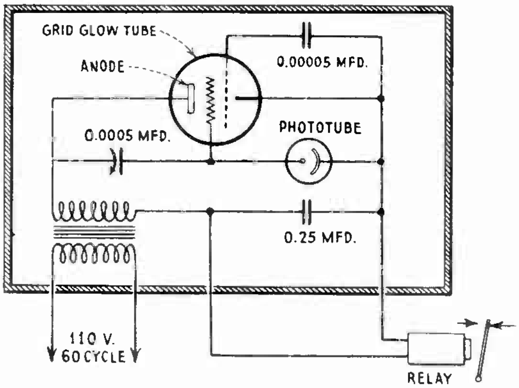

Fig. 16 - PHOTOTUBE SECTION OF A DEVICE WHICH CONTROLS TRAFFIC LIGHTS.

tric and Manufacturing Company has installed traffic lights operated by neon tubes on certain street corners for this purpose. It has long been felt that the stopping of traffic at regular time intervals

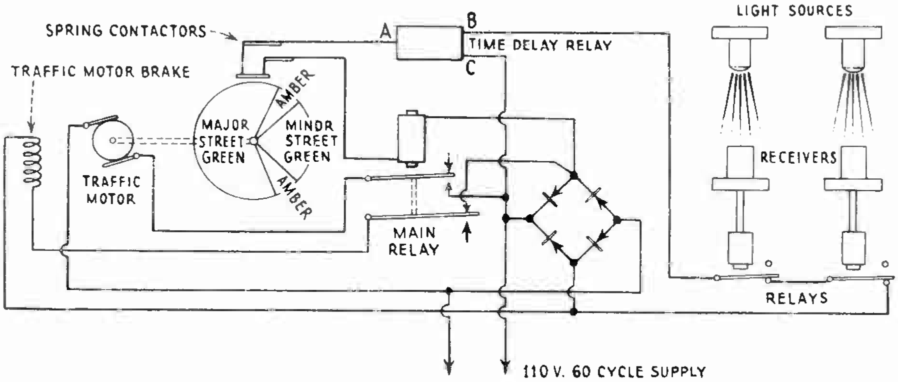

Fig. 17 - THE LIGHT AND RELAY MECHANISM OF A DEVICE USED FOR CONTROLLING TRAFFIC LIGHTS.

on main highways is wasteful of time as very often there are no cars waiting on the intersecting minor street to cross when the main thoroughfare light turns red. The ideal method would be to have a green light on the main thoroughfare at all times giving the right of way to the minor street only when it is needed.

The general arrangement of the phototube circuit and light and relay mechanism are shown respectively in Figures 16 and 17. The function depends primarily upon the interruption of a beam of light by an automobile or any vehicle which comes between the photocell and the light source. In order not to stop traffic on the main highway when cars make a right turn from the highway to the minor street a time delay relay is used which makes it necessary for a car to stop in front of the light beam for a few seconds before the traffic light will change color.

SMOKE DENSITY. Figure 18 shows a schematic diagram of a smoke density recorder which has been built in two units. One box contains a source of light giving a nearly parallel beam, a rectifier-filter system, a photoelectric tube measuring circuit, and a motor-rotated glass dust shield with a wiper to keep the lens system clean. A second box contains a pair of adjustable mirrors set to right angles together with another rotating glass shield with wiper. The shields with cleaning mechanism are important as the smoke to which the whole apparatus is

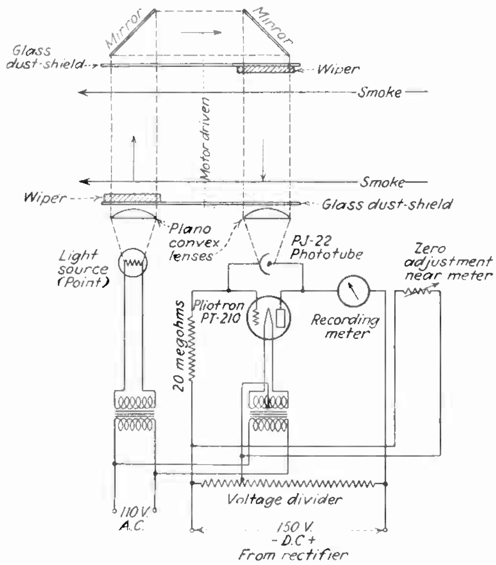

Fig. 18 - SCHEMATIC DIAGRAM OF A SMOKE DENSITY RECORDER.

exposed is heavily laden with carbon, oil, and gasoline fumes. In some cases the units were set about 80 feet apart giving a total beam length of 160 feet.

The system operates as follows: With no smoke interposed between the lens system and mirror system, a fixed amount of light reaches the photoelectric tube which keeps the grid positive with respect to the cathode allowing the plate current to assume a high value. When smoke is carried by the forced draft through the light beam the light is diffused depending upon the density of the smoke. The decreased light on the phototube causes the potential of the grid to become more negative and thus cause a decrease in plate current. This current is brought to the main supervisory control room and a graph is made on a recording milliammeter. A device also made by the Westinghouse Electric and Manufacturing Company for indicating the density of smoke makes use of a combination photocell and amplifier.

The unit is placed in a metal box and is mounted at the end of a small pipe, the end of which opens into one side of a chimney. On the other side of the chimney a lamp is placed so that its rays are directed toward the photocell at the end of the pipe. Thus the rays from the lamp first traverse the smoke in the chimney, then the small pipe, and finally reach the photocell where any change in the smoky medium through which the light rays pass will be recorded and amplified. The output of the amplifier tube is connected to a recorder upon which is kept an accurate record of the smoke density over a period of time. The color of flue gases in a chimney is indicative, to a certain extent, of the quality of combustion in the furnace.

When a chimney emits gases of a dark color it is usually an indication that the fire is poor. A similar device is used in the Holland Automobile Tunnel which connects New York City and Jersey City. The gas fumes given off by automobiles in this tunnel are measured so that the proper ventilation may be maintained to prevent injury to health.

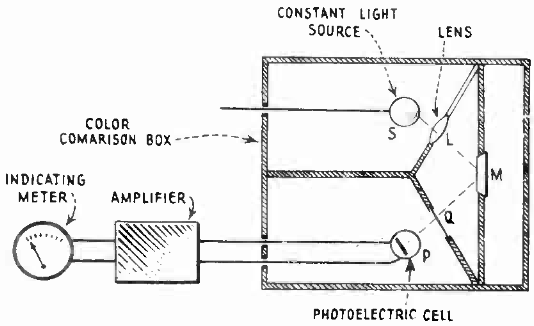

Fig. 19 - ILLUSTRATING THE GENERAL PLAN OF A PHOTOELECTRIC COMPARATOR FOR COLOR MATCHING.

PHOTOELECTRIC CELLS FOR MATCHING COLOR. The photocell may be used in various practical ways for the measurement of different qualities and intensities of light much more accurately than can be accomplished by the eye. This is particularly useful for matching colors.

Figure 19 shows in general how a phototube P, is connected through an amplifier to a meter to indicate any change in color at M. The meter is placed in the plate circuit of the amplifier to provide the indication. A constant source of light S is caused to pass through a lens L and is reflected from any material M whose color is to be compared with that of the standard color glass at Q. If the color of the substance at M is identical with that of the glass at Q no variation will be recorded by the photocell P, and therefore there will be no fluctuation of the indicating meter. The entire unit is made of a light proof material. Color filters may be used to match colors at various points in the spectrum. If, however, the color glass Q is omitted there will be an indication on the meter as the photocell responds to the particular color frequency to which it is sensitive.

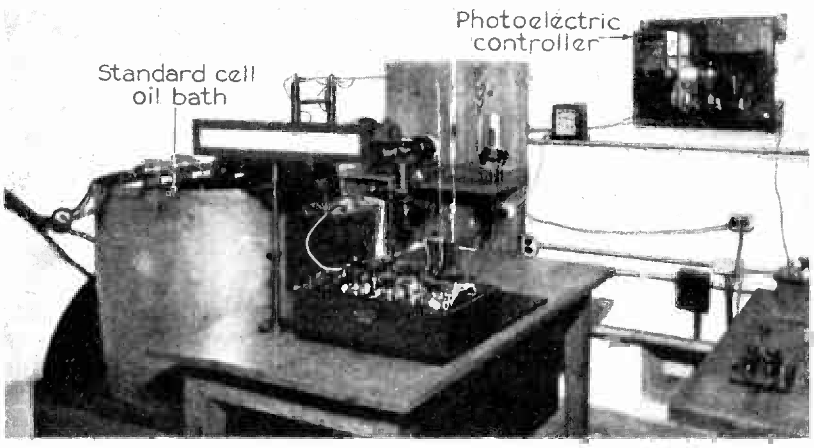

Fig. 20- VIEW OF INSTALLATION USED FOR MAINTAINING CONSTANT TEMPERATURE.

A PRECISION PHOTOELECTRIC CONTROLLER

The rapid strides made in the design and efficiency of electron tubes in the last few years has produced many ultra-sensitive instruments

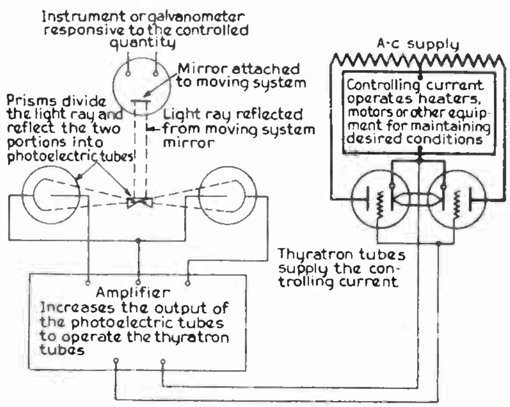

Fig. 21 - DIAGRAM OF CONNECTIONS FOR PHOTOELECTRIC CONTROLLER.

used in the measurement of both electrical and non-electrical quantities. One example is the photoelectric controller, shown in Figure 20, developed by the General Electric Co. for maintaining the standard cell oil bath at constant temperature: the oil bath is in the tank at the left. The schematic diagram of the controller is shown in Figure 21. In brief the equipment operates as follows: The basic instrument is connected across the balance points of a Wheatstone bridge consisting of copper and manganin resistance immersed in the oil bath. The bridge is adjusted to balance at 25° C. and will become unbalanced at other temperatures because of the difference in the temperature coefficient of opposite resistance arms. The illumination on the phototubes will become unbalanced when an unbalance in the bridge deflects the basic instrument. The unbalancing of the illumination on the phototubes sets up a potential which is amplified and applied to the grids of the thyratrons which in turn regulate the value of the heating current passing through resistors placed in the oil bath. The heating effect of the control current is continuously balanced against the cooling effect of water which circulates in the oil bath.

EXAMINATION QUESTIONS

1. What is the principal advantage of the caesium type phototube over the selenium cell?

2. What is the principal disadvantage of any phototube compared to the selenium cell?

3. What is the chief requirement of the load connected to a phototube?

4. What effect on the above is caused by a small capacity in shunt to the load?

5. Describe the structural form of phototubes most used in sound pictures.

6. (a) What is the advantage of a gas filled phototube over the vacuum type?
   (b) What is the disadvantage?

7. How may the gas filled phototube be protected?

8. Why does the photo-voltaic cell not require a battery?

9. Explain simply how a smoke density indicating device works.

10. Name two inventions in which a transfer is accomplished in opposite directions between radiant energy and electrons.

Courtesy General Electric Co.

A PHOTOELECTRIC TUBE OPERATES IN THIS COLOR COMPARATOR USED TO MATCH THE ROAST OF COFFEE BEANS.

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