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PHOTOELECTRIC CELLS; SELENIUM CELLS; THERMOPILES.

The purpose of this communication is to give general information on certain light-reactive devices. Up-to-date developments are to be sought in the current issues of the periodicals cited.

I. PHOTOTUBES: In recent literature the term "phototube" is used as an abbreviation for the type of photoelectric cell which consists of a thin wire electrode (the anode) back of which is placed a relatively large plate of metal (the cathode, of Ni, Ag, etc.), both suitably supported within a spherical or cylindrical inclosure of glass (or glass with a quartz window), transparent to ultraviolet of short wavelengths or, less commonly, of quartz. This inclosure is either highly evacuated or filled with an inert gas. The metal plate, which may be in contact with or on a separate support within the inclosure, is activated with a thin deposit of a metal (potassium, caesium, cadmium, titanium, zirconium) that emits electrons when exposed to radiation of certain wave lengths.

Most of the substances that exhibit a photoelectric response have a high sensitivity in the short wave lengths. The limit of the response in the long wave lengths is determined by the kind of metal used as an activator; and for any one kind of metal this limit is somewhat affected by the presence of water vapor and oxygen during the preparation of the cell. Phototubes are now obtainable commercially in which the long-wave-length limit of electron emission terminates at 2900 A, to 10,000 A. By means of suitable glass filters that limit the short-wave-length response, and a set of photoelectric cells (Wo, Ta, Zr, Ti, Ur, Na, Cs O), in which the long-wave-length limit of the response terminates at the approximate wave lengths 2500 A, 3000 A, 3200 A, 3500 A, 4000 A, 5000 A, and 10,000 A, it is possible to isolate and measure relatively narrow bands of radiation throughout the spectral range, extending from 2500 A to 9000 A without employing a spectroscope.

Phototubes require an external emf for operation. In the highly evacuated type of phototube, if the applied voltage exceeds a certain critical value, the sensitivity (the number of electrons emitted) is not affected by a change in voltage across the cell. It is, therefore, important to operate the phototube above the critical voltage when making precision measurements.

The response of the phototube is practically instantaneous and is not appreciably affected by changes in temperature. In the highly evacuated types (also in some of the cells containing an inert gas) the response is closely proportional to the irradiation, over a wide range of intensities. When subjected to continuous usage, they are likely to become fatigued and, in some types, the sensitive surface may be destroyed. Further data are given in Bureau of Standards Scientific Papers (No. 319), vol. 14, p. 507; 1918, which may be consulted in any of the government depository libraries.

II. <u>BARRIER LAYER PHOTOCELLS:</u> These cells function as a result of electron emission in solids when exposed to the action of light. The phenomenon is practically a transformation of light into electricity. They require no external source of emf for operation. (Some New Thermoelectric and Actinoelectrical Properties of Molybdenite, BS Sci. Papers No. 486, Vol. 19, p. 375; 1924, which may be consulted in any of the government depository libraries.)

This type of cell is regarded as being a dry plate rectifier. In commercial cells a metal plate that serves as one electrode is coated with a thin layer of a light-reactive substance such as cuprous oxide or selenium, upon which is deposited a thin film of metal (or mesh of fine wire) that transmits light to the photosensitive material and at the same time serves as the other electrode. On exposure of the cell to light, electrons tend to pass from the light-reactive layer to the metal thus producing an electric current. Recent commercial developments are the "Photronic Cell" and the "Photox Cell".

The spectral response of <u>selenium</u> barrier-layer photocells extends from the ultraviolet (about 3100 A) throughout the visible into the short-wave-length infrared (to about 9000 A), the maximum sensitivity being in the visible. By covering the sensitive surface of the cell with a suitable glass filter, the resulting spectral response may be made to closely simulate the spectral luminosity curve of the "average eye". Such a photocell and filter combination may be used as a photometer.

The spectral response curve of <u>copper-oxide</u> barrier-layer photocells follows the general shape of the spectral luminosity curve of the "average eye". The response of this type of cell is low in the red, however, being zero for wave lengths longer than 6500 A.

The current response of barrier-layer cells depends upon the external resistance and is approximately proportional to the illumination for low values of external resistance. For high values of external resistance, the current response curve of such cells deviates markedly from proportionality to the illumination. The precautions necessary for using barrier-layer photocells in photometry are described in the J. Research, NBS 25, 703, 1940.

Information on the design, construction and characteristics of light-sensitive cells is to be found in the following publications:

Anderson, John S. (editor), Photoelectric Cells and Their Applications, London, The Physical Society and The Optical Society, 1930.

Koller, L.R., The Physics of Electron Tubes, McGraw-Hill Book Company, Inc., New York.

Campbell, N.R., and Ritchie, Dorothy, Photoelectric Cells; their Properties Use and Applications, London and New York, Pitman and Sons, Ltd.

Hughes, A.L. and DuBridge, L.A., Photoelectric Phenomena, McGraw-Hill Book Company, Inc., New York.

Zworykin, V.K. and Wilson, E.D., Photocells and Their Applications, J. Wiley & Sons, New York.

Morecraft, J.H., Electron Tubes and Their Applications, J. Wiley & Sons.

Dow, W.G., Fundamentals of Engineering Electronics, J. Wiley & Sons.

Fielding, T.J., Photoelectric and Selenium Cells, Sherwood Press, Cleveland, Ohio.

Lange, B., Photoelements, Reinhold Publishing Corp., New York, N.Y.

The monthly journal, "Electronics", published by McGraw-Hill Publishing Company, Inc., New York, covers the whole field of photoelectric devices,--see a recent paper on "Characteristics of Phototubes" (1941).

The literature on photoelectric devices and their properties is extensive; important papers have been published in the following journals:

Electric Journal (1936); Jour. A.I.E.E. (1929); Trans. I.E.S. (1932 and 1937); Proc. Inst. Radio Engineers (1929); Rev. Sci. Inst. (1930, 1931, 1932); Journal Opt. Soc. Amer. (1929); Phys. Rev. (1928); Jour. I.E.S. (London, 1936, full bibliography on barrier-layer cells); R.C.A. Review, July 1941; Proc. Phys. Soc. (London 1939).

Photoelectric cells, commonly called "Phototubes" or "Photocells" are obtainable from numerous manufacturers and dealers, including the following makers of special cells:

Robert C. Burt, Scientific Laboratory, Pasadena, California, (NA-cells);
General Electric Company, Schenectady, New York (Cd-cells);
G-M Laboratories, Inc., 4313 North Knox Ave., Chicago, Ill., (K-cells, also others);
Herbach & Rademan, Inc., 522 Market Street, Philadelphia, Pa., (Caesium);
RCA Manufacturing Co., Inc., Camden, N.J., (different types of Cs-O cells);
Westinghouse Electric & Manufacturing Company, Bloomfield, N.J., (Photocells of Caesium, Cerium, Zirconium, Tantalum, Titanium, etc.);
Weston Electrical Instrument Corp., Newark, N.J., (barrier-layer photronic cells);
Photobell Corp., New York, N.Y., (photoelectric "eye" with many novel applications.

III. PHOTOLYTIC CELLS: These cells function as a result of a change in electromotive force that occurs when a certain kind of electrode is immersed in an electrolyte and exposed to light. They require no external battery. In the early models, first the one then the other electrode was exposed to light to reduce polarization. In recent models, a non-polarizing electrode is used. This type of photoelectric response-device seems to have fallen into disuse.

Reference: "Cuprous Oxide Photochemical Cells", T. W. Case, Trans-Amer. Electrochem. Soc. 31, pp. 351 and 364; 1917.

IV. SELENIUM CELLS: A selenium cell consists of a thin, suitably annealed, deposit of selenium between two parallel conductors mounted on an insulating support. It functions through a change (increase) in the electrical conductivity of the selenium between the conductors when exposed to light. It requires for operation an electric battery in the circuit.

Selenium is one of the first substances observed to have the property of changing in resistance on exposure to light. Because of this change in resistance (and, hence, the electric current flowing in the circuit) is relatively very large, the selenium cell, combined with a relay and an electric battery, in past years, was widely used in many patented applications; and even to this day it is still a subject of frequent inquiry.

The spectral response of a selenium cell to an equal energy stimulus depends upon heat treatment. A cell annealed at 200°C has its maximum sensitivity in the red part of the spectrum, while a cell annealed at 150°C has its maximum sensitivity in the blue-green part of the spectrum. The decrease in resistance on exposure to light and recovery after exposure are not instantaneous, especially when the cell is exposed to light of long wave lengths. At low temperatures the light sensitivity (also the resistance) is far greater than at 20°C.

Since the magnitude and the position of the maximum of the spectral sensitivity of a selenium cell depends upon heat treatment as well as upon temperature and perhaps humidity, and since the response (the change of resistance) of such a cell is not proportional to the illumination, it has been largely superseded by a wide variety of photoelectric cells of the electron emission type, in which the electric current flowing, on exposure to light, is relatively much smaller but is readily increased by means of vacuum tube amplifiers.

Information on the design, construction and characteristics of selenium cells may be found in the following publications:

"Selenium Cells (How Made)", by Thomas W. Benson (Spon and Chamberlain, 120 Liberty Street, New York, N. Y.);

"Selenium Cells and How They are Made", by Samuel Wein (Spon and Chamberlain, New York, N. Y.);

"The Moon Element", by E.F. Fournier d'Albe (D. vanNostrand Company, New York, N.Y.);

"The Selenium Cell, its Properties and Applications", by G. P. Barnard, (R.R. Smith, Inc., New York);

Bureau of Standards Scientific Papers (No. 319), vol. 14, p. 507; 1918. Reprints are no longer available. The original paper may be consulted in the nearest government depository library;

See also summary on Selenium Cells in a book on "Primary Batteries", by W. R. Cooper (D. vanNostrand Company, New York, N.Y.).

The element, <u>Selenium</u>, may be purchased from dealers in chemical supplies, e.g., Eimer and Amend, New York, N. Y.; or J. A. Samuels and Company, 220 Broadway, New York, N. Y.

Selenium Cells may be purchased from the following dealers:

James G. Biddle, Philadelphia, Pa.;
John J. Griffin and Sons, Ltd., London, England;
L. E. Knott Apparatus Company, Cambridge, Mass.;
Hugh H. Eby, Inc., Philadelphia, Pa.

V. THERMOPILES. These are sources of electromotive force which are maintained by temperature differences in an electric circuit. The method of construction, and properties of thermopiles are given in Bureau of Standards Scientific Papers No. 229, vol. 11, p. 131, 1914, on file in government depository libraries. Linear thermopiles (also pyrheliometers) are obtainable from the Eppley Laboratory, Inc., Newport, Rhode Island. Western Electric vacuum thermocouples (for measuring feeble alternating currents) are obtainable from Graybar Electric Company, New York, N. Y. High sensitivity vacuum radiation thermocouples are obtainable from R. C. Burt Scientific Laboratories, Pasadena, California; and from the General Electric Co., Schenectady, N. Y.

VI. MISCELLANEOUS: Bolometers are obtainable from the S. O. Hoffman Company, 835 Howard St., San Francisco, California.

Iron-Clad Thomson Galvanometers are obtainable from Leeds and Northrup Company, Philadelphia, Pa. This firm (also the Weston Electrical Instrument Corporation, Newark, N. J.) makes sensitive d'Arsonval galvanometers.

Portable Ultraviolet Meters are obtainable from the Hanovia Chemical & Manufacturing Co., Newark, N.J.;
General Electric Company, Nela Park, Cleveland, Ohio;
Westinghouse Electric & Manufacturing Co., (Lamp Div.), Bloomfield, New Jersey.

Measurements of Radiant Energy: Edited by W. E. Forsythe (McGraw-Hill Book Co., Inc., New York, 1937). This publication gives general information on instruments and methods of radiometry.

Procedures In Experimental Physics by John Strong and collaborators (Prentice-Hall, Inc., New York). This book describes important experimental procedures.

New types and designs of the above-described photoelectric and radiometric instruments are frequently to be found in the literature and in the advertisements published in "The Review of Scientific Instruments", "Science", "Electronics", the "Journal of Scientific Instruments" (London). A very complete list of names of manufacturers and distributors of photoelectric and photoelectric-control apparatus is published in "Instruments, The Magazine of Measurement and Control" (see the yearly index), published by The Instruments Publishing Company, Pittsburgh, Pa.

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