References and Notes

1. This article is paper No. 1074, University of California Citrus Experiment Station, Riverside.
2. S. E. Flanders, *Mededel. Landbouwhogeschool en Opzoekingssta. Staat Gent.* 20, 257 (1955).
3. J. D. Tothill, T. H. C. Taylor, R. W. Paine, *The Coconut Moth in Fiji* (Imperial Bureau of Entomology, London, 1930).
4. H. S. Smith, *J. Econ. Entomol.* 35, 809 (1942).
5. M. Hafez and R. L. Doutt, *Can. Entomologist* **86**, 90 (1954).
6. G. W. Groff and C. W. Howard, *Lingnaam Agr. Rev.* 2, 108 (1924).
7. P. Forskål, *Descriptiones Animalium, Avium, Amphibiorum, Piscium, Insectorum, Vermium; Quae in Itinere Orientali Observavit P. Forskål* (Post Mortem Auctoris Edidit Carsten Niebuhr, Hauniae, Molleri, 1775).
8. P. E. Botta, *Relation d'un Voyage dans l'Yemen* (Duprat, Paris, 1841).
9. C. P. Clausen, "Biological Control of Insect Pests in the Continental United States," *U.S. Dept. Agr. Tech. Bull. No. 1139* (June 1956).
10. H. S. Smith and H. M. Armitage, "The Biological Control of Mealybugs Attacking Citrus," *Calif. Agr. Expt. Sta. Bull. No. 509* (1931).
11. C. A. Fleschner, unpublished.
12. S. E. Flanders, *Hilgardia* 4, 465 (1930).
13. K. S. Hagen, *J. Econ. Entomol.* 43, 101 (1950).
14. ——— and G. L. Finney, *ibid.* 43, 735 (1950).
15. H. L. House and M. G. Traer, *Ann. Rept. Entomol. Soc. Ontario* 79 (1948), 50 (1949).
16. E. A. Steinhaus, *Principles of Insect Pathology* (McGraw-Hill, New York, 1949).
17. S. R. Dutky, "Method for the Preparation of Sporedust Mixtures of Type A Milky Disease of Japanese Beetle Larvae for Field Inoculation," *U.S. Dept. Agr. Bur. Entomol. Plant Quarantine, E.T. 192* (1942).
18. E. A. Steinhaus, *Hilgardia* 26, 107 (1956).
19. ———, *ibid.* 20, 359 (1951).
20. C. A. Fleschner, *Calif. Avocado Soc. Yearbook* 38 (1953), 125 (1954).
21. ———, *ibid.* 39 (1954), 155 (1955).
22. ———, *J. Econ. Entomol.* 45, 687 (1952).
23. W. E. Ripper, *Ann. Rev. Entomol.* 1, 403 (1956).
24. V. M. Stern, R. van den Bosch, D. Born, *Calif. Agr.* 12, 4, 13 (1958); I. M. Hall and P. H. Dunn, *ibid.* 11, 5, 14 (1957).

CURRENT PROBLEMS IN RESEARCH

Electroluminescence

New light sources, having theoretical as well as practical interest, are created by electroluminescence.

K. H. Butler

The art of producing light has gradually evolved from the original volume sources, typified by a bonfire or a lamp flame, through line sources, represented by incandescent filaments, to point sources, such as the concentrated arc lamp, and finally to a plane source, the electroluminescent lamp.

This newest member of the large family of lamps generates a sheet of light, not more than a few thousandths of an inch thick, by direct electrical excitation of a phosphor embedded in a dielectric layer. This light-emitting surface can be applied directly to a thin piece of metal, giving a lamp no thicker than half a dozen pages of a magazine, with two fine wires leading to a source of power. The simplicity and mechanical strength of the electroluminescent lamp thus presents a striking contrast to the complex supporting structure and fragile glass envelopes of practically all other electrical lamps.

While natural phosphorescent materials must have existed for many thousands of centuries, no known record exists prior to A.D. 980, when it was noted by the Japanese that calcinated oyster shells could store up light by day and give it off at night. After several more centuries other materials were recognized which would convert ultraviolet radiation, or other special sources of energy, into visible fluorescent light immediately. The systematic studies by Becquerel, Lenard, and Nichols between 1860 and 1920 laid the foundations for the modern development of phosphors.

While phosphors are generally excited by bombardment with high-speed electrons, as in television tubes, or by ultraviolet radiation, as in the fluorescent lamp, many other methods can be used to make them luminesce. However, the results are usually only of scientific interest and have no practical value.

In the early 1920's Gudden and Pohl made some noteworthy studies of the luminescence and photoconductivity of zinc sulfide phosphors. In the course of these investigations they found that if a phosphor were excited by ultraviolet radiation, the application of a strong electric field during the phosphorescent decay gave a temporary increase of light emission. Further studies by Schmidt, Hinderer, and Destriau confirmed and extended this observation. Destriau reported also that a strong field applied to certain phosphors, without previous ultraviolet excitation, would give a transient light emission and that if the field were alternating, the light emission would be sustained.

This scientific observation remained essentially dormant until 1950, with some scientists doubting the existence of the effect, until Payne, Mager, and Jerome announced the development of a practical electroluminescent lamp in their report to the Illuminating Engineering Society. Commercial production of the lamp followed immediately.

The potential importance of this unique light source was obvious, and there has been a rapid burgeoning of interest in electroluminescence for the last ten years, with a proliferation of papers in many journals.

In the present article an attempt is made to winnow out and present the more significant facts on electroluminescence from the extensive literature.

Lamp Construction

Basically, the commercial electroluminescent lamp is a flat-plate condenser with the dielectric medium between the two electrodes containing a phosphor in suspension. When alternating current in the audiofrequency range is supplied, power consumption by the suspended particles results in excitation of the phosphor with emission of visible light. Since the light is generated in the dielectric phosphor layer, at least one of the electrodes of the condenser must be transparent or translucent to give a useful lamp.

Figures 1A, 1B, and 1C show three types of construction which have been used in manufacture during the last eight years. In type A, a sheet of glass is

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sprayed while hot with a solution of tin chloride. This treatment gives a conductive layer of tin oxide on the surface, and a display of interference colors in the film shows that the thickness is only a few microns. This conductive surface is coated with a suspension of electroluminescent phosphor in an organic dielectric, usually a thermosetting type of plastic. The thickness of this layer varies from .001 to .005 inch, depending on the operating voltage of the lamp. The minimum value is limited by the size of some of the phosphor particles. A layer of white pigment in plastic is sometimes used over the electroluminescent layer to increase light output because of its high reflectance and to improve voltage breakdown. A back electrode is formed by evaporating aluminum on the organic layers. Contacts to the tin oxide film and to the aluminum film complete the lamp.

While this simple construction gives a useful lamp, an improved construction, described below, has several advantages. These are (i) greater ruggedness; (ii) greater ease of forming complex shapes; (iii) higher breakdown strength, which minimizes localized arcing at large phosphor particles; (iv) elimination of the tendency to carbonize and form a permanent conductive path, if arcing occurs; (v) elimination of evaporated aluminum and, as a result, of some adhesion difficulties between the aluminum film and the dielectric; and (vi) prevention of moisture penetration into the dielectric. Such penetration is generally followed by electrolytic decomposition of the phosphor to give free zinc, with resultant darkening accompanied by a rapid loss of light output.

With organic materials the problem of localized arcing is quite severe for 120-volt lamps, which require a very thin dielectric layer. The short life due to moisture-vapor penetration is more serious and demands, for adequate solution, an additional plastic coat on the back of the lamp to protect the aluminum film, plus a thick wax coating and a sheet of metal or glass behind the wax for mechanical protection. These preservative measures increase the lamp thickness to 3/16 inch, so that the many obvious advantages of a thin sheet of light are lost.

The use of a low-melting glass for the dielectric in which the phosphor is suspended has eliminated many of the complexities encountered with organic dielectrics and has led to type B and C constructions. In type C, a sheet of steel, preformed to the desired shape and size, is coated with a layer of powdered glass of special composition which is fused by heating to a continuous layer. A second coat, consisting of a mixture of the electroluminescent phosphor and ground glass, is applied and fused to the powdered coat. After removal from the furnace, the top surface is sprayed with a tin chloride solution to provide a conductive film. Finally, a clear glass coat is fused over the layers. Since the figure is not drawn to scale, it may be of interest to tabulate layer thicknesses for a typical type C lamp (Table 1).

Table 1. Layer thickness for a typical type C lamp.

Layer	Thickness (10^{-3} in.)
Sheet steel	20.0
Ceramic ground coat	1.5
Phosphor in ceramic	1.5
Conductive film	0.05
Ceramic glaze coat	1.0
Total thickness	24.05

Moisture vapor cannot penetrate glass layers for more than a few microns, so the problem of short life due to phosphor decomposition is nearly eliminated. Glass is conductive when very hot, but the conductivity vanishes on cooling; hence, no permanently conductive paths are formed, even if temporary arcing, due to severe overvoltage, occurs.

Type C lamps are in commercial production, and Fig. 2 shows a typical lamp, together with the clock for which it provides an illuminated face. Type B lamps have specialized uses in various devices which are discussed below.

In addition to these types of construction, some progress has been made toward development of a flexible lamp, where the phosphor is embedded in a thermoplastic resin and electrodes are applied to both sides of a thin sheet. A useful flexible lamp would require formation of a translucent conductive electrode through which the light would be emitted and elimination of moisture penetration into the plastic, which causes short life.

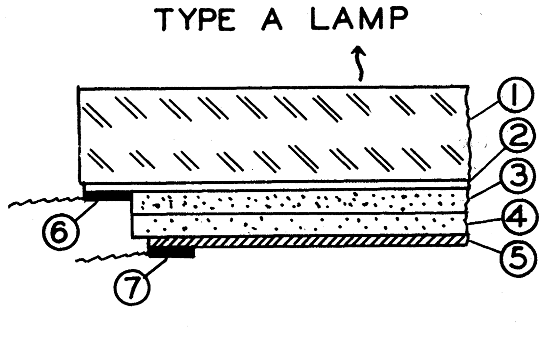


Fig. 1A. Construction of type A lamp: 1, glass; 2, conductive film of tin oxide; 3, phosphor in plastic dielectric; 4, TiO_2 in plastic dielectric; 5, evaporated aluminum; 6, silver paste contact, fused to surface; 7, silver paste contact, air-dried.

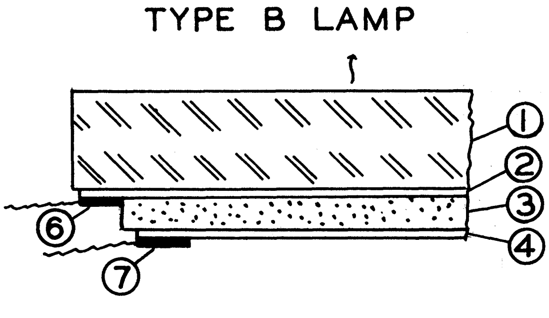


Fig. 1B. Construction of type B lamp: 1, glass; 2 and 4, conductive films of tin oxide; 3, phosphor in ceramic dielectric; 6 and 7, silver paste contacts, fused to surface.

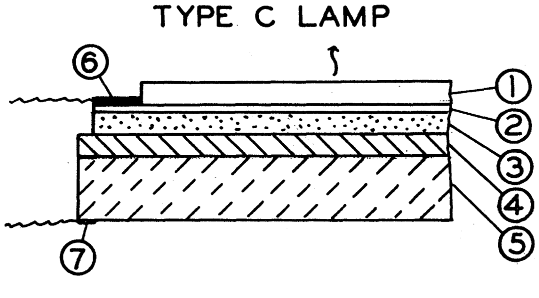


Fig. 1C. Construction of type C lamp: 1, transparent ceramic glaze; 2, conductive film of tin oxide; 3, phosphor in ceramic dielectric; 4, white ceramic ground coat; 5, metal sheet; 6, silver paste contact, fused to surface; 7, soldered contact.

Lamp Characteristics

Since the electroluminescent lamp is an alternating-current device, it can be operated with a wide range of frequency, voltage, and wave form. The amount and color of the emitted light, though primarily determined by the phosphor, are also influenced by the dielectric medium and the power applied.

The best electroluminescent phosphors available at present, showing reasonable efficiency in generating light, are zinc sulfides activated by copper. Control of the copper content allows either blue or green emission to be obtained at will. Addition of manganese, in increasing amounts, gradually suppresses emission at the shorter wavelengths, with concomitant development of emission at longer wavelengths in the yellow-orange portion of the spectrum.

Figure 3 indicates the variation in the spectral energy distribution of the emitted light for three typical phosphors. Other colors can be obtained by overcoating the lamp (by this means an organic phosphor will give excellent reds) or by using phosphors modified by the addition of selenium. These particular energy distributions are obtained with specific phosphors when the lamp is operated at 400 cycles per second. As the alternating-current frequency increases from 100 to 1000 cycles per second, the emitted light changes color, emission at short wavelengths being more pronounced. At higher frequencies, there is little or no additional color change.

In further discussion of lamp characteristics the behavior of green lamps will be indicated, since blue and yellow lamps generally show a parallel behavior, though with some minor variations. The surface brightness and total light emitted by an electroluminescent lamp are strongly dependent on both frequency and voltage applied, as shown in Figs. 4 through 7. It would be more precise, though less convenient in practice, to say that the brightness at a given frequency is determined by the voltage gradient or electric field between the two parallel electrodes. In manufacture, electroluminescent lamps are designed to withstand a voltage either 25 percent above their rated voltage or 100 volts above rated voltage. Because of these two separate criteria, it is convenient to divide lamps into two classes, the first being low-voltage lamps for 120- to 250-volt operation, where the safety factor demands a rather low electric field with consequent lower brightness; the second being high-voltage lamps, for operation above 400-volts, where a higher electric field is possible and where greater brightness results.

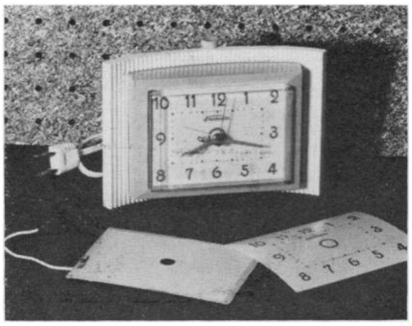


Fig. 2. Typical clock with lamp and overlay for lighted face. [Eric H. Muller]

Figure 4 shows data for a low-voltage lamp, while Fig. 5 gives data for a high-voltage lamp at selected frequencies. These curves of brightness can be represented by the equation

$$B = cf^{a} \exp\,(-\,bE^{-1/2})$$

where B is brightness in foot-lamberts (*1*); f is frequency in cycles per second; E is volts per mil of thickness; and a, b, and c are constants dependent on phosphor and dielectric properties (a is usually within the range 0.50 to 0.75).

Figures 6 and 7 indicate how the performance of a typical high-voltage lamp can be delineated by a modified form of this equation in which actual lamp voltage rather than field strength is used as the independent variable.

In addition to voltage and frequency, lamp temperature causes an appreciable change in light output, as is indicated in Fig. 8. It should be noted that the lamp brightness holds up well at low temperatures but begins to drop sharply when the temperature rises above 150°F. This sharp drop, combined with the low efficiency of the present commercial lamp, limits the useful operating range of such lamps to brightnesses somewhat below 100 foot-lamberts, unless provision is made for cooling the lamp.

As is mentioned above, the electroluminescent lamp has the character of a condenser, but with appreciable power consumption. This is brought out in the curves of Fig. 9, which show brightness, power factor, and current for a low-voltage lamp. The power factor is the ratio of watts, determined on an electronic wattmeter, to the product of volts and amperes, determined as root-mean-square values. Because of the distortion of wave shapes, phase-angle meters give very unreliable results if used for measurement of the power factor of these lamps.

The usual lumped-constant equivalent circuit will not adequately describe the electrical properties of the electroluminescent lamp, since both the capacity and the resistance appear to be nonlinear functions of voltage. Instead of a phase shift of the current with respect to voltage as the power factor changes, a distortion of the current wave shape occurs, with the gradual appearance of an in-

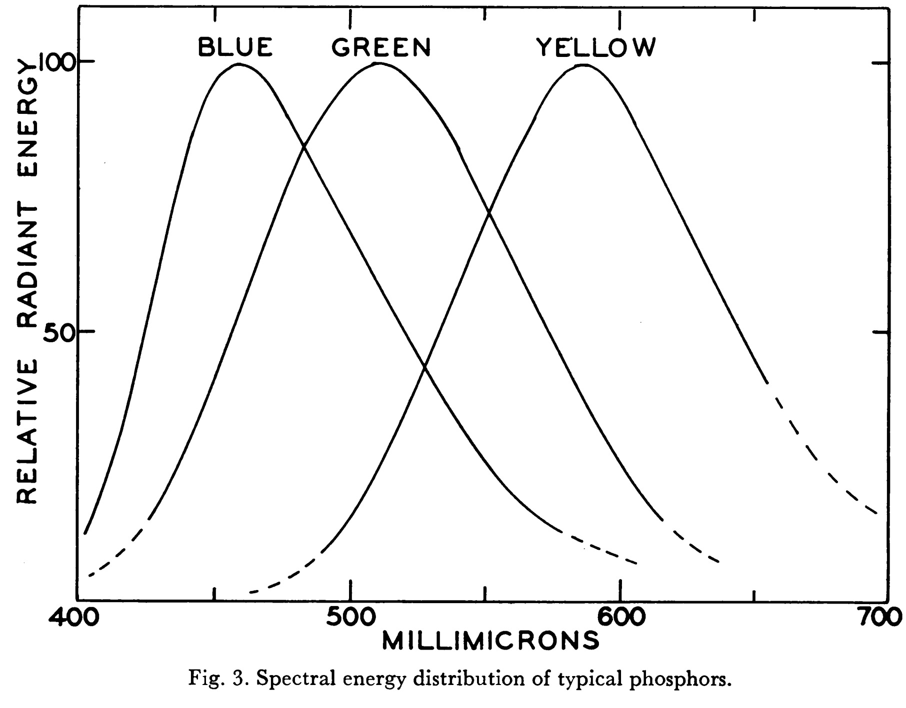
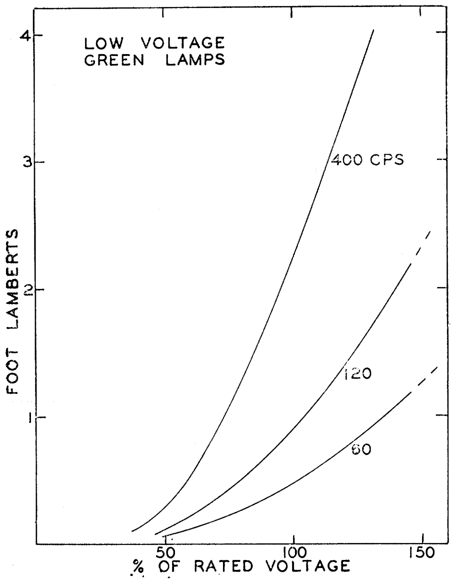


Fig. 3. Spectral energy distribution of typical phosphors.



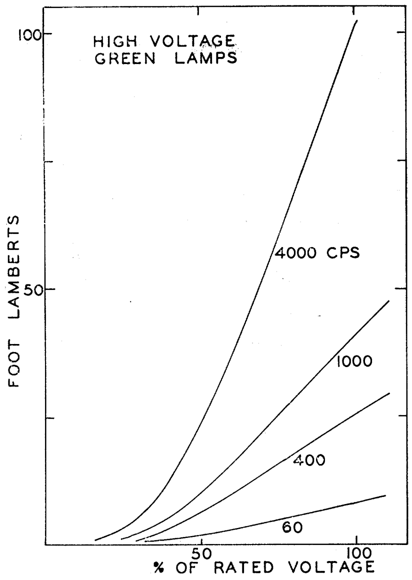


Fig. 4 (left). Variation of light output with voltage and frequency for 120-volt lamps.
Fig. 5 (right). Variation of light output with voltage and frequency for 600-volt lamps.

phase current component as the applied voltage is increased. The light output, however, remains nearly 90 degrees out of phase with the voltage and shows no phase shift, as the oscilloscope tracings of Figs. 10 and 11 show.

If, instead of a dual trace record, the oscilloscope is used to observe current as a function of instantaneous voltage, tracings like those of Fig. 12 are obtained. In this diagram the unshaded areas indicate when the lamp is absorbing power, while the shaded areas represent a release of stored energy. The resemblance to a B-H hysteresis (*2*) loop obtained with magnetic materials is rather striking, though field limitation rather than current saturation occurs, in contrast to the flux saturation at high field strengths evident with magnetic materials.

As an approximation, it is possible to consider an electroluminescent lamp as a nonlinear impedance, the relationship between current and voltage being $I = ZV^n$ ($n = 2$ to 3).

The efficiency of the commercial electroluminescent lamp considered as a light source is relatively low. Commercial lamps of type-C construction will normally have efficiencies of 1.0 to 2.0 lumens per watt in contrast to incandescent lamp efficiencies of between 10 and 20 lumens per watt and fluorescent lamp efficiencies of up to 75 lumens per watt. Design compromises can increase commercial efficiencies to 5 lumens per watt if power limitations require this. While, by designing for efficiency only, electroluminescent lamps of low surface brightness can be made with efficiencies up to 10 lumens per watt, when operated at optimum voltage and optimum frequency.

Solid-State Physics

Electroluminescence, like photoluminescence and photoconductivity, is a frontier region in solid-state physics where the experimental physicist has accumulated a mass of empirical information which is still awaiting an adequate interpretation. The modern theories of solid-state physics were given their first impetus by the need for an adequate explanation of conduction of metals. This need was met by the development of theories for the behavior of free electrons in the conduction band of a crystal lattice of metal atoms.

Every atom has certain fixed energy states (or energy levels) which its electrons can assume. These states can be grouped together in classes which, according to the Bohr theory of atomic structure, are related to the shape of the orbit. To select two examples, one class, the "s" electrons, has two energy levels; another class, the "p" electrons, has six energy levels. When a large number of atoms join together to form a crystal, the original energy levels shift somewhat, because of the interaction of the forces between atoms, so that the fixed energy levels of the separate atoms become an energy band in the solid. Since there are billions of atoms in a real crystal, the energy band contains billions of very closely spaced energy levels, but only one level per atom is present, corresponding with the one level per atom before formation of the crystal. These bands have, however, a fixed width of energy, determined by the particular atoms forming the solid and their arrangement in the crystal and not determined by the total number of atoms in a particular crystal. So we find an energy band for the "s" electrons and another energy band for the "p" electrons, containing $2N$ and $6N$ states, if there are N atoms in the crystal.

If the atoms making up the crystal do not contribute enough electrons to match the total number of available states in a given band, we have a partly filled band. In this case, an electron can gain a little energy and move into empty states in the band. When this occurs, the electron is no longer tightly bound to a particular atom but moves through the lattice freely, just as passengers in a partly filled railroad coach can move freely from seat to seat. One example of this type of solid is copper, where each atom has only one rather than the two possible "s" electrons, so that the "s" band is only half full. The electrons are free to move, and metallic conduction results in the solid.

If the number of electrons matches the number of available states, we have a filled band, and such materials are insulators. The analogy is a railroad coach with every seat filled, where only an interchange of position is possible, with no free movement.

In the individual atom we may have an electron in a given state; when the

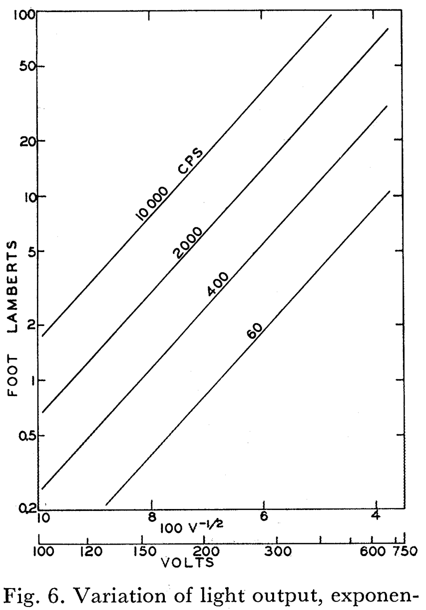


Fig. 6. Variation of light output, exponential equation representation with voltage being used as prime variable.

atom is excited with radiation of the right wavelength, energy is absorbed and the electron enters another state of considerably higher energy which is normally empty. The same phenomenon is possible in solids. By imparting sufficient energy to an electron in a filled band, it can be moved into an empty state in another band, called the conduction band. When this occurs the electron becomes free to move, and conduction results. The analogy is a passenger in a full coach moving into a second empty coach.

In some solids there is a definite energy gap between the various energy bands, which gives clearly defined and well-separated filled and conduction bands. In other solids, the bands are rather broad and overlap, so there is no energy gap; here conduction will occur even though there seem to be enough electrons to fill the band. Such is the case with zinc.

In a further development of solid-state theory, the behavior of rectifiers and transistors led to concepts of impurity states with nearly-free electrons which proved fruitful in the semiconductor field. In these materials the energy gap between the valence band and the conduction band is small, and the thermal energy of vibration at high temperature can give enough impetus to an electron to move it into the conduction band. This is true for pure germanium, which has four electrons but which shows a definite filled band and a conduction band separated by a small gap. If a few arsenic atoms, which have five electrons, are mixed with the germanium in the crystal, the extra electron is nearly free and provides a new energy state, the impurity level, just below the conduction band. Then, the amount of thermal energy needed to make the material conduct becomes minute, and we have quite good electrical conductivity even at room temperature.

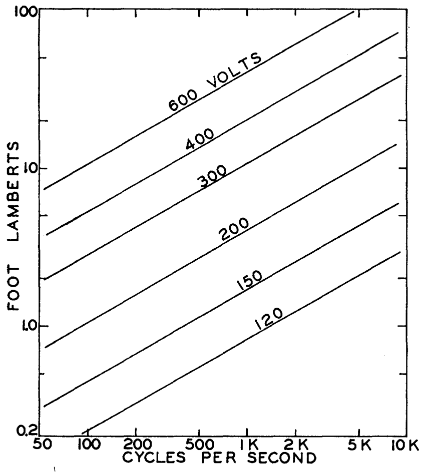


Fig. 7. Variation of light output, exponential equation representation with frequency being used as prime variable.

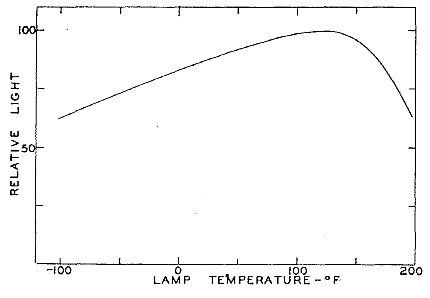


Fig. 8. Effect of lamp temperature on light output.

Thus, important modifications in the original band theories were made when they were extended to semiconductors. In electroluminescent and photoluminescent materials, the energy gap is considerably wider, the concentration of impurities is much greater, and we are forced to consider the behavior of nearly-bound electrons requiring far more than thermal energy to release them into the conduction band. In these fields still further modifications of prior theories are being made, and electroluminescence can well serve as another steppingstone in the gradual development of solid-state theory.

Theory of Electroluminescence

The energy equivalent of green light is 2.4 electron volts, and it is very easy to show that simple acceleration of electrons in a uniform electric field cannot account for the usual type of electroluminescence. The usual electroluminescent lamp has a field of 100 volts per mil, or 4×10^{-4} volts per angstrom. Hence, a free path of 6×10^3 angstroms would be required to accelerate an electron to the energy needed for light emission. Since this is 60 times the mean-free path of an electron in an ideal crystal of zinc sulfide, the ratio of the probable number of electrons reaching this energy to the total number of free electrons is given by log $(n/n_0) = -60$. This infinitesimal number cannot possibly account for any light emission. Moreover, the number of electrons reaching the required energy would vary directly with the field E, while the observed light varies at $E^{\frac{1}{2}}$.

For a better explanation we can turn to the theory of rectifying junctions between metals and semiconductors. Here it is shown that migration of electrons and holes results in a space-charge barrier layer between the metal and the semiconductor and that most of the voltage drop occurs across this barrier layer. The thickness of the layer is given by $D = k(V_0/N)^{\frac{1}{2}}$, where V_0 is the potential drop across the barrier and N is the number of ionized impurity atoms. The field across the barrier becomes $E_0 = k_1 V_0^{\frac{1}{2}}$.

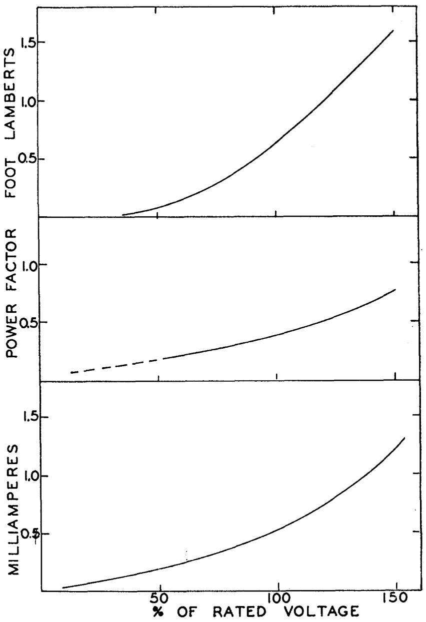


Fig. 9. Variation of light output, power factor, and current for a typical 120-volt lamp; area approximately 12 square inches.

For particles in suspension in a dielectric, the voltage drop across a particle will be $V_0 = k_2 E l$ where l is the length of the particle and E is the field in the dielectric. This voltage will be concentrated at the barrier layer. Thus, we arrive at the result that the barrier-field, E_0, which accelerates electrons, varies as the square root of the dielectric field, E. This is in agreement with experimental data on light emission where the exponent contains $E^{\frac{1}{2}}$ rather than E.

Evidence for the Theory

Consideration of the methods of phosphor synthesis and the results of microscopic observation of electroluminescent phosphors in a field lends added weight to the hypothesis of a barrier layer.

Electroluminescent zinc sulfides are frequently prepared by two firings. In the first firing the activator and coactivator are introduced; this gives a material with excellent photoluminescence but little or no electroluminescence. This material is treated in any one of a variety of ways and refired to give an electroluminescent phosphor. After this second firing, the body color of the material is much darker, suggesting formation of a surface layer of differing composition. Microscopic examination of electroluminescent phosphors shows that the light is not generated all through the particle but rather at localized spots near the surface.

While we have a qualitative hypothesis, which seems reasonable, much work is needed before a firm quantitative theory can be developed on which everyone is agreed. Some of the disputed points are: What are the compositions of the layers on either side of the barrier? Are the layers *n*-type or *p*-type semiconductors? What are the depths of the energy levels below the conduction band? How thick is the barrier layer? What are the electrical properties of semiconductors suspended in a dielectric and how do barriers affect these properties? How efficient is the mechanism of electroluminescence and where do losses occur?

Many approaches to disputed points are being attempted, involving precise experiments on macroscopic crystals, on powders in suspension in various media, and on microscopic particles, either single crystals or polycrystalline particles. New techniques for micromanipulation, for pulse excitation with high voltages, and for measurement of minute amounts of light and of current are being developed. With the various attacks an adequate theory should soon be evolved, serving to guide further research and development.

Applications of Electroluminescence

In spite of the recent advent of the electroluminescent lamp and of the competition from older, well-established light sources, the unique properties of the lamp have already generated numerous uses.

The uniformity of brightness over large areas, combined with extreme thinness, makes the lamp nearly ideal for various lighting uses, such as clock dials, instrument dials, radio panels, aircraft control panels, telephone dials, darkroom safelights, highway signs, and special decorative lighting.

The type-B construction, shown in Fig. 1, can be modified in a variety of ways by breaking up the conductive films into bars or other selected areas. This leads to uses for alpha-numerical indicators, where selected elements of a matrix area are switched to form a numeral or letter. In other applications, it is possible to select and light any one of the *mn* elements by using a cross-grid arrangement in the conductive films such that one film is broken into *m* parallel bars and the other into *n* bars.

The type-B construction also lends itself to devices using electroluminescence in conjunction with photoconductive control. If there is no feedback of light generated in the electroluminescent layer, the device can be used as an image converter, by means of which an x-ray image, an ultraviolet image, or an infrared image projected on the photoconductor generates a replica in visible light on the electroluminescent panel; if visible light is used, we obtain a light amplifier. If feedback is allowed, with provision for localization to discrete areas, light-storage devices can be made in which a momentary pulse of light will cause a selected element in an array to

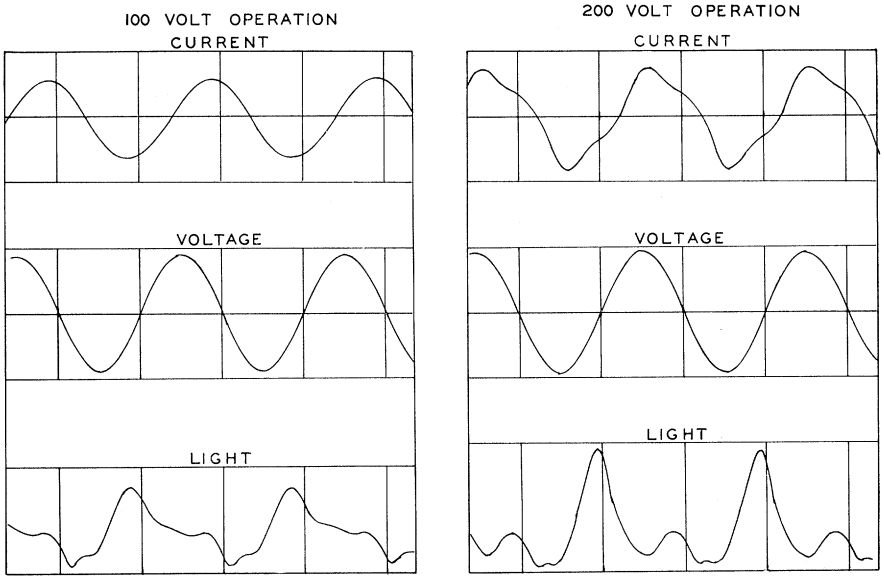


Fig. 10 (left). Oscilloscope traces of current, voltage, and light output for a lamp operated at 40 percent of rated voltage. Fig. 11 (right). Oscilloscope traces of current, voltage, and light output for a lamp operated at 80 percent of rated voltage.

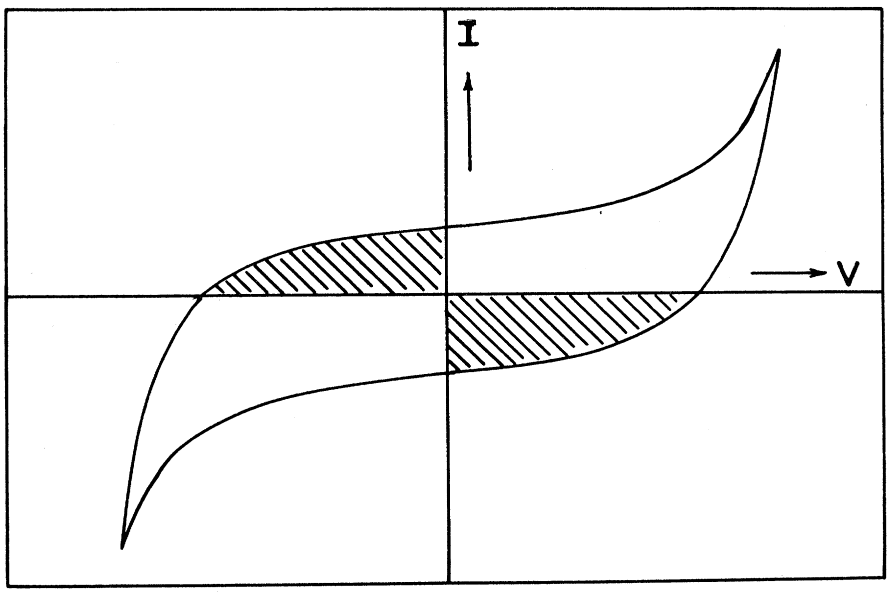


Fig. 12. Voltage-current trace of a typical lamp displayed to give a Lissajous figure.

light and remain lit indefinitely. By further modification the element can be triggered to the lit condition by a pulse of voltage superimposed on the holding voltage and, when desired, can then be turned off by another voltage pulse.

Conclusion

As this brief review indicates, electroluminescence is a true frontier in science and technology, now being explored as a new development in solid-state physics, as a new and useful light source, and as a new tool for development of information displays.

Notes

1. A foot-lambert is a measurement of brightness of a surface emitting light. It is equal to a foot-candle, which is a measure of the light incident on a surface. The usual fluorescent lamps have surface brightness up to 2500 foot-lamberts. Room illumination ranges from 5 to 50 foot-candles.
2. Hysteresis is a phenomenon occurring in the magnetization of steel where the change in magnetization lags behind changes in the field creating the magnetization.

Bibliography

K. H. Butler, C. W. Jerome, J. F. Waymouth, *Elec. Eng. Trans. Am. Inst. Elec. Engrs.* 73, 524 (1954).

K. H. Butler and F. Koury, *Sylvania Technologist* 10, 98 (1957).

K. H. Butler and J. F. Waymouth, *Brit. J. Appl. Phys. Suppl.* 4, S33 (1954).

G. Destriau, *Phil. Mag.* 38, 700 (1947).

——— and H. F. Ivey, *Proc. I.R.E.* (*Inst. Radio Engrs.*) 43, 1911 (1955).

D. R. Frankl, *Phys. Rev.* 100, 1105 (1955).

S. T. Henderson, *Brit. J. Appl. Phys.* 9, 45 (1958).

A. N. Ince and C. W. Oatley, *Phil. Mag.* 46, 1081 (1955).

E. F. Lowry, *Phys. Today* 6, 4 (1953).

E. C. Payne, E. L. Mager, C. W. Jerome, *Illum. Eng.* 45, 688 (1950).

R. M. Rulon, *Sylvania Technologist* 8, 45 (1955).

News of Science

American Oceanography Survey and Proposals for Ten-Year Program Made by NAS–NRC Committee.

The state of American oceanography today and its needs for the future have been assessed by a committee on oceanography of the National Academy of Sciences–National Research Council. The picture is dark now, the committee reports, and will be black by 1970 unless a major effort—a doubling of our deep-sea research during a ten-year program—is undertaken soon. Such a program would cost $651.5 million. According to a spokesman for the committee, the program may be expected to be well received on the grounds that oceanography is viewed by top government science planners as one of the three fields of greatest concern in the next decade. The other two are meteorology and nuclear physics.

This information was made public with the release of the first chapter—"An Introduction and Summary of Recommendations"—of an extensive report to be published later under NAS–NRC sponsorship. The report represents the committee's work since its establishment in 1957 by Detlev W. Bronk, president of the Academy–Research Council. Harrison Brown, professor of geochemistry at the California Institute of Technology, is the chairman.

Principal Recommendations

The three principal recommendations of the committee were that the Government should expand its support of the marine sciences at a rate which will result in at least a doubling of basic research activity during the next ten years; that this expansion should be accompanied by a new program of ocean-wide surveys twice as large as the present one; and that the support of the applied marine sciences should also be expanded, particularly in the areas of military defense, marine resources, and marine radioactivity. These recommendations were coupled with the warning that "action on a scale appreciably less than that recommended will jeopardize the position of oceanography in the United States relative to the position of the science in other major nations, thereby accentuating serious military and political dangers, and placing the nation at a disadvantage in the future use of the resources of the sea."

Reasons for Urgency

A note of urgency runs through the committee's report. In addition to the basic fact that oceanography is an important field that should not be neglected, the committee feels that it will have great bearing on future military and political relationships. It is the committee's view, for example, that "the submarine armed with long range missiles is probably the most potent weapon system threatening our security today." Other benefits of the program, the report states, would be a fuller utilization of the sea's resources, especially in the matter of providing animal protein for the underfed peoples of the world, and a better understanding of the origins and evolution of the planet.

Need for Ships

The ten-year program will require considerable increases in manpower and facilities, the committee reports. Stating that ships are to the oceanographer what cyclotrons or reactors are to the nuclear physicist, the report undertakes to map out a detailed program for the construction of a fleet of research ships which, by 1970, would give the United States a total of 85 oceanographic vessels. The present total is 45, of which number only 25 are classified as "principal oceanographic ships" in an article in *Research Reviews*. The committee's recommendations call for the construction of 70 ships of 500- to 2200-ton displacement between 1960 and 1970 at a total cost of $213 million. New ships are required, the committee states, because conversion of existing surplus vessels to oceanographic duties has been found to be uneconomical and unsatisfactory. Although not specifically mentioned by the committee, there is a competition under way in the field of oceanographic research vessels. The Russians and the Japanese are continually building to improve their fleets. One comparison illustrates the problem. In 1957, the U.S.S.R. commissioned the *Mikhail Lomonosov*, a fully equipped research vessel of 5960-ton displacement. The largest United States ship in the field is the *Spencer F. Baird,* a converted seagoing tug, built in 1944 and displacing 505 tons.

Need for Men

The committee advocated the broadening of educational opportunities in oceanography for graduate scientists through action by universities, the Federal Government, and the scientific community at large. This might be accomplished, the report stated, by increasing the size of oceanographic faculties, by