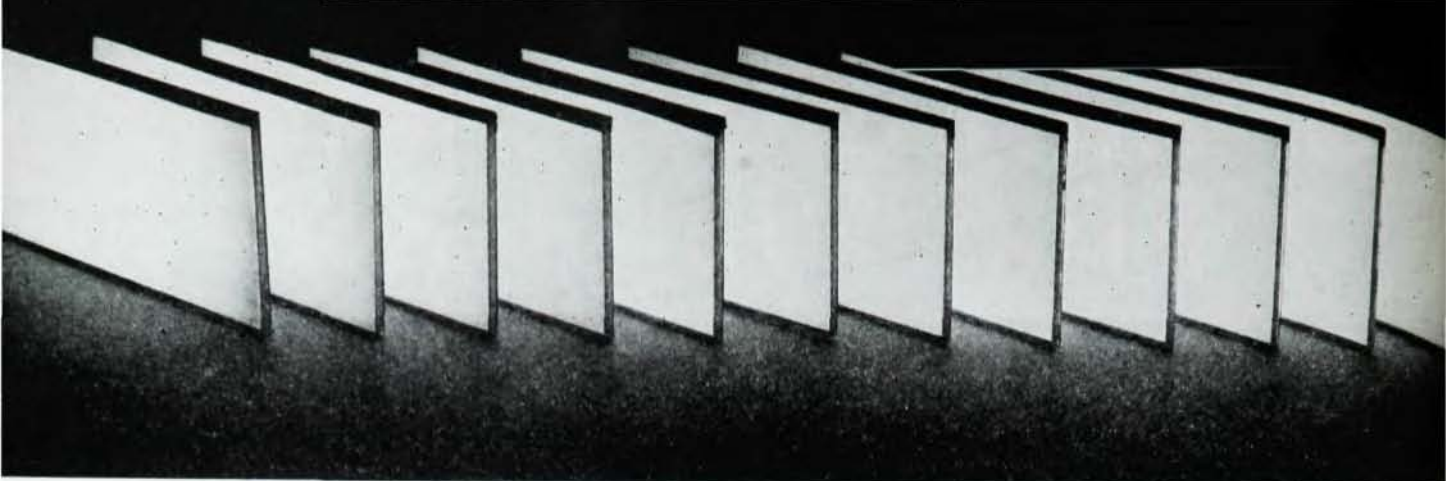




ELECTROLUMINESCENCE

By *Erwin F. Lowry*

Recent developments in illumination have resulted in the addition of an area source of light, the electroluminescent lamp, to the more conventional point source of the incandescent lamp and to the linear source of the electric discharge lamp.

IT IS A CURIOUS THING, but the Dawn of Civilization coincides with the beginnings of Night Life. When our ancestors learned how to light their way to bed, they were able, for the first time, to come down out of the trees. The ability to build a fire was one of the early distinguishing marks of *Homo sapiens*. By reason of the light and heat from the fires he made, he was enabled to establish his career on the ground. The anthropoid ape remained in the trees.

The ability to produce light at will has remained one of the most important assets of the human race. As much, if not more, effort and ingenuity has been devoted to obtaining more and better lighting than to any other branch of technical endeavor. We are proud of our tremendous electrical industry whose growth and accomplishments have been so spectacular. Yet this industrial giant owes its very being to the invention of the incandescent lamp, and at the time this paper is being written somewhere between 25 and 40 percent of all the electrical power consumed in this country is being used to light our homes, stores, and factories, our streets, and athletic fields.

In spite of the enormous economic and social value of artificial lighting and the vast amount of inventive genius devoted to developing new and better light sources, it is curious indeed that for 50,000 years, from the Mousterian age to the latter part of the 19th Century, there was only one way to get a light and that was

to light a fire. We were entirely dependent on combustion as a source of light until Edison developed the incandescent lamp something less than 75 years ago.

It was not until the beginning of the present century that Peter Cooper Hewitt developed the first practical method of generating light by luminescence rather than incandescence. This was the low-pressure mercury arc lamp which bears his name. Another thirty-five years went by before ways and means were found to combine the low-pressure mercury arc with synthetic fluorescent materials to obtain a long-life, high-efficiency light source of great practical usefulness. This was less than twenty years ago!

Up to the present, then, we have had just two methods of generating light—incandescence and the electric discharge. Incandescence is best exemplified by the incandescent filament lamp which is, essentially, a point source. The electric discharge lamp of which the fluorescent lamp is the best example is a linear source.

In view of the tremendous economic importance of artificial lighting, the discovery of a new method of generating light is an exciting development, particularly when this new type of lighting rounds out the line and, for the first time, gives us an area source of light.

Such a discovery is that of electroluminescence by which phosphors may be excited directly by application of an electric field. This phenomenon was described by G. Destriau¹ who spread a thin paste of $\text{ZnS} \cdot \text{ZnO}$ dispersed in castor oil upon a metal plate, and covered this paste with a sheet of mica upon which, in turn, was spread a layer of conducting liquid such as sea

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water. When an alternating voltage was applied between the metal and sea water electrodes, light was emitted by the zinc compounds suspended in the castor oil. This experimental arrangement did not, of course, constitute a practical device and the light emitted was, according to Leverenz,² very dim indeed.

As a result of intensive researches carried on over the past several years, a practical electroluminescent lamp has been developed,³ the light intensity has been tremendously increased, and a great deal of information has been obtained regarding the electro-optical characteristics of this phenomenon.

THE ELECTROLUMINESCENT LAMP in its present form consists of a sheet of conducting glass coated with a thin layer of suitable phosphor suspended in a solid dielectric. The phosphor-dielectric layer is coated in turn with a metal foil, usually a film of vaporized aluminum. Conducting leads are attached to the conducting surface of the glass and to the metal foil. This arrangement constitutes a sandwich in which a phosphor-dielectric layer is spread between two conducting sheets, one of which is transparent. Another way of describing this lamp is to say that it forms a capacitor in which the phosphor-bearing layer forms the dielectric, the conducting glass and metal foil the plates of the condenser. In this instance, of course, we have to do with a luminous condenser because when an alternating voltage is applied to the plates on the condenser, the phosphor-dielectric emits light.

The amount of light emitted depends upon the applied voltage, its frequency, the thickness of the phosphor layer, and upon the phosphor used.

Hundreds of phosphors of various types have been investigated. Of them all, only a few exhibit electroluminescence to any appreciable extent, and even then only those which have been specially treated emit appreciable amounts of light. A phosphor which has been found to be especially suitable for this purpose is zinc sulfide of very high purity which has been activated with copper and lead. Other additives, particularly chlorine and manganese, serve to vary the color so that at present electroluminescent lamps may be constructed which emit light varying in color from blue to yellow-orange. Figure 1⁴ indicates the way in which this color variation takes place. The light emitted is composed of three Gaussian bands centered at 460, 520, and 580 millimicrons respectively. The resultant color of the radiation depends on the relative amplitudes of these three bands. Phosphors containing no manganese and little, if any, chloride radiate mostly at 460 $m\mu$ and, therefore, are blue in color. With increasing amounts of chloride, the green band at 520 $m\mu$ becomes predominant and the relative importance of the yellow band at 580 $m\mu$ increases. The addition of manganese results in a yellow phosphor. If sufficient manganese (1% by weight) is added, a deep yellow-orange luminescence is obtained. The blue and green bands are completely suppressed and the resultant light emission consists of a single Gaussian peaking at 585–590 $m\mu$.

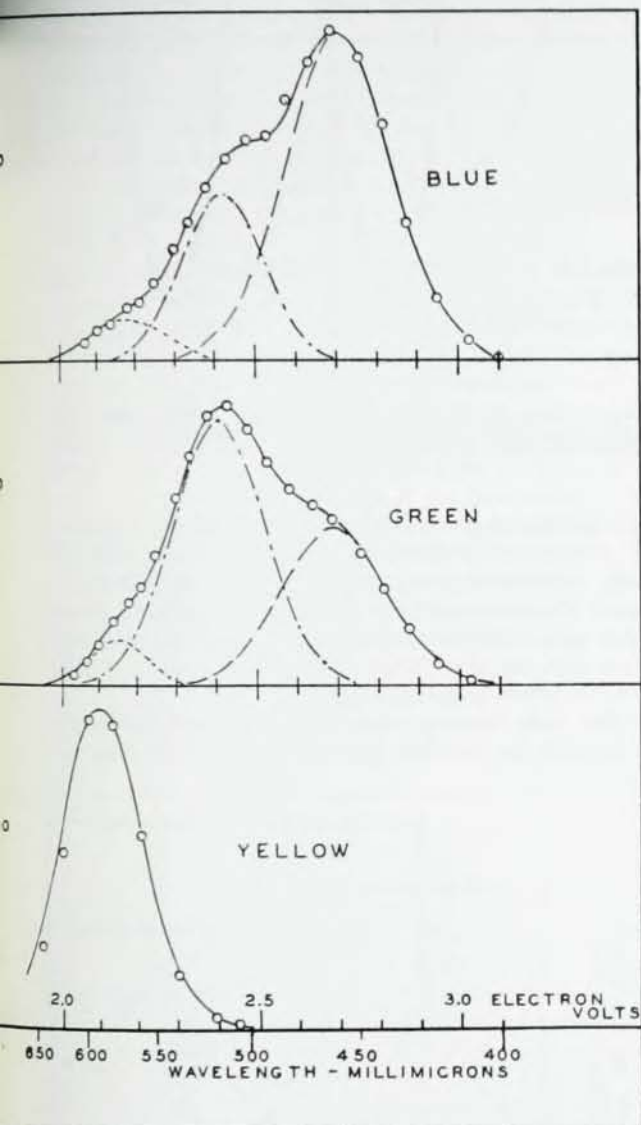


Fig. 1. Curves showing the variation in the Spectral Energy Distribution of Electroluminescent lamps depending on phosphor formulation. The observed values are indicated by the plotted points. The dotted curves show the position and relative intensities of the Gaussian bands which contribute to the resultant overall energy distribution.

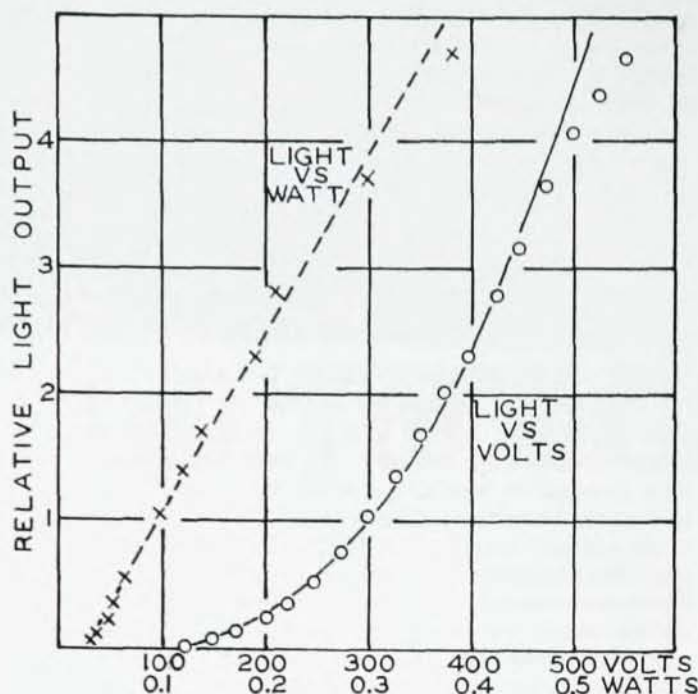


Fig. 2. Curves showing the light output of electroluminescent lamps as a function of applied voltage and as a function of power consumed by the lamp.

The relation between applied voltage and light intensity is shown in Figure 2, which is taken from the Payne paper,³ as is Figure 3 which shows typical phase relationships between voltage, current, and light output. It will be apparent from Figure 2 that the efficiency of light emission does not change appreciably with voltage but that light output varies linearly with the power consumed. Some recent work by Waymouth⁴ shows that light is emitted from these phosphors only at discrete spots (Figure 4). Many of these luminous spots are located at interfaces between two crystallites composing part of an agglomerate, and there probably is a threshold voltage gradient across this interface below which no measurable amount of light is emitted. Furthermore, Waymouth has found that this threshold or minimum excitation voltage varies with the angle between the plane of the interface and the direction of the applied voltage, Figure 5. The exponential character of the curve of light emission versus voltage may, therefore, be explained on the basis that as the voltage is increased more and more active regions are exposed to voltage gradients above the threshold level. If such an effect is added to a linear increase in light output for a given center with increasing voltage above the threshold level, the exponential type of curve shown in Figure 2 should result.

The phase relationships between voltage, current, and light output shown in Figure 3 indicate that electroluminescence takes place only when the energy content of the capacitor is changing, i.e., when both voltage and current are in the same quadrant, and further that

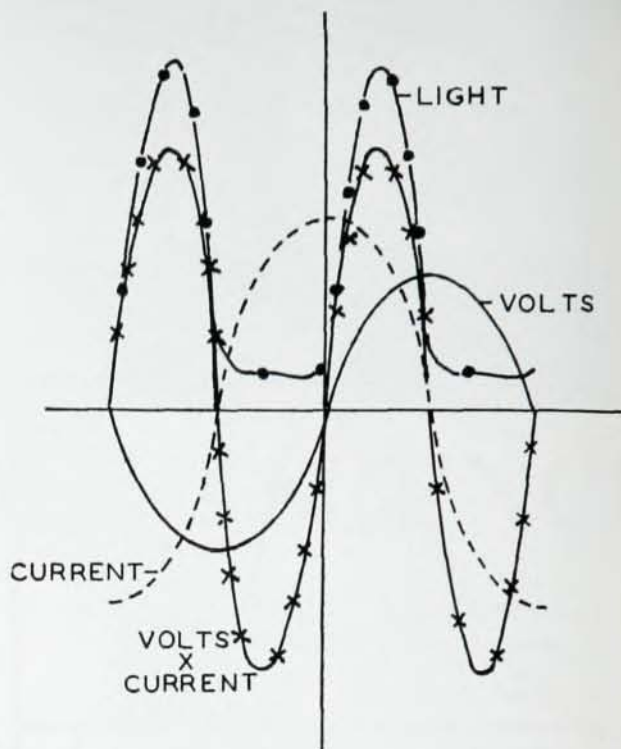


Fig. 3. Curves showing the phase relationships between voltage, current, instantaneous volt-amperes, and light output from a typical electroluminescent lamp operated on 60 cycle alternating current.

no luminescence may be expected when the capacitor is subject to sustained dc potentials. This is undoubtedly the situation when the phosphor is embedded in a good dielectric medium. However, it has been shown that when phosphor crystals are in good electrical contact with the electrodes a steady luminescence may be excited when dc potentials are applied.

Not only does the intensity of electroluminescence vary with the potential gradient but with the frequency

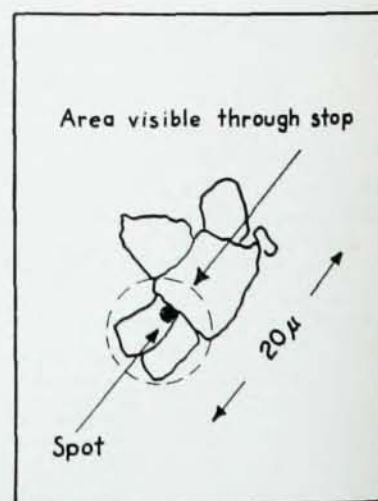


Fig. 4. Sketch of a typical phosphor agglomerate showing the localized luminescent spot at an interface between crystallites.

of the alternating voltage.⁷ The variation of light output with frequency, as well as with applied voltage, is shown in Figure 6. Since a certain amount of light is generated each time the luminous condenser is charged or discharged, it would be expected that the more rapidly this cyclic operation is repeated, the more light would be generated. This increase of light output with frequency tends to saturate at high frequencies as the curves of Figure 6 indicate. There are probably several reasons for this, one of the most important being the time element involved in the activation of the luminescent centers discussed in the next paragraph. Recent lamps give about 6 footlamberts at 600 volts, 60 cycles and between 30 and 50 footlamberts at 1000 cycles and the same voltage. At 6000 cycles, light intensities as high as 150 footlamberts have been obtained. At 120 volts, 60 cycles, the surface brightness of these lamps is between 0.2 and 0.3 footlambert.

IT IS VERY INTERESTING to note that the color and, therefore, the spectral energy distribution of the light from these devices vary with frequency. Some lamps which are green at 60 cycles radiate a pale blue color at 1000 cycles. Waymouth⁴ explains this phenomenon by saying, "The amplitude of the blue (Gaussian) band increases almost linearly with frequency, while that of the green band saturates at about 1000 cps. This can only be the case if the time required to 'activate' blue luminescent centers is very much shorter than the shortest period encountered (5×10^{-4} sec), so that the same number of blue centers are active each cycle, and the total emission from them is proportional to the number of cycles per second." By similar reasoning, it is concluded that the time required to activate green centers is comparable with 5×10^{-4} sec. Therefore, the green luminescence tends to become in-

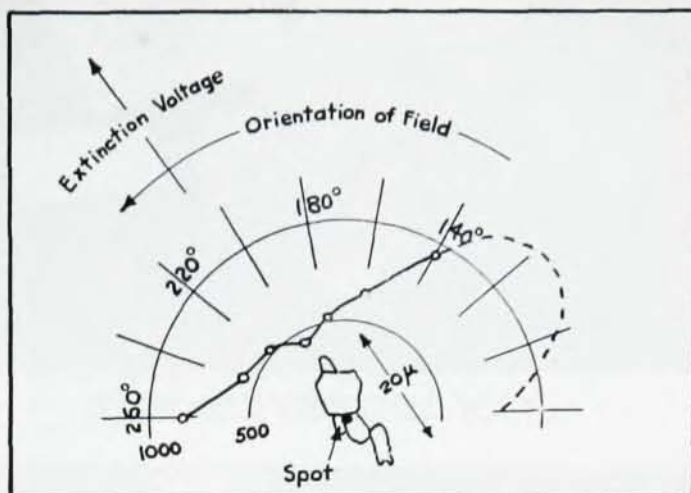


Fig. 5. Diagram showing the variation in extinction voltage as a function of field orientation with respect to the plane of the interface at which the luminescent spot appears.

dependent of frequency at about 1000 cps, whereas the blue luminescence continues to increase linearly with frequency. No similar shift in spectral energy distribution takes place with variations of the applied field.

It is obvious that life and lumen maintenance of any light source are quite as important parameters as is the initial brightness. Figure 7 represents graphically what may be expected from electroluminescent lamps. As a matter of fact, these lamps should have extremely long life since there are no filaments or cathodes to fail, no vacuum conditions to maintain, and no deleterious effects of ion bombardment to contend with. Barring accident, the useful life of these lamps should terminate only when their light output decays to unsatisfactory levels. As phosphors, dielectric materials, and process-

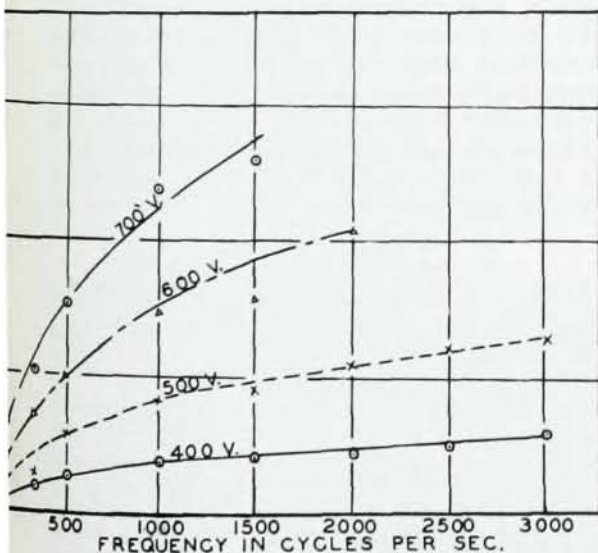


Fig. 6. Curves showing the variation of light output of a typical electroluminescent lamp as a function of frequency for various applied voltages.



Fig. 7. Curve showing the variation of light output from a typical electroluminescent lamp as a function of operating time.

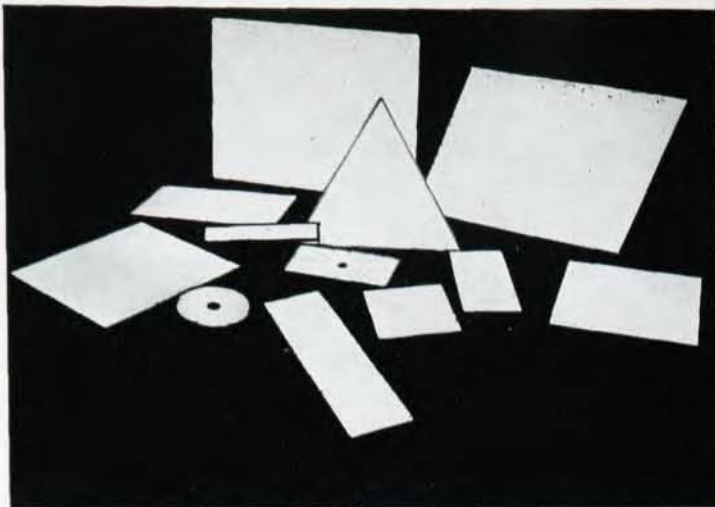


Fig. 8. Photograph of several electroluminescent lamps showing some of the sizes and shapes which are readily fabricated.



Fig. 9. Photograph of a clock and its surroundings. The light by which this photograph was taken was furnished by the electroluminescent dial with which the clock was provided.

ing techniques are improved, the slope of the light output curve also improves. Some lamps show no loss of light output whatever after nearly 3000 hours of operating life.

The luminous efficiency of recent electroluminescent lamps is slightly in excess of 3 lumens per watt under

normal operating conditions. This figure is rather low compared to other modern light sources. However, there are many applications where this type of light source is extremely useful. Any reasonable efficiency is adequate and in many cases high surface brightness is neither necessary nor desired. The fact that electroluminescent lamps are essentially two dimensional light sources emitting light of uniform intensity over an extended area is of paramount importance. These lamps are not necessarily flat sheets. They may be made in any desirable size or shape, provided only that the surface to be activated is one on which the phosphor-dielectric layer may be spread to a uniform thickness. Electroluminescent lamps have been made satisfactorily in sizes from about $\frac{1}{4}$ inch square up to 3 x 6 feet. Extremely large sizes are not too practical because of the difficulties of maintaining perfectly uniform thicknesses of coating over large areas. Some of the sizes and shapes of electroluminescent lamps which can be readily fabricated are shown in the photograph (Figure 8). The largest lamp shown here is about 10" x 10".

At present, the applications for which electroluminescent lamps are best suited are self-luminous objects such as clock or radio dials, house numbers, direction signs, and similar devices. Figure 9 is a photograph of a large clock and its surroundings in which the luminous clock face furnished the light by which the picture was taken.

The light from an 8" x 8" lamp furnishes ample illumination for use as a night light in fairly large rooms (12 x 16 feet). The illumination from such a light source is particularly attractive when the lamp is laid flat on the top of a table or other piece of furniture where the source itself is not visible. Hundreds of similar applications have been suggested which have equal merit.

Although the primary goal of most lamp engineers is to make the most efficient lamp for lighting large areas, the very fact that some 10,000 different types and sizes of incandescent lamps alone are being made and sold indicates the tremendous variation in lighting requirements demanded by our modern civilization. There are any number of applications where an extended area source of relatively low surface brightness is very desirable. The electroluminescent lamp is such a source.

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