Characteristics of Fluorescent Lamps

By G. E. INMAN

The fluorescent lamp is a new type of light source which produces white or colored light at high efficiencies; furthermore, the spectral quality of white light can be controlled as desired. Although the physics of light production of such lamps is somewhat complicated, necessitating extreme care in the design[1] and manufacture, fluorescent lamps are simple in form and easy to operate. A discussion of the operating equipment, color, spectral distribution, temperature characteristics, phosphorescence, and lamp life represent important features which form this paper.

GENERAL DESCRIPTION AND DESIGN

THE fluorescent lamp recently made commercially available is an electrical discharge device which makes use of ultraviolet energy to activate a fluorescent material coated on the inside of the bulb surface. The powdered material may be any one of several or a mixture of definite inorganic chemicals, known as phosphors. These phosphor powders transform short-wave invisible radiation into visible light. They are made synthetically for reasons that they must be carefully controlled for composition, purity, and physical condition to obtain uniformly high efficiencies. The fluorescent powder used must respond to the particular type of ultraviolet generated, and much work has been done in recent years in developing efficient and easily used powders.

The lamp consists, in its present form, of a tubular bulb with two external contacts at each end which are connected to filament-type electrodes made of coiled tungsten wire. These filament electrodes are coated with an active electron emissive material. Within the bulb there is a small drop of mercury and also a low pressure (a few

---

TABLE I—ELECTRICAL RATINGS AND INITIAL LIGHT OUTPUTS OF
FLUORESCENT LAMPS

	18″ x 1″	18″ x 1½″	24″ x 1½″	36″ x 1″
Rated lamp watts...................	15	15	20	30
Rated lamp amps...................	.27	.33	.35	.30
Rated lamp volts...................	63	50	65	115
Rated line volts...................	110–120	110–120	110–120	208–230
Approximate lumens/watt for each available color:				
Blue...........................	18	18	19	21
Green..........................	60	60	65	70
Pink...........................	20	20	22	24
Gold...........................	18	18	19	21
Red............................	3	3	3	3
White..........................	30	30	32	35
Daylight........................	30	30	32	35
Lumens/foot of length for white and daylight......................	300	300	320	350
Brightness in foot-lamberts for white and daylight..................	1220	810	860	1400

millimeters) of pure argon gas to facilitate starting. After starting, the current is carried essentially by the mercury vapor. It remains at a low current density and allows only a small temperature rise, resulting in a low vapor pressure. Under these conditions the desired resonant radiation of mercury at a wave-length of 2537 Angstroms is efficiently produced.

The color of light from fluorescent lamps depends principally upon the chemical nature of the powder but physical form is also important for efficiency and ease of application. Five colored and two white lamps are now commercially available. Three of the colored lamps, the blue, green, and pink, and the two whites all appear white when unlighted; the other two colors, the gold and the red, appear in their natural color since they have additional coatings of colored pigment in order to enhance the desired shades with the phosphors now available. The lamps are being made in three wattage sizes—15, 20, and 30; the 15-watt size in both the 1-inch and 1½-inch diameter tube, 18 inches in length; the 20-watt size in a 1½-inch tube, 24 inches in length; and the 30-watt size in a 1-inch tube, 36 inches in length (Fig. 1). These are listed in Table I where the chief electrical characteristics and efficiencies are given. It will be noticed that the longer lengths are more efficient. For large lighting installations the longer lamp lengths are more practical because of lower lamp cost per foot
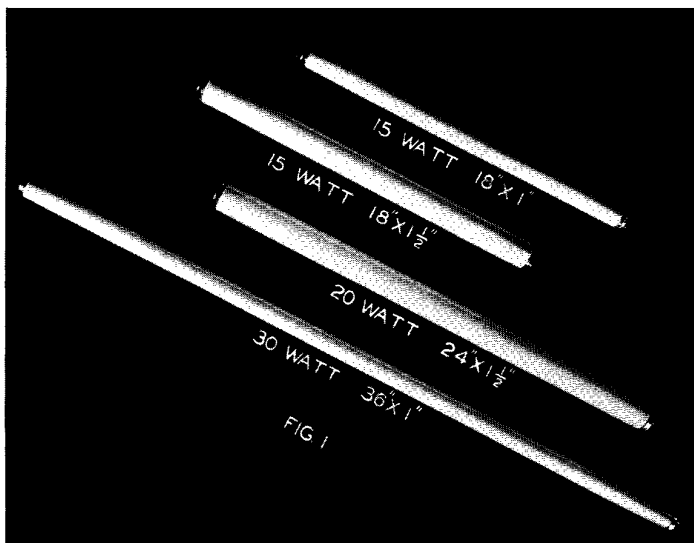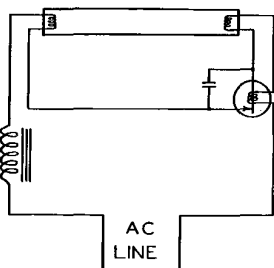
Fig. 1—Photograph of four sizes of fluorescent lamps.

and lower auxiliary cost per foot as well as because of the higher efficiency. The different colors have widely different efficiencies as might be expected. The actual conversion efficiencies of the phosphors are very nearly the same but the lumens vary due to the sensitivity of the eye to the various colors. The brightnesses vary, of course, in accordance with the lumens per foot and the bulb diameters and although the values for only the white lamps are shown they may be figured for the other colors from the data which are given. The 36-inch lamp is designed for use only on nominal 220-volt circuits while the other three are for use on nominal 115-volt circuits. These voltage limitations were made desirable by the starting and operating characteristics and the ballast losses. For greater detail the reader is referred to the A. I. E. E. paper mentioned above.

OPERATION

Fluorescent lamps in common with other discharge lamps have negative volt-ampere characteristics, and require some sort of ballast equipment. In order to simplify starting, this equipment has been made so that the electrodes are preheated. This makes lower starting voltages possible; consequently, the two smaller sizes can be run from 115-volt circuits without stepping up the voltage.
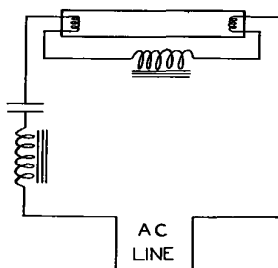
THERMAL SWITCH TYPE   RESONANT TYPE

FIG. 2—Starting and operating circuits.

Several devices may be used for operating fluorescent lamps. In one type of equipment a thermal switch permits current to pass through the filament-type electrodes until they are hot, the switch opening, automatically allowing the arc to strike. An inductive kick from the choke as the switch is opened gives a greater safety factor in starting. It is obvious, however, that occasionally the switch will open when the voltage is close to the zero point in the cycle so that the lamp will not start. In such cases there is about three or four seconds delay until the switch can operate a second time. This type is made small enough to be placed in a standard wireway, such as "Curtistrip". Somewhat the same kind of starting can be accomplished by means of a magnetic switch which operates in connection with the ballasting choke. This switch alternately opens and closes the electrode heating circuit until the lamp draws sufficient current and there is enough magnetic flux to hold the switch open. A third type employs a resonant circuit to provide the necessary heating current and starting voltage. Typical thermal switch and resonant circuits are shown in Fig. 2. Each method which requires a specifically designed type of auxiliary has its advantages. The thermal switch circuit is lowest in cost and provides positive preheating which is conducive to long lamp life. The magnetic switch circuit provides quick starting and a reasonably low cost. The resonant circuit gives quick starting and is free from moving parts. Which one of the circuits will be used the most in the future can not be predicted at the present time. The ballast losses for the 18″ x 1″ lamp run from one to four watts depending upon the circuit and the

A. WITH A LOW COST CHOKE
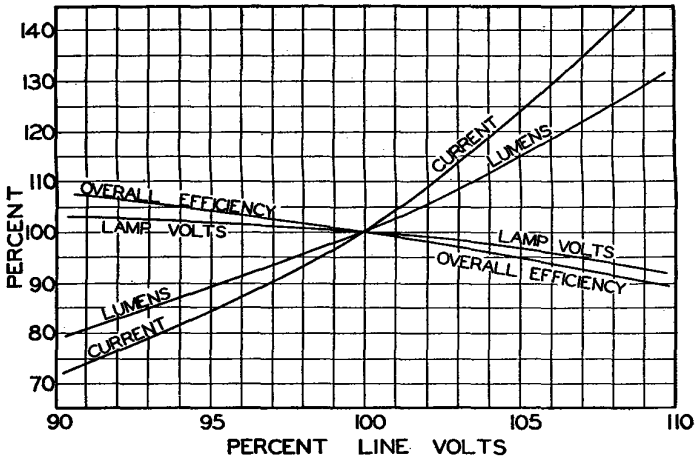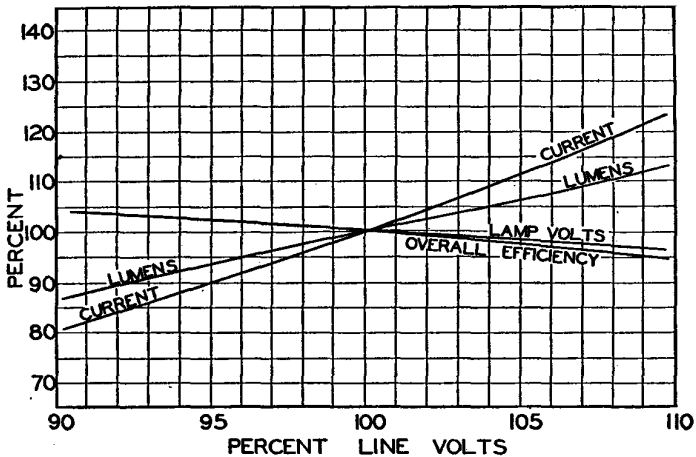

B. WITH A HIGH QUALITY CHOKE

Fig. 3—Characteristic changes with variations in line voltage for a 15-watt, 18 x 1-inch lamp.

quality of the parts. The switch circuits can not be expected to be satisfactory if line voltages are more than 10 to 15 per cent below normal because of the inability of the switches to hold open. The

type of resonant circuit which is shown in Fig. 2, however, will start a lamp with a voltage as low as 50, but operation and performance are unsatisfactory at this voltage.

The power factor of the lamp itself is approximately 90 per cent, being less than unity due to wave distortion.   Practically, however, with the necessary auxiliary the power factor is reduced to 50 per cent to 60 per cent; the power factor is lagging except that it may be either lagging or leading in the case of a resonant circuit depending on the placement of the condenser.   In the hook-up shown in the diagram the power factor is leading.   The momentary (approximately one second) starting current may be about one half ampere for each lamp with its equipment while the operating current is about one quarter to one third ampere depending on the lamp size.

The light output of the lamps is not affected by variations in line voltage to the same extent as is the case with filament lamps.   The wattage delivered to the lamp is influenced, of course, by the type of operating equipment and by the characteristics of the chokes in that equipment but, in general, with the ordinary type of auxiliary using no capacitance it may be said that a one per cent change in line volts means a two per cent change in lumens from fluorescent lamps instead of a three per cent change in lumens as with filament lamps. In the case of the resonant circuit a one per cent change in volts means a one per cent change in lumens.   The curves for lamp volts, lamp current, lumens, and over-all efficiency versus line volts are shown in Fig. 3.   These were obtained using a 15-watt, 18 x 1-inch lamp and standard auxiliaries consisting of (A) a small low-cost choke with thermal switch, and (B) a large high quality choke with a magnetic switch.   It is interesting to note that as the line voltage goes up the lamp voltage goes down and although the lumen output increases the efficiency decreases.   The reasons for this are that the increased line voltage causes the choke to pass more current to the lamp which lowers the resistance of the discharge path and produces the lower voltage drop.   The watts input to the lamp are slightly increased, and therefore the lumens increase over a certain range, but because of the higher current density in the discharge space the short ultraviolet radiation is generated less efficiently.   Consequently, the luminous efficiency of the lamp decreases.

The lamp is designed to give its best, all-around performance at the specified wattage.   Lowering the wattage will not necessarily
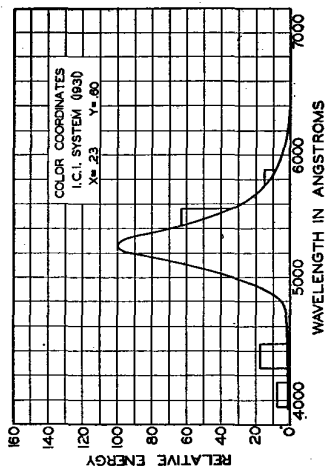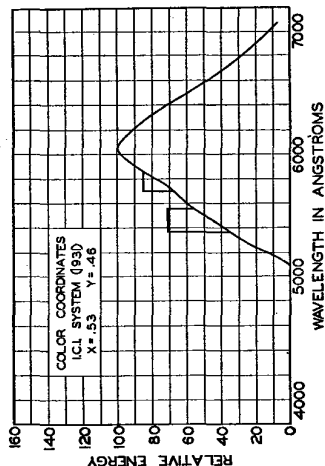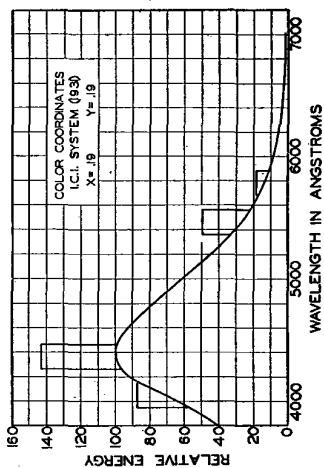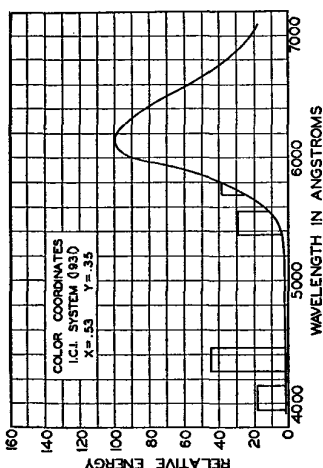
FIG. 4—Spectral distribution of radiation from fluorescent lamps.
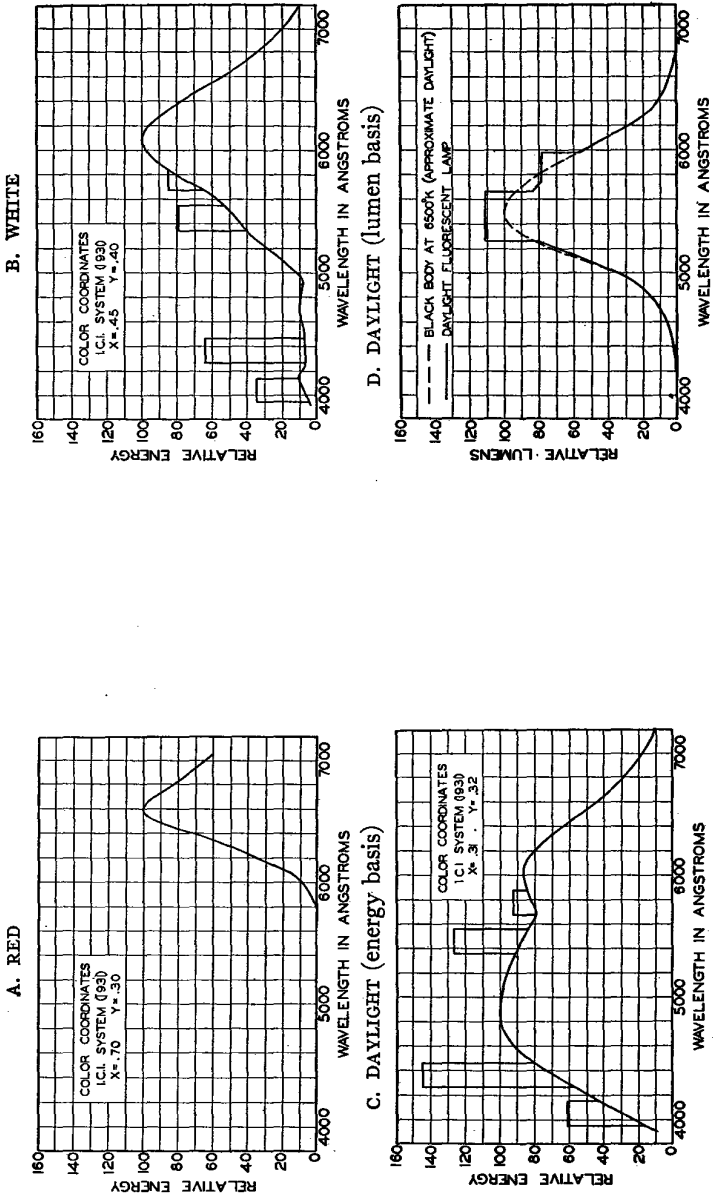
Fig. 5—Spectral distribution of radiation from fluorescent lamps.

increase the life of the lamp as is the case with filament lamps, because such treatment places a greater burden on the electrodes causing them to operate too cool and be bombarded too severely. On the other hand, excessive wattage also causes a shortening of the life due to the more rapid use of the active material on the electrodes.

SPECTRAL CHARACTERISTICS

The light from fluorescent lamps is made up of the broad band spectra produced by the fluorescent powders (see Figs. 4 and 5) and also by the characteristic visible line spectrum produced by the mercury vapor; the latter is incidental to the production of the short ultraviolet. The light from the line spectrum is predominantly blue and influences the resulting color of some lamps to an appreciable extent, since there would be $3\frac{1}{2}$ lumens of mercury light for each watt of input if the fluorescent powder were left out of the bulb. Actually, the per cent of the total radiation represented by this mercury line radiation depends, of course, on the efficiency and color characteristics of the phosphor in any particular type of lamp. It is a small percentage of the total light in the case of the green lamp where the efficiency is high, while it is more pronounced in the case of the pink lamp. In the case of the red lamp, however, where the additional red color coat is used, very little, if any, of the visible mercury lines get through, being absorbed by the red coating.

Single phosphors which produce their own characteristic spectral curves are employed in the five colored lamps. In the case of the white and the daylight lamps, however, three specially selected phosphors in proper proportion are used in each so that a more nearly continuous spectrum is obtained. Thus, by varying the mixtures, definite color temperatures can be standardized. The spectral distribution curves showing the radiated *energy* in the visible range from both the phosphors and the mercury vapor are shown quantitatively in Figs. 4 and 5. In these charts the energy in the mercury lines is indicated by drawing them as if they were bands 200 Angstrom units wide, thus giving an indication of their magnitude by the area under them. Actually, of course, they have no appreciable width and, as a matter of caution, their effect can not be reliably interpreted by an ordinary graph unless experienced judgment is used.

It may be somewhat surprising to see such irregularities in the spectral curves when the lamps have such definite colors. But since the eye is ordinarily less critical of the shapes of these curves than

might be expected, the results when the lamps are used for ordinary purposes are highly satisfactory.   In Fig. 4-A it will be seen that the radiation is confined chiefly to the blue but that there is some in the green.   The curve for the green lamp (Fig. 4-B) is the narrowest one in the group indicating that the phosphor is the nearest to being mono-chromatic.   It peaks at about λ5250 Angstroms which is about 300 Angstroms toward the blue from the point where the eye is the most sensitive.   Its color, however, is more nearly described as a yellow-green than a blue-green.   The pink lamp has a broad curve (Fig. 4-C); it includes some yellow and some of the red.   In addition the two blue mercury lines have a marked effect on its hue.   In Fig. 4-D the broad curve including the yellow and some of the red regions, and with the absence of the blue lines, is indicative of the rich golden color which is produced.   The curve for the red lamp in Fig. 5-A shows that it is confined almost entirely to the red region and that no mercury lines add to its light or change its hue.   This red is slightly deeper than a neon red.

The white fluorescent lamp whose curve is shown in Fig. 5-B is the result of many trials and experiments with the idea of producing a source of light having a warmth to its character and under which people and also various objects would have a pleasing and yet reasonably natural appearance.   All of the colors are present and although their distribution is not similar to that of an incandescent solid they are so proportioned that the results are quite satisfactory.   The color temperature is close to 2800 K but this light source can not be compared directly to a black body radiator.   The daylight lamp (Fig. 5-C) has a color temperature of 6500 K which is the recognized standard value for natural daylight, and represents the light coming from an overcast sky.   The three phosphors in it have been so mixed that their light covers the visible spectrum and the mercury lines approximately make up for the depressions except in the red region.   There is no satisfactory phosphor available which can adequately augment the deep red.   The eye is not very sensitive in this region, however, and the lack of some red and the other more minor irregularities are not easily detected in actual use.

The curves shown in Fig. 5-D are drawn to compare the lumens (not energy) of the daylight lamp with the lumens from theoretical black body radiation at 6500 K which is commonly accepted as being very close to natural daylight throughout the visible spectrum. These give a different perspective than the preceding curve and more
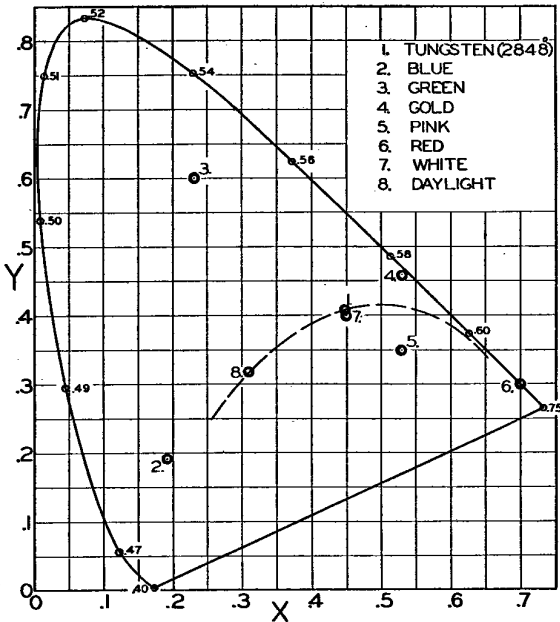
FIG. 6—Color points for fluorescent lamps (I. C. I. System, 1931).

nearly indicate the slight differences which actually exist. In this case the mercury lines are drawn as if 400 Angstroms wide. For very critical color matching the daylight lamp cannot be recommended without reservations, but for this purpose it is undoubtedly superior to any other low priced source on the market today.

In Fig. 6 the points for all seven lamps are plotted on an I. C. I. Color Diagram (1931 System). On this drawing we have shown the black body color temperature curve and have shown the point for tungsten at 2848 K. This corresponds to that for a 60-watt, gas-filled Mazda lamp. Subjective colors represented by additional points between any two or more of the points shown on the chart may be obtained, of course, by mixing light from two or more lamps.

TEMPERATURE CHARACTERISTICS

Since the fluorescent lamp operates most satisfactorily when mercury-vapor pressure is at a certain value it can be said that it is influenced by ambient temperatures. During normal operation

with ambient temperatures of 70 to 80 F the one-inch lamps operate at 104 to 113 F (bulb wall readings). When the ambient temperatures become higher, such as at 90 or 100 F there is a very slight falling off in lumens. At the lower temperatures, however, there is a more serious decline in lumens so that with the thermometer near the freezing point a lamp gives only about 25 per cent of its normal lumens if burned in the open with still air and no protection. This condition may be very largely corrected by using coves, reflectors, shields, etc. For example, with an ambient temperature of 74 F an 18-inch x 1-inch lamp gave 100 per cent lumens, while at 15 F it gave 8 per cent lumens. The same lamp in a fully enclosing jacket of a high quality translucent plastic gave 80 per cent normal lumens at the lower temperature.

Fluorescent light is sometimes referred to as cool light and there is considerable justification for that expression. In addition to requiring less watts for a given light output the fluorescent lamps actually radiate less heat per lumen than do filament lamps. A standard 40-watt inside-frosted filament lamp gives about 475 lumens and radiates 78 per cent of its input or about 31 watts; this radiation, of course, is mostly infrared. The 15-watt white fluorescent lamp gives about 450 lumens but radiates only 47 per cent of its input, or about 8 watts when used bare. This means that for equal lumens from lighting installations using the two types of lamps there is approximately one-fourth as much heat radiated from fluorescent lamps as from incandescent lamps. Most of the waste energy is *conducted* from fluorescent lamps while with the incandescent it is largely *radiated*. In the one case much of the heat stays near the lamps usually in the upper parts of a room while in the other it may fall directly on the persons and other objects in the room. The advantage of the lesser radiated heat from the standpoint of comfort of a person using artificial light and in connection with air conditioning is obvious. However, the total heat will be a direct ratio of the wattage employed.

FLICKER OR STROBOSCOPIC EFFECT

Fluorescent lamps being electric discharge lamps have somewhat the same characteristics as mercury or sodium lamps with respect to the lack of constancy of light flux due to the alternations of the current upon which they are operated. The fluorescent powder, how-

TABLE II—FLICKER OF FLUORESCENT LAMPS

Caused by 60-cycle Current

Lamp	Variation in lumens from mean value
40-watt tungsten..	12%
15-watt green fluorescent...................................	15%

Caused by 10% Reduction in Line Voltage for 3-cycle Interval

Lamp	Reduction in mean lumens 100% volts to 90% volts
40-watt tungsten..	29%
15-watt green fluorescent...................................	13%

ever, has in most cases a persistence of glow, known as phosphorescence, which tends to reduce the flicker effect normally produced by this on and off operation. The phosphor used in blue fluorescent lamps has practically no phosphorescence and, consequently, between each half cycle their light output drops to less than 10 per cent of the peak value and the stroboscopic effect is quite noticeable. The green lamps have a very marked phosphorescence of short duration which practically eliminates cyclic flicker. The pink and red lamps are even better from this standpoint. Figures are given in Table II showing the actual results for green fluorescent lamps versus tungsten lamps with respect to cyclic flicker; also with respect to flicker caused by momentary reduction in line voltage.

LIFE

The life of a lamp is influenced by many factors—not only by precision of manufacture, the circuit, the operating equipment, and line voltage, but also by certain other operating conditions. In general, lamps of this sort lose their usefulness due to lumen depreciation before they fail to operate. Darkening of the bulb occurs because (1) of the effect of mercury on the fluorescent coating and (2) of material given off by the electrodes. The latter especially contributes to the darkening at the ends of the bulb, which occurs late in life. The rate of depreciation in light output diminishes throughout life; the first hundred hours produces as much or more darkening as the following 1000 hours. The per cent lumens at 1000 hours' life

may on the average be expected to be as good or better than for vacuum filament lamps of the same colors.

Frequent starting of lamps may take more life out of the electrodes than long hours of burning because momentarily there is a higher than normal voltage drop at the electrodes which sputters off the active material. If a lamp is started once a minute, for example, the hours of burning will be shorter than normal, but if it is turned on and burned continuously its life will be longer than normal. Flashing with the present lamps and equipment can not be recommended. When the active material on the electrodes is used up the voltage required for starting and operating becomes too high and a lamp is then said to have failed. Under ordinary circumstances, however, it may be expected that fluorescent lamps will live longer than the standard filament lamps.

The author wishes to acknowledge the assistance of Dr. B. T. Barnes in collecting data for the spectral distribution curves.

DISCUSSION

MATTHEW LUCKIESH: With levels of illumination rapidly increasing in lighting practice, heat and heating effect become serious problems. One interesting aspect of higher levels of illumination is the radiant energy accompanying the foot-candles. For equal foot-candles at a thermopile (with only air between it and the light-source) A. H. Taylor of our laboratory found the following approximate values of relative radiant energy:

Daylight fluorescent lamp	1
Tungsten filament lamps:	
30-watt T-8 lumiline	10
40-watt A-19 bulb, inside frost	5
100-watt A-23 bulb, inside frost	4.5
200-watt PS-30 bulb, inside frost	4
500-watt PS-40 bulb, inside frost	3.5

We also found that a sheet of quartz 1.5 mm thick transmitted about 38 per cent of the radiant energy from a daylight fluorescent lamp and about 80 per cent of the energy from the various tungsten-filament lamps. The values for ordinary plate glass $\frac{1}{16}$ to $\frac{1}{8}$ inch in thickness were about 33 and 70 per cent respectively for the daylight fluorescent lamp and tungsten-filament lamps. Obviously by placing a piece of clear glass between these light-sources and the surface to be illuminated the foot-candles supplied by the fluorescent lamp are still more

"cool." Obviously, under these conditions at least ten times more radiant energy accompanies a foot-candle obtained from ordinary tungsten-filament lamps than from daylight fluorescent lamps. Of course, air conditioning must take care of the total energy introduced into an interior.

This low energy per foot-candle is bound to be a desirable factor in addition to the other favorable characteristics of the daylight fluorescent lamp. Incidentally, it is interesting to compare data Mr. Taylor obtained some time ago (*The Science of Seeing*, Luckiesh and Moss, p. 450) of the relative energy per foot-candle reflected from ordinary white paper used for printing purposes. For natural daylight and tungsten lamps we obtained approximately the following relative values of energy reflected from a newspaper for equal foot-candles:

Skylight through window-glass	1.0
Skylight through open window	1.3
Tungsten filament lamps:	
60-watt	12.2
100-watt	10.1
500-watt	7.8
1000-watt	7.5

Thus it is seen that the possibilities of simulating natural daylight extend beyond that obvious from the luminous efficiency of the daylight fluorescent lamp and the quality of light it supplies.

Roy A. Palmer: It is only a few years ago that the illuminating engineer needed to give consideration only to the visible part of the spectrum. As I have been listening to these two papers on fluorescent lamps, I have been impressed with the fact that we have had to extend our thinking into not only the visible but also the invisible portions of the spectrum.

Our knowledge of incandescent lamps, their characteristics and their operation, has extended over a period of years, and therefore we have become quite intimately acquainted with them. In fluorescent lamps we have an entirely different type of light source in its operation. In some cases, it is diametrically opposite to the tungsten filament. Therefore, to apply these lamps in a practical way, we have had to learn something about the invisible portions of the spectrum. We now must become thoroughly familiar with the data regarding the

operation of these lamps so that we can design, recommend and install them to the best interests of the customer.

One thing that has impressed me is the fact that, whether the lamps are burning over-voltage or under-voltage, in *both* cases the life may be affected adversely, which is somewhat different from our thinking as applied to incandescent lamps. With fluorescent lamps then, the problem of proper wiring to assure good voltage regulation is as important, if not more so, than with tungsten-filament lamps.

In Mr. Inman's paper he states that the desirable resonant radiation of mercury is efficiently produced at a wave-length of 2537 Angstroms. I should like to ask why the particular wave-length, 2537, is more desirable than some other wave-length. I assume that we get the brightest fluorescence from the powders and also that we are getting the most efficient production of ultraviolet radiation at that point.

This is a low-pressure lamp, and I assume that it is low pressure in order that we might obtain the maximum 2537 radiation, but I am wondering what would happen if higher voltages were used. What effect would that have on the resonant radiation wave-length?

In the case of the red fluorescent lamp, where we are using mercury which has a characteristic blue-green spectral quality, would it be practical or desirable to use neon gas which has a reddish spectral quality, and thereby take advantage of that in the production of red light?

The paper states that we are getting about $3\frac{1}{2}$ lumens per watt useful light or visible light from the mercury. In the case of all of these lamps, then, I assume that we are using that visible radiation of mercury to the best possible advantage. I should like to ask if the fluorescent materials transmit most of that visible radiation or just how is that utilized? Is the coating so thin that that radiation can get through and thereby become useful in the production of light?

Another thing that I think we ought to emphasize, and I again bring out the point Mr. Inman made, is the fact that while these lamps will last considerably over 1,000 hours of useful life, they will still continue to burn, and in many cases, as we all know, users are going to continue to burn those lamps as long as they will burn, regardless of whether or not they are delivering the maximum lumen output that it is possible to obtain from a fluorescent lamp. Therefore, we have a new educational job to do in convincing users that they ought to operate the lamps only until the brightness of the lamp has become lowered through darkening and then replace them with new ones,

which is going to be quite a problem on the part of the lighting engineer in the field.

Of course, the most interesting thing to the laymen about these lamps is the fact that they are available in wattages of 15, 20 and 30-watts, which are very considerably lower wattages generally than we have been talking of in years past. On the part of some utility men, I have noted that they are rather skeptical because of the low wattage of the lamps. I do not believe it is necessary to point out to this group, because it is rather elementary to all of us, that that will not be the case. These new lamps are creating new sockets, there are new applications, and in addition, where they may be replacing old sockets that formerly used higher-wattage lamps, it is going to be possible to increase the levels of illumination, requiring additional wattage. What is even more important, we have found always that whenever we give a customer better lighting, he is going to use more of it. Where we have poor lighting, it doesn't make much difference whether it is turned on or not, but where we can have good lighting it invariably will be used longer hours. In the k w h, the k w may be smaller but the h is going to be bigger. Therefore, in the use of these lamps we can look forward to an increase, not decrease, in the revenues of utilities, as well as to greater usefulness to the consumer.

A. L. POWELL: There is a problem in connection with the use of the 208-volt type of lamp on three-phase, four-wire systems. In many communities there are local rulings requiring the grounding of the neutral. It has been pointed out that where ordinary fusing is used across both sides of the 208-volt line, and one fuse blows for one reason or another, one side of the circuit will still be 120-volts above ground. The solution of the wiring complexity is entirely a local problem. But in my belief the way to get around such conditions is to install a small two-pole circuit breaker of the proper capacity, and if the circuit opens up at all, both sides of the line are dead.

ROBERT W. JEFFERY: In Fig. 5-D we have a curve showing the daylight characteristics of the lamp. In the center of that curve we have a block showing the mercury lines. Farther along in the paper the author states: "For very critical color matching the daylight lamp cannot be recommended without reservations." I wonder if the author would care to elaborate on that particular point?

WARD HARRISON: Five speakers appeared on the platform this morning reporting on industrial lighting studies. I wish I had kept track of the number of times they used a certain phrase, but I didn't think of it until several of them had finished, so I will have to guess. My guess is they used that phrase between ten and twelve times, and the phrase was this: "The best results were secured with a source of large area and low brightness."

In fluorescent lighting, we do have "a source of relatively large area and low brightness"; also when used in some of the parabolic troughs which you have seen in the displays here, fluorescent lamps give you very excellent artificial ceilings or artificial windows.

While all of the slides and most of the conversation about fluorescent lamps this morning have been in regard to commercial installations, I think you are going to find that this lamp represents the solution of a number of your vexing problems in industrial lighting, particularly the ones where you need high foot-candle values and you find that with the incandescent lamps you are bothered by heat.

Considerable has been said too about daylight quality. Almost every advance in illuminants we have had in thirty years has been accompanied by the claim that the new lamp gives practically "daylight quality." In most cases this has been a gross exaggeration due to over-enthusiasm, pardonable or otherwise.

However, we believe that this daylight fluorescent lamp is close enough to daylight for nearly all practical purposes. Mr. Inman pointed out that there is some deficiency in the extreme red end of the visible spectrum, but this is slight. We have made quite a number of color comparisons with daylight, and we have not yet discovered cases where with colored materials that departure from daylight was sufficient so that we could detect it. We are a little suspicious that on certain classes of whites the absence of that long wave-length red, strangely enough, may be discernible, where it isn't on colors.

I do not think, however, that you ought to feel that you are at the end of your rope if you should run into a color problem where this lamp, in the opinion of the inspectors who had to use it, failed to equal daylight. For these rare instances, combination with incandescent lamps, for example, lumiline lamps, will, of course, supply all the red which may be desired. In this case some blue-white fluorescent lamps may be added also to keep the color temperature up to 6500 degrees with such combinations.

There is one other subject that was mentioned, namely, the power factor. Fluorescent lamps give about twice as much light as incandescent lamps of the same wattage, and this should be a great boon to thousands of people who want more light, but who are stymied because their wiring is already overloaded. However, the power factor of fluorescent units is 60 per cent, which just about cancels the advantage they would otherwise have in providing more light from existing wiring. The power factor must therefore be corrected, and devices are already available which will do this for an entire circuit. Capacitors for one lamp or a small group of lamps are also under development.

LEONARD V. JAMES: I just want to supplement the remarks that have been made about the use of these lamps for industrial purposes by reporting to you that 300 of the 30-watt lamps have been installed recently over the pairing tables in the Real Silk Hosiery Co. mill at Indianapolis, with wonderful satisfaction to all concerned. I thought it would be encouraging to you to know that the lamps are not being used merely in a small way but that a reasonably large installation of this character has been made.

E. D. ALTREE: Since we know that the fluorescent coating of these lumiline lamps is fairly opaque to transmitted light, I should like to ask Mr. Inman if he would tell us whether or not, in the design of indirect luminaires, in which a number of one or more sizes of fluorescent lamps are used, it has been found necessary and, I presume, certainly desirable, to use individual reflectors inside the luminaires in order that the maximum utilization may be obtained.

I assume that, if several lamps are placed relatively close together, the loss of light from the individual lamps, due to that portion of their flux which is transmitted through adjacent lamps, is reasonably appreciable.

ARTHUR B. ODAY: It is undoubtedly true that almost without exception every member of the Illuminating Engineering Society is definitely interested in fluorescent lamps. We are interested in them because they give us a new tool with which to work, a light source that makes it possible to do lighting that we couldn't do before and to do some lighting much better than we have done it before.

We have all been especially interested in the last two papers that have dealt particularly with the characteristics of fluorescent lamps. However, it did occur to me that perhaps you might also be somewhat interested in where they are used, why they are used, and who is using them.

We think of the fluorescent lamp as an infant, but perhaps you would be surprised to learn that to date there have been made some 40,000 lamps, and we have actually sent out for installation work about 25,000 of them. The others were used more or less experimentally.

You recall that the lamps were perhaps prematurely announced so that they could be used for installation at the New York World's Fair. For the New York Fair some 5000 lamps have been installed or are being installed, and about 2500 lamps have been shipped to San Francisco for the World's Fair there, and they are now being installed. So that, outside of the fairs, which of course we thought of as our principal place of use, we have shipped something like 18,000 lamps for actual installations. Of course that doesn't make much of a scratch on the lighting surface of the United States, but it is an indication that installations are going ahead.

G. E. INMAN: Mr. Palmer has remarked about the effect of line voltage on the life of fluorescent lamps. I wish to call attention to the fact that an incorrect voltage does not affect fluorescent lamps as markedly as it does the ordinary filament lamps. The effect depends somewhat on the regulation provided by the auxiliary, and actual figures are not sufficiently well determined at the present time to be able to state the magnitude of this effect under various conditions. It is important to note, however, that if fluorescent lamps are burned on line voltages considerably under normal, the life is adversely affected, rather than improved.

Mr. Palmer is correct in assuming that the 2537 U. V. line is the one most efficiently produced. This is true to a very marked extent. Fluorescent materials are then selected, which will respond to this general region and then the formulas and manufacturing technic are adjusted to bring the peak of response of the phosphor as close as possible to the 2537 line.

Fluorescent lamp voltages are automatically predetermined by the cathode design and operation, the tube dimensions, and the current

density. With cathodes operating properly, and tubes of a given diameter, and with a fixed current, the voltage is nearly proportional to the tube length, if one allows for the cathode drop.   Longer, higher voltage tubes are more efficient than short ones, chiefly because of the lower electrode loss per unit length.   This matter, then, is chiefly one of length rather than one of tube voltage. If tubes are made which take the same wattage as our standard lamps but operate at a lower current density, and at a higher voltage due to increased tube length, the efficiency of producing the short ultraviolet is slightly increased.   Such tubes will not start satisfactorily on our standard lines, however, without a voltage step-up and when that is done auxiliary losses are increased which counteract the advantages.   Insulation requirements may also be more severe.   Ordinary high-voltage fluorescent sign tubes have additional losses imposed by the electrodes and in comparison are efficient only in very long lengths.

Regarding the use of neon in fluorescent lamps, I can make the following comments: Some short ultraviolet is generated in the neon discharge and consequently, some fluorescence is produced.   The efficiency of producing light, however, is low compared with the case of using mercury.   Furthermore, there are other difficulties in connection with lamp operation when neon is used, so that it does not seem practical up to the present time to use this combination (neon plus fluorescent material) in low-voltage lamps, even for producing red light.

The fluorescent coating on a bulb is translucent and has a high transmission; consequently, the visible radiation produced by the mercury glow is a very important factor in the production of light in all but the gold and red lamps.

Mr. Jeffery asked for more particulars about the spectral quality of the daylight lamps.   Mr. Harrison has already commented on this. Even though the spectrum is not perfect, the quality of the light is far superior than that obtained from daylight Mazda lamps, or in fact from any other reasonably priced light sources, that I know of.   We have made spectral setups, with which we could examine colored objects and also specially-prepared color charts, under both our daylight fluorescent lamps and under natural daylight, at exactly the same time.   When the two are compared side by side, the appearance is identical in almost all cases.   There are, however, a few so-called, very "tricky" colors, where it is sometimes possible to see a very

slight difference by a critical comparison test such as this. Unless the two sources were used side by side, I do not believe that the difference would be noticed, even on these particular colors.

Mr. Altree has asked about the use of fluorescent lamps in indirect luminaires. Since this is a question which pertains chiefly to the use of the lamps, I am going to ask Mr. Oday if he will give the answer.

A. B. ODAY: Referring particularly to the question raised by Mr. Altree, I believe it usually will be found desirable to provide a reflector especially designed to handle the light from each individual lamp when more than one lamp is used in an indirect trough. This would be particularly true if the trough or the reflector within the trough has a relatively longer opening. If the trough has a rather large opening and the lamps are not placed very close together, perhaps the reflector having a single rather flat contour would prove satisfactory.

With reference to the absorption of light from adjacent lamps, especially when lamps are placed rather close together, this will be an important factor to consider. If lamps are relatively close together a fairly high absorption would probably result.