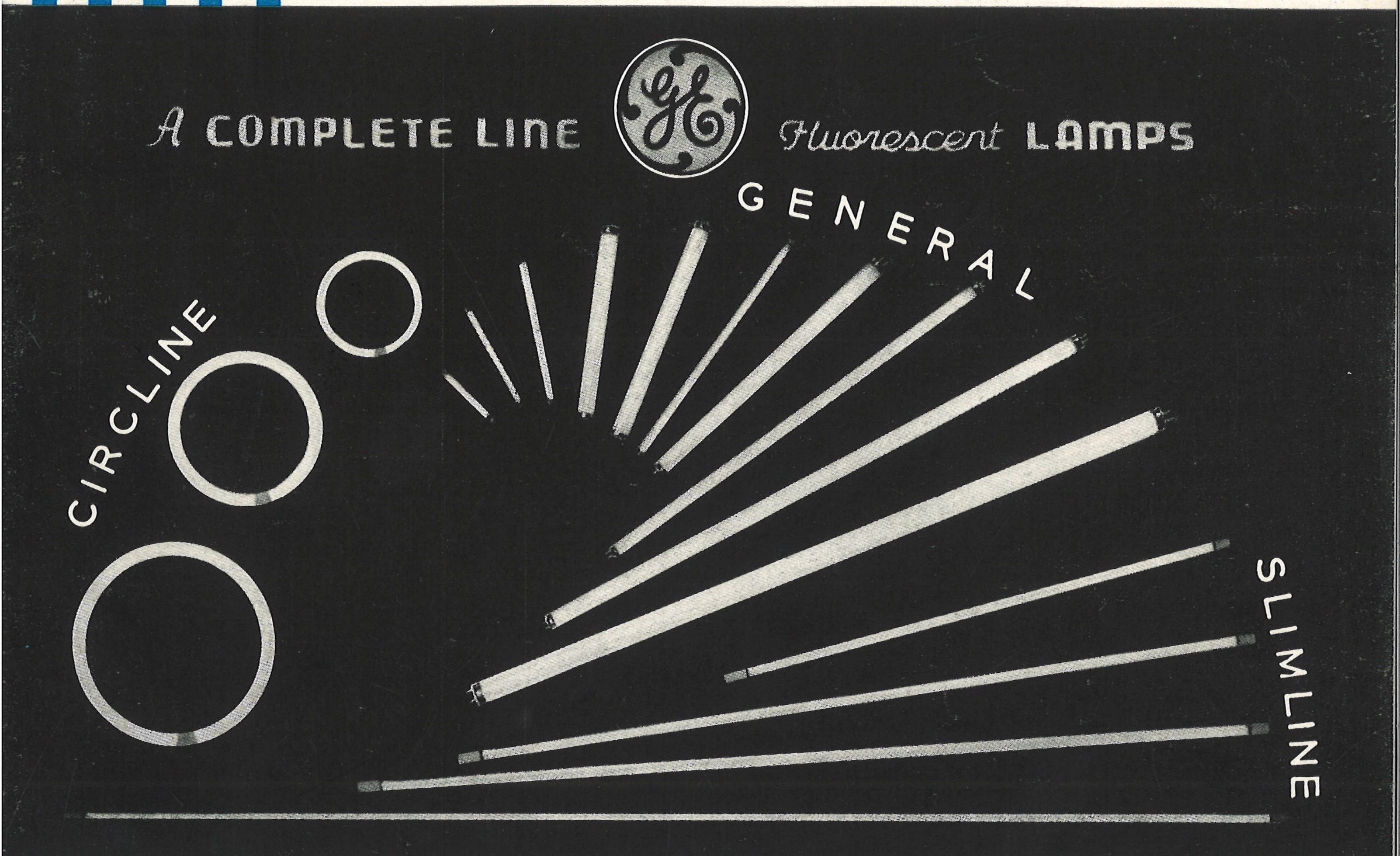


FLUORESCENT LAMPS

ENGINEERING DATA ON LAMPS AND AUXILIARY EQUIPMENTS WITH PERFORMANCE FACTORS AND OPERATING CHARACTERISTICS

GENERAL ELECTRIC

ENGINEERING DIVISION, LAMP DEPARTMENT

GENERAL LINE LAMPS

Bipin base construction for preheat starting circuits.

	Miniature Bipin Base			Medium Bipin Base						Mogul Bipin	
Wattage Size	**6**	**8**	**13**	**14**	**15** (T-8)	**15** (T-12)	**20**	**30**	**40**①	**40**①	**100**
Nominal Length, Inches	9	12	21	15	18	18	24	36	48	60	60
Diameter, Inches	⅝	⅝	⅝	1½	1	1½	1½	1	1½	2⅛	2⅛
Bulb	T-5	T-5	T-5	T-12	T-8	T-12	T-12	T-8	T-12	T-17	T-17
Approx. Lamp Amperes	0.145	0.16	0.16	0.37	0.30	0.33	0.35	0.34	0.41	0.40	1.45
Approx. Lamp Volts	48	57	100	41	56	48	62	103	108	110	72
Circuit Voltages	Depends on ballast types available for various lamps—see Table on Page 9										
Rated Average Life	See Table on Page 16										
Lumen Output—											
3500 White	210	330	......	490	615	600	920	1470	2300	......	4200
Daylight	186	295	......	......	585	540	800	1350	1920	......	3900
Soft White		......			480	465	700	1170	1720	......	3300
4500 White	198	310	545	460	600	570	860	1380	2100	2100	4000
Footlamberts—											
3500 White	2620	2950	......	1410	2080	1360	1450	2260	1750	......	1850
Daylight	2330	2640	......	......	1980	1230	1260	2080	1470	......	1710
Soft White	......	......	......	......	1620	1060	1100	1800	1310	......	1450
4500 White	2470	2770	2520	1310	2030	1290	1360	2120	1610	920	1760

① The 40-watt T-12 instant-start lamp has a medium bipin base with pins short-circuited inside end caps and will not operate on preheat ballast circuits; the 40-watt T-17 mogul bipin is of the same construction.

SLIMLINE LAMPS

All Slimline lamps have a single pin base—for instant-start hot-cathode operation.

Nominal Length and Bulb Diam.	**42″—T-6**		**64″—T-6**		**72″—T-8**		**96″—T-8**	
Maximum Lamp Length, Inches	40		62		70		94	
Diameter, Inches	¾		¾		1		1	
Minimum Starting Voltage	450		600		600		750	
Rated Life	See Table on Page 16							
Lamp Watts (Add Auxiliary Watts for Total)	**16**	**25**	**24**	**39**	**22**	**38**	**29**	**51**
Lamp Current Milliamperes	**100**	**200**	**100**	**200**	**100**	**200**	**100**	**200**
Approx. Lamp Volts	180	150	285	230	250	220	335	295
Lumen Output—White	880	1320	1370	2150	1340	2250	1800	3050
Footlamberts—White	1600	2450	1600	2450	1000	1650	1000	1650

CIRCLINE LAMPS

4-prong, connector-type base.

Lamp Watts	32 Watts	Light Output (White)	1600 Lumens
Outside Diameter of Circle	12″ ± ¼″	Brightness	2040 Footlamberts
Diameter of Tube	T-10 (1¼″)		
Lamp Amperes (Operating)	0.43 Amps.		
Lamp Volts (Operating)	84 Volts		

Circline lamps in 8″ and 16″ diameters (approx. 20 and 40 watts) will also be available as production facilities permit.

FLUORESCENT LAMPS

● The fluorescent lamp may take a variety of forms, and is the most versatile of all lamps. Fundamentally it is a most efficient generator of ultraviolet radiation, concentrated at one principal wavelength of 2537 Angstroms.

● **2537A Radiation.** The secret of high transformation of the electrical watts input into radiation of 2537A wavelength lies largely in the low mercury vapor pressure within the bulb. This pressure is of the order of 6 to 10 microns (roughly one, one hundred-thousandth of normal atmospheric pressure) under standard conditions; slight changes in such a small normal pressure can have appreciable effect on lamp characteristics.

● **Germicidal Lamps.** Short-wave ultraviolet radiation of 2537A wavelength is not encountered in the sun's radiation (the shortest wavelength from the sun is about 2900 Angstroms) and this short wavelength is lethal to germs and air-borne bacteria. This radiation does not pass through ordinary glass—but when a special glass is used that will transmit this short-wave ultraviolet energy, we have a Germicidal Lamp now available in several sizes.

● **Phosphors.** These are powders or chemicals with which the inside of fluorescent lamps are coated. They transform 2537 radiation into longer wavelengths. Certain phosphors merely transform the short-wave ultraviolet to longer wave ultraviolet which is effective for suntan, and black light effects. The line of BL (black light) lamps is an example of converting 2537 radiation into longer wavelength ultraviolet radiation. Other phosphors convert 2537 radiation into visible light of various wavelengths or colors. Mixtures of two phosphors produce white light.

— the majority of the particles in fluorescent coatings are extremely small (.00008 to .0002 inches in diameter) and the total coating weight of a 40-watt white or daylight lamp is only 2 to 3 grams (a gram is approximately 1/28 ounce). This particle size must be closely controlled — if too large, the lamp will appear coarse or grainy on close examination but the milling required to make the particles extremely small injures them somewhat and reduces the fluorescent intensity.

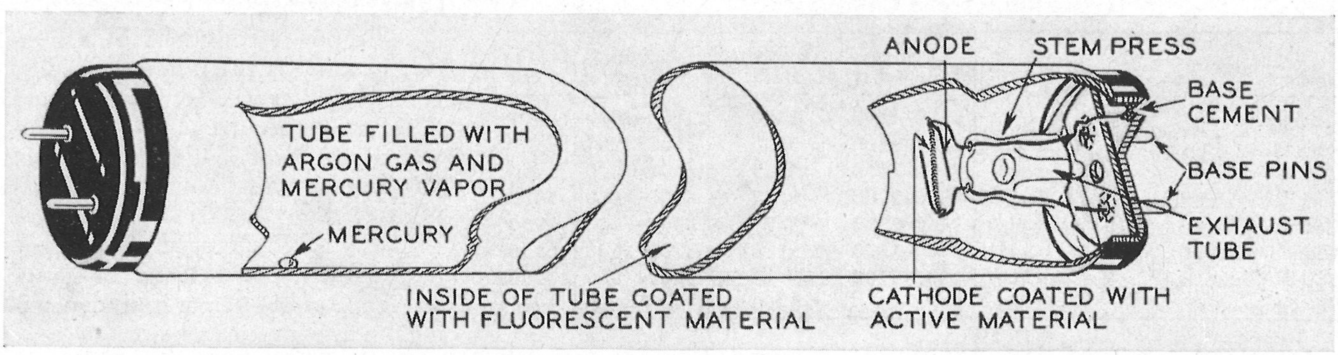
— When not lighted, fluorescent coatings are matte white, translucent and almost completely diffuse. However, suitable fluorescent materials are not available to produce all the desired final colors, so in the case of gold and red lamps an inner coating of that pigment is applied before the phosphor coating. Because of this "filter" the gold and red lamps do not appear white when unlighted.

● **Lamp Types.** The first lamps were introduced commercially in 1938, and the standard line has been extended to include long, slim tubes known as Slimline lamps, and circular lamps known as Circline. All operate on the same principal, although there are variations in design to meet new needs as these have developed. The principal variations concern the starting and operating current and voltage, and all require some sort of auxiliary ballast to transform and regulate ordinary "house-circuit" voltages to the requirement of each type and size of lamp.

The fluorescent lamp is one form of "electric discharge" source. It consists of a tubular bulb with an electrode sealed in each end. Flow of current takes place through mercury vapor. In a filament lamp, electricity flows from one lead wire to another through the solid tungsten wire, thus heating it to incandescence. In electric discharge lamps the two electrodes are separated from each other with no apparent connection between them. When proper voltage is impressed on these electrodes, a flow of negatively charged electrons is driven from one electrode, attracted or pulled to the other. This flow of electrons can be made to take place either in a vacuum or in a gas. When a gas or vapor is present, the electrical path is of lower resistance and the discharge or flow will take place at lower voltage.

The ability of a gas or vapor to become "luminescent," that is, to give off light under the influence of the flow of electrons through it, involves a somewhat intricate theory of the structure of atoms. Popular explanations of this theory usually resort to the idea of a "collision" of the speedy electrons with the atoms of the gas as real in concept as two automobiles colliding on a highway, or as a bowling ball striking a set-up of tenpins. When these encounters take place there is a state of excitation, which in the case of the excited gas, produces light. This production of light comes about from the energy given up as the disturbed molecule, atom, or ion settles down to its stable or neutral state.

Many types of electric discharge sources have long been available—the ones popularly known employ neon, mercury, and sodium vapor; other gases, such as argon, helium, carbon dioxide, xenon, and many metallic vapors such as zinc and cadmium have been used either commercially or experimentally. The fluorescent lamp without its coating of powder is essentially a glass tube containing a small drop of mercury and a small amount of argon gas to facilitate starting. In the case of most lamps the electrical characteristics, vapor pressure, current density, and voltage are so regulated that the resultant discharge produces directly as much light as possible. In the case of



fluorescent lamps these elements are adjusted so that the discharge produces very little visible light directly, but does crowd as much energy as possible into the ultraviolet radiation at one specific point—the 2537A line. Mercury is used as the conducting vapor because of its high efficiency in the production of ultraviolet radiation that activates the phosphors which are coated on the inside of the bulb.

To attempt an explanation of the theory of fluorescence introduces more complications than those involved in the explanation of the production of light directly by the flow of electrons through a gas. The explanation of the property of materials which do fluoresce under the action of ultraviolet radiation is simply that such materials absorb energy at one wavelength, reradiate it at longer wavelengths in much the same manner as a transformer absorbs wattage at one voltage and current, delivers this power or energy at a different voltage and current. The reradiated energy of the fluorescent powders, however, is spread over a considerable range or continuous band of visible wavelengths.

FACTORS WHICH INFLUENCE LAMP PERFORMANCE

The choice of lamp dimensions and electrical values is determined not only by the maximum luminous efficiency, but by numerous other factors, such as brightness, lumen output, lumen maintenance, reliable starting and satisfactory regulation preferably without stepup or stepdown from suitable line voltages, minimum wattage loss in ballast equipment and commercial adaptability to manufacture, shipment and use.

Choice of Lamp Voltage

For most satisfactory starting and regulation of preheated-cathode lamps, only about half or less of the available open-circuit voltage should be used by the lamp, the remainder by the ballast. Thus lamps having voltages below 62 are used on 110—125-volt supplies with only series chokes as ballasts. Lamps like the 30- and 40-watt sizes (103- and 108-lamp volts) require an autotransformer (built into the ballast case) to step up the 110—125 line voltage to around 200 so that approximately one-half of the open-circuit autotransformer voltage is available for the ballast. Such lamps, however, may be used on 208- or 236-volt lines with only series choke ballasts. If the open-circuit voltage is much more than twice the lamp voltage, the wattage loss in the ballast will be needlessly high; if much less than twice the lamp voltage, excessive cathode preheating currents, wide fluctuation of operating current and wattage with line voltage variation, and starter troubles will result. For instant starting, the open-circuit voltage must be sufficient to start the arc without any preheat and the ratio of open-circuit to lamp voltage commonly exceeds 2 to 1 (it is in the order of 4 to 1 for the 40-watt instant-start circuit). In cathode preheating circuits the opening of the starter-switch contacts supplies the high-voltage kick required for reliable starting.

The chief determinants of lamp voltage are arc length, bulb diameter and lamp current. The type of cathode is also a factor—hot-cathode lamps have lower voltages than corresponding sized lamps operated cold cathode at the same current because the former commonly have 70—100 volts less fixed voltage drop at the electrodes. For a given current and bulb diameter the lamp voltage rises as the length is increased, and falls as the diameter is increased for a given current and length. For fixed dimensions, the lamp voltage decreases with increased lamp current. For current ratings in the present standard line, the lamps having the same length/diameter ratio will have approximately the same lamp voltage.

Mercury Vapor Pressure

The pressure of the mercury vapor within a fluorescent lamp has an important effect on the electrical characteristics of the lamp. The normal pressure of a given size of lamp depends on the bulb-wall temperature, which in turn is determined by the input wattage and the area (a function of length and diameter) available to dissipate the heat. The optimum pressure is that which produces most efficiently the ultraviolet radiation that excites the phosphor. As shown by the accompanying curves, the lamp temperature affects efficiency because the pressure falls above or below the optimum value—increased current in a given sized lamp raises temperature and pressure above the point of most efficient ultraviolet production.

Lamp Wattage

The power consumed by a fluorescent lamp is the product of volts, current and power factor. A study of the voltage, current, watts, length and diameter of lamps in the table on page 2 will indicate combinations of those five factors which are employed in standard fluorescent lamps. The power factor of standard lamps is 86—96 per cent, depending on the particular size.

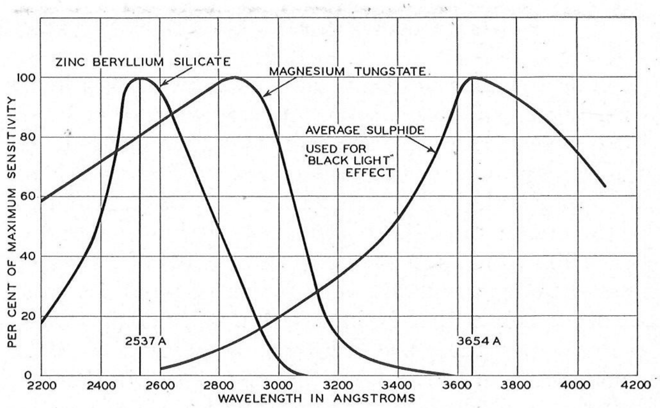
Fluorescent Chemicals

Phosphor	Lamp Color	Exciting Range*	Sensitivity Peak	Emitted Range	Emitted Peak
Calcium Tungstate	Blue	2200–3000	2720	3100–7000	4400
Magnesium Tungstate	Blue-white	2200–3200	2850	3600–7200	4800
Zinc Silicate	Green	2200–2960	2537	4600–6400	5250
Zinc Beryllium Silicate	Yellow-white	2200–3000	2537	4800–7500	5950
Cadmium Silicate	Yellow-pink	2200–3200	2400	4800–7400	5950
Cadmium Borate	Pink	2200–3600	2500	5200–7500	6150
360 BL Phosphor	Blue Ultra	2200–3200	2500–2800	3200–4500	3600
"E" Phosphor	Blue Ultra	2200–2650	2475	2700–4000	3250

* 2200A is lower limit of measurements.

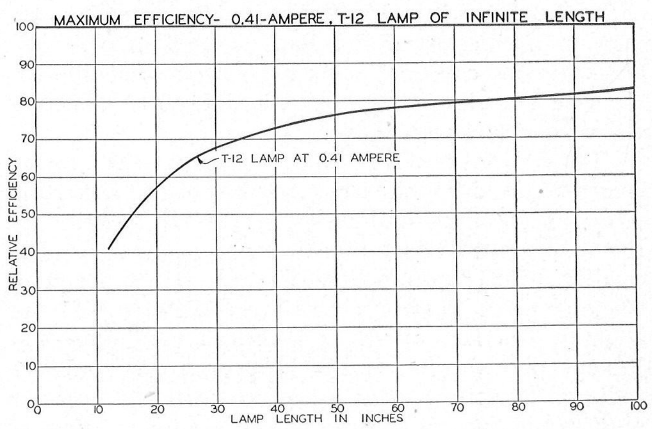
Phosphor Response

Many compounds fluoresce when ultraviolet radiation falls upon them, but for the most efficient operation of fluorescent lamps the phosphor used should have its maximum response at the particular wavelengths of ultraviolet generated within the lamp. Since no other measured spectral line of the low pressure discharge in the fluorescent lamp exceeds 2 per cent of the 2537 line, whenever possible, phosphors have been selected whose maximum sensitivity lies between 2500 and 2600A. The table on page 58 indicates that several of the phosphors have sensitivity peaks at or near 2537A. Response curves are shown for zinc beryllium silicate and magnesium tungstate, the phosphors used in different combinations to make daylight, white and soft white lamps. Also shown is an average curve of several sulphides used for "black light" effects where the maximum response is to radiation at 3654A.



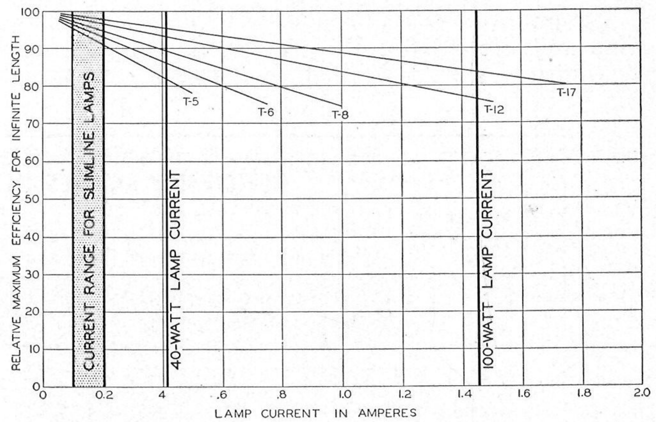
Lamp Length vs Efficiency

The curve shows the efficiencies of various lengths of 1½-inch diameter white fluorescent lamps operating at 0.41 amperes (near the 40-watt rated current). For hot-cathode operation the voltage drop at the electrodes is fixed somewhere between 14 and 18 volts, depending on electrode size, cathode emission and filling gas. Since the electrode drop represents mostly wasted energy, and remains constant, the efficiency for a given loading increases as lamp length is increased, but at a decreasing rate. In addition, the end loss in light output becomes a proportionately smaller part of the total as the ratio of length to diameter is increased. The efficiency of a 1½-inch 0.41-ampere lamp of infinite length, based on present design and manufacturing methods, would be around 80 lumens per watt. Further progress in efficiency is largely a matter of development in the chemistry of phosphors and manufacturing techniques.



Maximum Efficiency and Lamp Current

The theoretical efficiency of a fluorescent lamp of infinite length (positive-column efficiency) decreases as the lamp current is increased because conditions are less favorable for conversion of input energy to 2537 and other exciting radiation. For a given current the theoretical efficiency is improved by increasing the bulb diameter; in an actual lamp of ordinary length, efficiencies are somewhat less because of end losses. Larger diameters are best for the currents necessary to secure high lumens per foot of lamp.

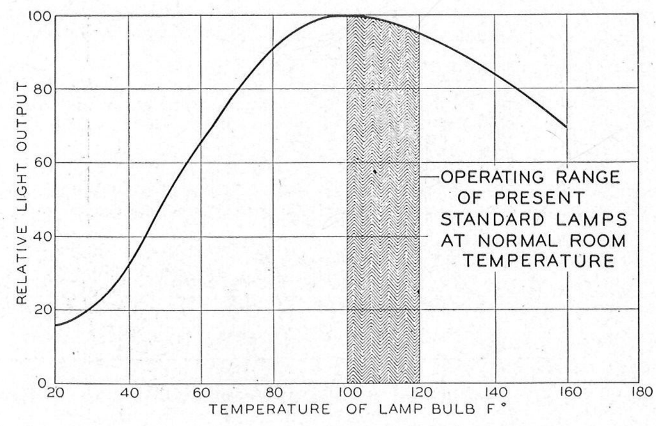


Effect of Bulb-wall Temperature

At low temperatures the mercury vapor condenses and the internal vapor pressure drops below the point at which the exciting ultraviolet radiation is produced most efficiently.

If lamps are sufficiently loaded or if enclosures raise the bulb-wall temperature to the extent that the mercury vapor pressure exceeds the value for optimum production of the exciting radiation, such lamps or units may produce more light below normal room temperature than under ordinary conditions.

Because of the difference in watts per square inch, the 100-watt lamp will be better able to maintain a favorable bulb-wall temperature at low ambient temperatures than the 40-watt size. On the other hand, the 100-watt lamp will fall off more in light output at high ambient temperatures.

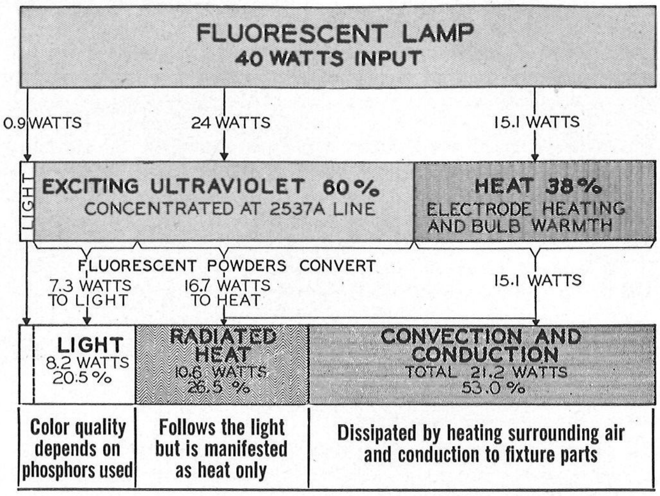


CONVERSION LOSSES—Theoretical to Practical Efficiencies

The diagram at the right shows the approximate distribution of energy in the 40-watt fluorescent lamp. The top bar indicates the electrical energy input, the middle bar shows the conversion of energy within the lamp and the third bar gives the ultimate nature of the energy output. Skillful lamp design and proper operating conditions result in three-fifths of the input energy being converted into exciting radiation, practically all of which is in a single line (2536.7 Angstroms) less than an Angstrom in width. A little over 2 per cent of the energy is represented in the four principal mercury lines within the visible spectrum: 4047, 4358, 5461 and 5780A. The rest of the input plus the conversion loss in the phosphor coating is emitted as far infrared radiation or dissipated by conduction and convection. Part of this unavoidable loss keeps the cathodes hot—an essential condition for the free emission of electrons and highest efficiency at low operation voltages.

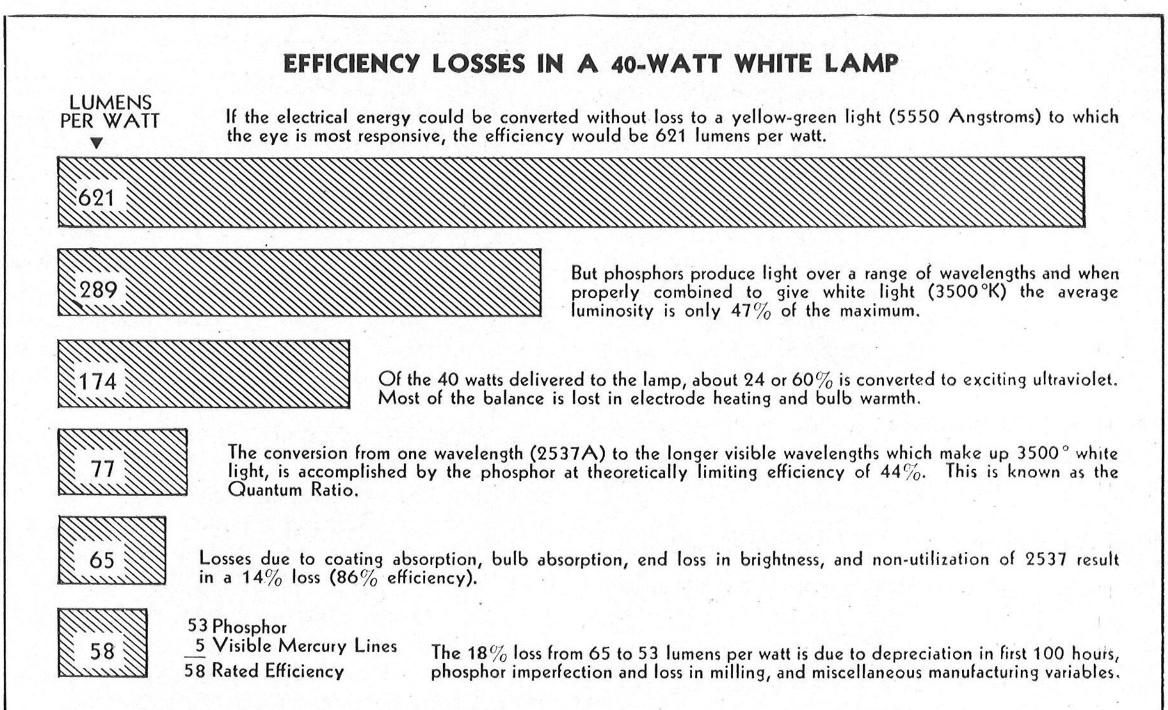
The regions marked "light" represent the radiant energy emitted in the visible portion of the spectrum. The phosphor used determines the distribution of this energy and thus the lumen output and color quality. The diagram below indicates why the rated efficiency of a 40-watt white fluorescent lamp is but a small fraction of the theoretical maximum—621 lumens per watt if all the input wattage could be radiated as yellow-green light to which the eyes are most responsive. The values given are for the present 40-watt lamp. The values will be different for lamps of different wattage and design.

Because it converts the shortwave ultraviolet radiation to visible light, the fluorescent chemicals or phosphors as they are called, are in effect, the heart



of the lamp. This coating must be subjected to close manufacturing control; careful blending and heat-treating of the chemicals themselves and close tolerances on the coating thickness. For example, if the thickness is below the optimum value the exciting radiation is not fully utilized, and if the coating is too thick, excessive absorption of the light generated by the phosphors (due to multiple internal reflections) will result.

Fluted and corrugated bulbs have been tried to spread the ultraviolet exciting radiation over a larger area of fluorescent material but no gains were produced. These and other tests indicate that no appreciable phosphor saturation or fatigue effects are present in fluorescent lamps.



Note that over-all lamp efficiency is the sum of the phosphor output and the light generated directly by the mercury arc.

FLUORESCENT LAMP TYPES

As far as the principles of fluorescent lamps are concerned, these are the same for all types of lamps regardless of size, design or type—whether mass produced as stock catalog items or whether custom-built and shaped to order in letter or pattern form. All make use of phosphor-coated glass tubing, excited by the predominant 2537A line ultraviolet radiation produced by an electrical discharge through a very low-pressure mercury vapor medium. As previously discussed, the problem of lamp design is one of composing many variables; among these are the phosphor efficiency, proper control of mercury vapor pressure and gas-filling pressure, lamp loading or current density, bulb wall area which is controlled by lamp length and diameter and which in turn affect the loss or conservation of heat which in turn affects the internal vapor pressure. These design elements are common to every type of fluorescent lamp. Any further differences in lamp design lie in the field of electrical circuits agreeable to the method of starting the lamp and developing the proper current and voltage relations as required by its design. This applies whether the lamp is to be operated in series or multiple, instantaneous or preheat starting. These matters of design are conditioned upon application needs and preferences as far as quick starting, starting reliability, over-all efficiency, ballast size, cost and weight, power factor correction, circuit frequency, separate starters, and dimming and flashing requirements. Some of these factors are regulated by the design of the lamp cathodes or terminals which are the source of electrons from which the flow of current through the mercury vapor comes about.

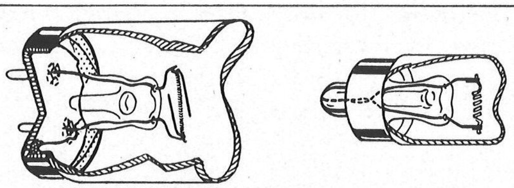
Emission of Electrons

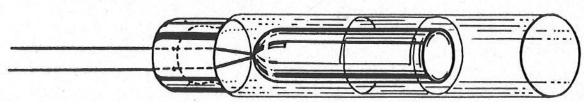
When a discharge or flow of electricity takes place through a conducting medium (in this case, mercury vapor) electrons flow or are attracted by difference of electrical pressure or voltage between one end of the lamp and the other. This requires an abundance of free electrons. These are commonly furnished by a coating of barium and strontium oxide on a convenient metal base such as iron or tungsten. Some electron emission is available from the base metal but is multiplied enormously by the oxide coating. There are several ways in which materials can be persuaded to give up electrons:

1. Electrical field emission: by application of sufficiently high voltage differentials, electrons may be pulled out of an unheated cathode. This is the sole method of cold-cathode lamps and is also a contributing factor in hot-cathode lamps.
2. Thermionic emission: by heating the electron-emitting material, the electrons boil out with less persuasion of voltage and this is the system used by the so-called hot-cathode lamps.
3. Photoelectric emission: where free electrons and current flow are provoked by the energy of light striking the material. This is the principle on which the General Electric Lightmeter and Exposure meter operate, the light-sensitive cells generating enough electricity to move a pointer over the scale of the meter in proportion to the light falling on them.

Types of Cathodes

Many hundreds of different cathode designs have been made experimentally or used in practice, but these narrow down to two principal classes, each adapted to the electrical circuit that may be used for starting and operating. The two types of cathodes shown in the illustration have become known as cold- and hot-cathode types; this nomenclature is misleading since the cold cathode must actually dissipate more heat than does the hot cathode.





Cold-cathode Characteristics

This type of cathode in a variety of forms has been used for neon tubing ever since its development over 30 years ago. Its use developed around long lengths of tubing or a series of lengths fabricated into letter or pattern form and used in series on special high-voltage circuits. Cold-cathode dictates that the electrode be of fairly large size in order to provide a large electron-emitting surface. High-voltage starting produces quite a shock to a thermionic cathode and sputters off some of the metal or coating (that is why G-E fluorescent lamps have special cathodes when operated on instant- or quick-starting auxiliaries; otherwise, lamp life is greatly reduced). With the large-area iron thimble-type cold cathode, an abundance of emitting area is provided to insure long life, even when used on flashing circuits. The cathode during operation attains a temperature of about 150° C and does not get higher because of the low current in relation to a large metal area which dissipates the heat. Because of the higher voltage required at the cathode to maintain the electron emission, there will be a higher voltage drop at this point which, for a given current, actually means a greater wattage loss at the cathode, and the bulb area at each end will be 40 to 60 degrees higher in temperature than the same bulb area of hot-cathode lamps.

Hot-cathode Characteristics

These cathodes are made of coiled tungsten filaments coated with electron-bearing materials. By passing a current through the filament at starting it is heated to around 950° C and by "thermionic emission" an abundance of free electrons becomes available and the arc is established at a lower voltage. Because of the small size of the cathode the normal current flow maintains a high temperature at a small portion of the entire cathode, although the voltage drop and consequently the wattage loss at the cathode is relatively low; this in turn makes for greater lamp efficiency and actually a cooler bulb than with a so-called "cold" cathode. Hot-cathode lamps can be started cold cathode (that is, without preheating) by sufficient starting voltage; however, they will operate hot cathode by virtue of the impinging arc heating a few segments of the small filament wire to red-hot temperature in a fraction of a second. The lamps can be dimmed slightly but, if the current is reduced too much the filament heating is reduced to the point where thermionic emission fails. Dimming cannot continue further because the operation would become equivalent to cold-cathode performance and higher voltage would then need to be introduced to maintain the arc.

Lamp Designs

Lamps designed for preheat circuits have bipin bases, but the new Slimline lamps have only one terminal at each end since they are designed for instant-starting. However, because of the filament-type cathode, they operate as hot-cathode lamps. Because of the higher efficiency of this type of construction due to lower electrode losses, considerable advantage is gained, particularly in lamps of shorter length. They are not adaptable to dimming or flashing. Cold-cathode lamps, because of their inherently long life, are advantageous for special custom-built shapes and patterns and for applications difficult to replace. Their over-all operating efficiency, that is, lumens per watt produced, will be less than hot-cathode operation. The fact that cold-cathode lamps have generally been operated in series is not inherent with this type, since either type, cold-cathode or instant-start, may be operated either on series or on multiple circuits. Cold-cathode operation is more favorable at relatively low current values which in turn suggests smaller diameter tubing which fortunately is favorable to bending for exposed sign designs and luminous decorative patterns. For general lighting purposes and fixture applications where lamps are enclosed or shielded, the choice of one type of lamp over another should be governed largely by analysis of over-all cost comparisons based on initial investment and operating and maintenance cost in delivering lumens of light—assuming a comparable system and distribution of light in each case. As far as illumination results are concerned as appraised by the science of seeing, there is no difference between one type of lamp and another.

Types of Ballasts for Preheat Starting Circuits

A fluorescent lamp ballast may be simply a coil of insulated copper wire wound on an iron core made up of layers of thin iron stampings. The ballast is placed in series with the lamp and, properly designed, will limit the current to the value for which each lamp is designed. Such ballasts may be employed for occasional use of single, low-wattage lamps, but they are not acceptable for general use because of the relatively low power factor. Low power factor means a differential in phase relation between voltage and current. The addition of a capacitor will correct this differential and bring the two into close relationship.

The capacitor consists essentially of a thin metallic foil separated by thin layers of special insulating paper. Capacitors for correcting power factor are available as separate units; however, because of the importance of high power factor to the user in terms of rates for current, and capacity of electrical wiring, high power factor ballasts are now the rule. The General Electric Company recommends the use of power factor corrected equipments.

It should be remembered that any design of fluorescent lamp as to length, diameter or wattage requires a specific lamp voltage and current, and it is the function of the ballast to deliver these essentials. Therefore, ballast design must be predicated (1) on the circuit or distribution voltage on the user's premises and (2) on the frequency of the system. The first may involve four voltage classifications—118, 208, 240 and 260 volts as nominal circuit ratings and the latter involves principally three frequencies—60, 50 and 25 cycles. While the lamp remains the same for each condition, this means that ballasts must be properly specified for the circuit on which fluorescent lamps are to be used.

Buying incandescent lamps for replacements requires a specification as to circuit voltage, but this is not necessary in buying fluorescent lamps. When the installation is first made, the ballast selected must agree in both circuit voltage and frequency. For every lamp type and wattage available, ballast manufacturers must provide specially designed ballasts for each classification of circuit voltage and frequency, with further modification for power-factor correction.

The latter is not as complicated as it reads, because in the United States we have reached more than 95 per cent standardization on 110—125-volt, 60-cycle circuits. Where available, 220—250-volt circuits, while disadvantageous for filament lamps, are advantageous for fluorescent lamps. Twenty-five and 50-cycle fre-

Representative List of 60-cycle Ballasts

For 15- and 20-watt Lamps—Small Cross-section

Lamp Watts	Circuit Voltage	Catalog Number Std. Line	Size, Inches	Weight, Pounds	Approx. Watts Loss	Line Current, Amps.
2–15	110–125	58G678	1 5/16 x 2¼ x 14¼	3¼	9	0.35
2–20	110–125	58G679	1 5/16 x 2¼ x 14¼	3¼	9	0.45

For 30- and 40-watt Lamps—Intermediate Cross-section

Lamp Watts	Circuit Voltage	Catalog Number Std. Line	Size, Inches	Weight, Pounds	Approx. Watts Loss	Line Current, Amps.
2–30	110–125	58G940	1 13/32 x 2¼ x 18¼	6	16	0.7
2–30	199–216	58G941	1 13/32 x 2¼ x 18¼	5½	10	0.4
2–30	220–250	58G942	1 13/32 x 2¼ x 18¼	6	12	0.35
2–40	110–125	58G943	1 13/32 x 2¼ x 18¼	6	19	0.85
2–40	199–216	58G944	1 13/32 x 2¼ x 18¼	5½	13	0.5
2–40	220–250	58G945	1 13/32 x 2¼ x 18¼	6	15	0.43

For 30-, 40- and 100-watt Lamps—Standard Cross-section

Lamp Watts	Circuit Voltage	Catalog Number Std. Line	Size, Inches	Weight, Pounds	Approx. Watts Loss	Line Current, Amps.
2–30	110–125	58G980	2⅜ x 3⅛ x 9½	7	12.5	0.7
2–30	199–216	58G981	2⅜ x 3⅛ x 9½	7	10.0	0.4
2–30	220–250	58G982	2⅜ x 3⅛ x 9½	7	10.5	0.35
2–40	110–125	58G983	2⅜ x 3⅛ x 9½	7	15.5	0.85
2–40	199–216	58G984	2⅜ x 3⅛ x 9½	7	11.5	0.5
2–40	220–250	58G985	2⅜ x 3⅛ x 9½	7	12.5	0.43
2–40	240–280†	58G922	2⅜ x 3⅛ x 9½	7	15.0	0.4
3–40	110–125	59G276	2⅝ x 3⅛ x 14 5/16	11	23	1.3
3–40	199–216	59G277	2⅝ x 3⅛ x 14 5/16	9¾	16	0.7
3–40	220–250	59G278	2⅝ x 3⅛ x 14 5/16	9¾	20	0.6
3–40	240–280†	58G996	2⅝ x 3⅛ x 14 5/16	10¼	20	0.6
2–100	110–125	58G696	2⅜ x 3⅛ x 19 3/16	14½	32	2.1
2–100	199–216	58G697	2⅜ x 3⅛ x 19 3/16	14½	32	1.25
2–100	220–250	58G698	2⅜ x 3⅛ x 19 3/16	14½	32	1.1
2–100	240–280†	58G923	2⅜ x 3⅛ x 19 3/16	15	35	1.0
4–100	250–280†	59G265		17½	36	1.65

For 6-, 8- and 13-watt Miniature Bipin Lamps

Lamp Watts	Circuit Voltage	Catalog Number Std. Line	Size, Inches	Weight Pounds	Approx. Watts Loss	Approx. Power Factor	Line Current, Amps.
6	110–125	58G800	1 3/16 x 1¾ x 4¼	1	2	45	0.16
8	110–125	58G616	1 3/16 x 1¾ x 4¼	1	2.8	45	0.175
13	110–125	58G400	1 15/16 x 2¼ x 7½	2¼	7	45	0.37
13	110–125	58G403	1 5/16 x 2¼ x 10¾	3	6	95	0.19

For 14-, 15-, 20-, 30- and 40-watt Lamps—Small Cross-section

Lamp Watts	Circuit Voltage	Catalog Number Std. Line	Size, Inches	Weight Pounds	Approx. Watts Loss	Approx. Power Factor	Line Current, Amps.
14	110–125	58G864	1 5/16 x 2¼ x 8¾	1½	3.6	85	0.18
15	110–125	58G640	1 5/16 x 2¼ x 8¾	1¾	4.5	90	0.19
20	110–125	58G641	1 5/16 x 2¼ x 8¾	1¾	4.5	90	0.23
30	110–125	58G644	1 5/16 x 2¼ x 14¼	3¾	9	90	0.36
30	199–216	58G643	1 5/16 x 2¼ x 10⅝	2½	6.5	90	0.23
30	220–250	58G642	1 5/16 x 2¼ x 10⅝	2½	7	90	0.20
40	110–125	58G647	1 5/16 x 2¼ x 14¼	3¾	9.5	90	0.50
40	199–216	58G646	1 5/16 x 2¼ x 10⅝	2½	8.5	90	0.29
40	220–250	58G645	1 5/16 x 2¼ x 10⅝	2½	9.5	90	0.26

For 40- and 100-watt Lamps—Standard Cross-section

Lamp Watts	Circuit Voltage	Catalog Number Std. Line	Size, Inches	Weight Pounds	Approx. Watts Loss	Approx. Power Factor	Line Current, Amps.
40	240–280†	58G925	2⅜ x 3⅛ x 9½	6	10	90	0.22
100	110–125	58G628	2⅜ x 3⅛ x 14 5/16	10¼	24	90	1.22
100	199–216	58G629	2⅜ x 3⅛ x 14 5/16	10¼	30	90	0.75
100	220–250	58G630	2⅜ x 3⅛ x 14 5/16	10¼	30	90	0.65
100	240–280†	58G967	2⅜ x 3⅛ x 14 5/16	10¼	30	90	0.5

For Circline Lamps

Lamp Watts	Circuit Voltage	Catalog Number Std. Line	Size, Inches	Weight Pounds	Approx. Watts Loss	Approx. Power Factor	Line Current, Amps.
32	110–125	59G420	1⅜ x 6″ dia.	4	11	50	0.67
32	110–125	59G425	1⅜ x 8″ dia.	6	9	90	0.38
2–32	110–125	59G424	1⅜ x 8″ dia.	7	16	95	0.73

† For Y-connected networks rated 254/440, 265/460 and 277/480 volts. Ballasts are connected line to neutral. In no case use less than 250 volts.

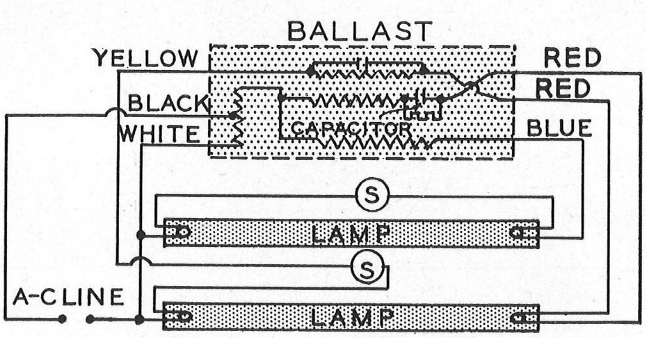
quency is uncommon in the United States, and the few places where such frequency is encountered are being converted to standard 60-cycle systems. The principal types of 60-cycle fluorescent lamp ballasts are listed above; additional listings are available for 25- and 50-cycle circuits. The several types of ballast circuits for fluorescent lamps might be described briefly as follows:

High Power Factor Single-lamp Ballasts

These ballasts contain a shunt capacitor which gives a power factor of 90 per cent lagging or higher at rated volts.

Tulamp Ballasts

These use the "split-phase" principle with one of the lamps ballasted by inductive reactance only and the other by inductive and capacitive reactances in series. The result is an over-all power factor of 95 per cent or more and at the same time the stroboscopic effect is reduced because of the 120-degree phase displacement in the two branches of the circuit. Tulamp ballasts for 118-volt operation of 30-, 40- and 100-watt lamps consist of an autotransformer winding and two reactor windings on a single core.



Typical Tulamp Ballast wiring diagram

Tulamp ballasts for 15- to 40-watt lamps inclusive require a starting compensator—an inductive winding connected in series with the leading-circuit's starter—to insure satisfactory life and lumen maintenance and to provide more positive starting conditions at low temperatures and voltage frequently encountered. Most modern ballasts now incorporate the compensator in the ballast itself. When this is not the case, the compensator should be wired in as a separate element. This is mentioned because where such compensators have not been used, unsatisfactory lamp performance is likely to be encountered, especially if the lamps are started frequently.

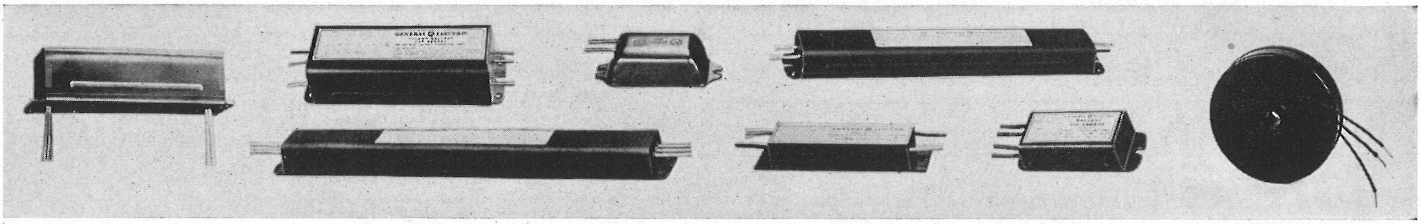
Three-lamp Ballasts were made available for 40-watt lamps because of the wide application of 3-lamp industrial units which formerly required the use of two ballasts. In these ballasts a leading (capacitor with inductive ballast) circuit is in parallel with two lagging (inductive only) circuits. This provides an over-all power factor of approximately 85 per cent. On nominal 208- and 236-volt service, the lamp voltage characteristics of the 40-watt lamp are such that the usual autotransformer type ballast is not necessary. Ballasts of this simplified design (59G304 and 59G305) are cheaper, conserve on the use of copper and iron and were especially designed for wartime saving of critical materials when these voltages were available.

Forlamp Ballasts

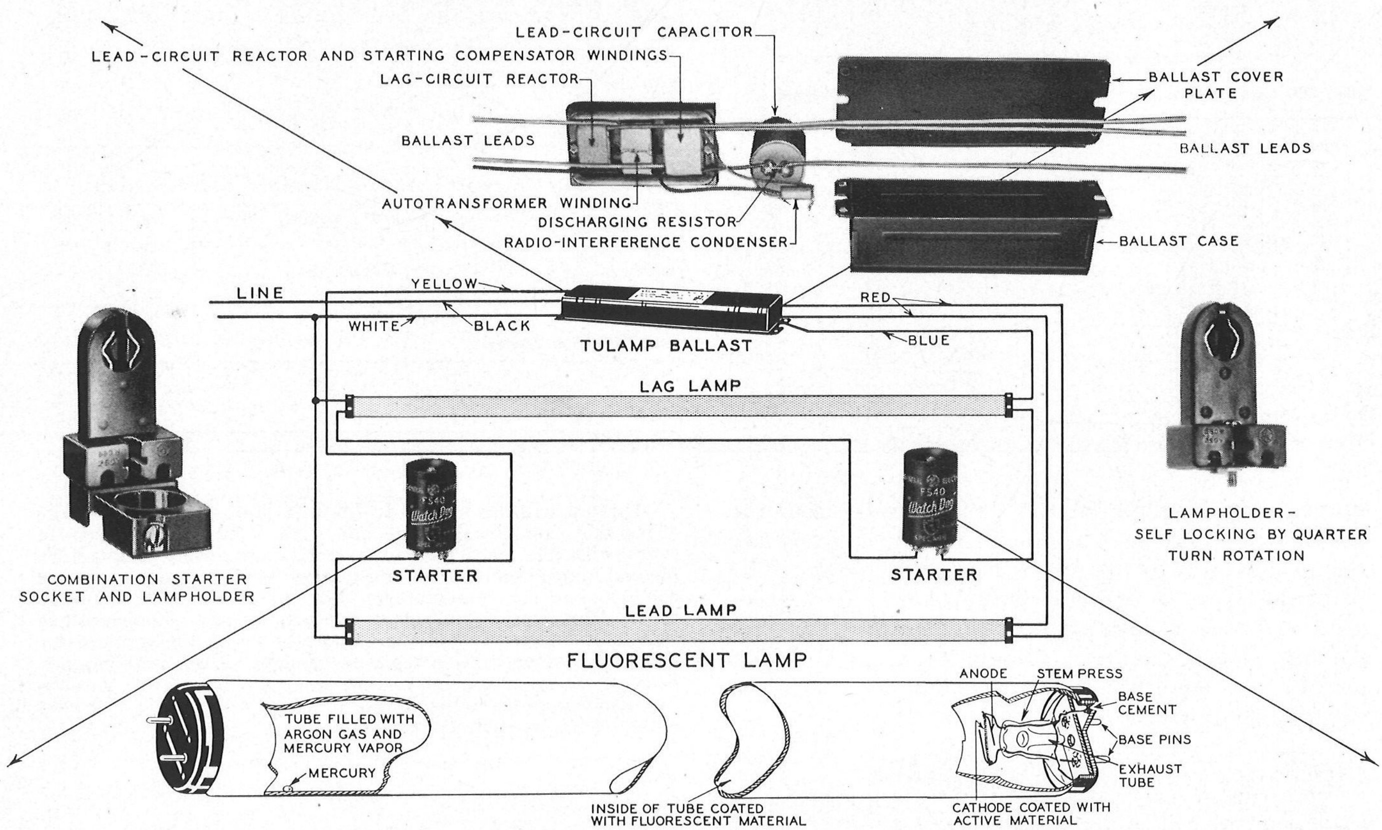
The four-lamp ballast for the 100-watt lamp takes advantage of the voltage rating of the 100-watt lamp to operate 2-in-series on each leg of a modified tulamp ballast. Its application is confined to a Y-connected network distribution rated at 254/440, 265/460 and 277/480 volts. Ballasts are connected line to neutral. Operating two lamps in series is often referred to as sequence (starting) circuits and is practical where the sum of the lamp voltages does not greatly exceed one-half of the circuit voltage. If the sum of the lamp voltages approaches the circuit voltage the remaining ballast voltage will be too small to give proper regulation to the volt-ampere requirements of the lamp

ELEMENTS OF PREHEAT STARTING CIRCUITS

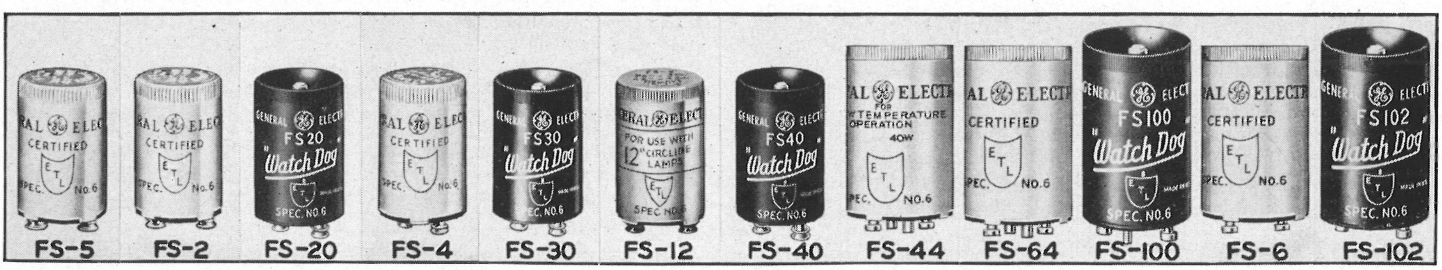
TYPICAL FLUORESCENT BALLASTS—for single and tulamp circuits



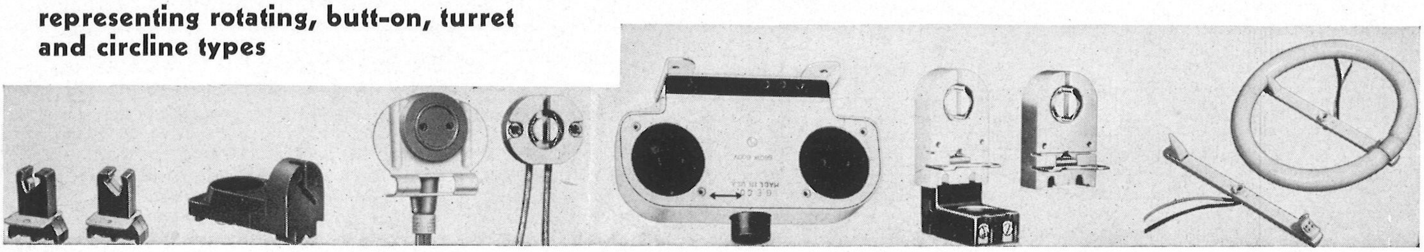
TYPICAL TULAMP CIRCUIT—showing wiring arrangement and component parts



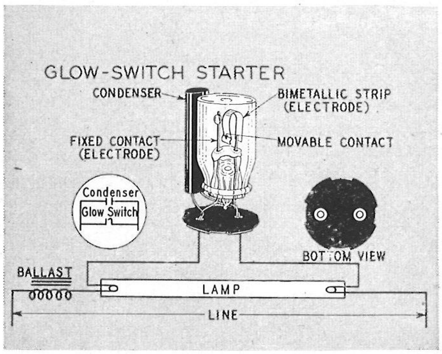
REPLACEABLE STARTERS—the complete line for all lamp sizes on preheat circuits



TYPICAL LAMPHOLDERS—
representing rotating, butt-on, turret and circline types



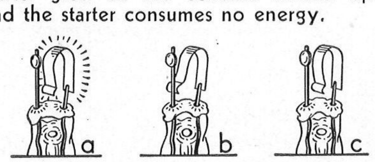
TYPES OF STARTERS

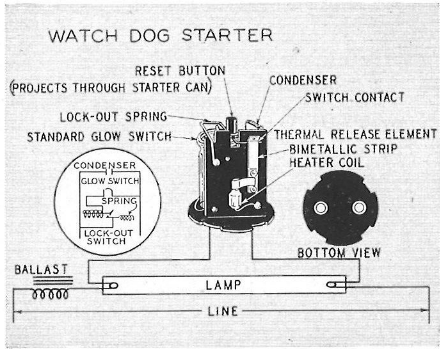


FS-5	FS-2	FS-4	FS-12	FS-6
6-watt 8-watt	14-watt 15-watt 20-watt	30-watt 40-watt	32-watt	100-watt †

† For replacement in 2-terminal, 100-watt starter sockets.

Glow-switch Starters. The glass bulb is filled with neon or argon, depending on the lamp voltage. On starting, when there is practically no voltage drop at the ballast, the voltage at the starter is sufficient to produce a glow discharge between the U-shaped bimetallic strip and the fixed contact or center electrode **(a)**. The heat from the glow actuates the bimetallic strip, the contacts close and cathode preheating begins **(b)**. This shorts out the glow discharge, so the bimetal cools and in a very short time the contacts open **(c)**. The inductive voltage kick from the ballast is then sufficient to start the lamp. During normal operation, there is not enough voltage across the lamp to produce further starter glow so the contacts remain open and the starter consumes no energy.

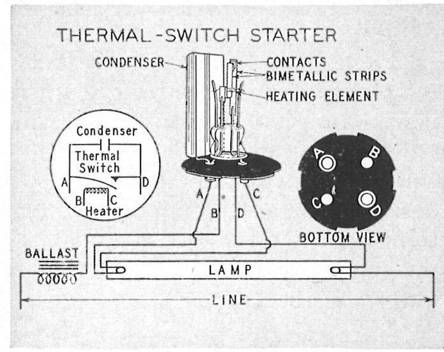




FS-20	FS-30	FS-40	FS-100*	FS-102
20-watt	30-watt	40-watt	100-watt	100-watt †

* The FS-100 starter has 4 terminals.

G-E Watch-dog Manual Reset Starters. This type uses the glow switch principle and during normal starting the switch functions in the manner described. This starter has an added feature which consists of a wire-coil heater element actuating a bimetallic arm which serves as a latch to hold a second switch in a normal closed position. When a lamp is deactivated or will not start for some reason after making repeated attempts by blinking on and off, enough heat is developed by the intermittent flow of cathode preheating current so that the latch pulls away and releases a spring-operated switch in the starter circuit. This occurs after 15 to 20 seconds at rated line voltage, thus removing the annoyance of blinking and conserving the life of the starter. At the time the lamp is replaced, the starter is reset to operating position by pushing down on the reset button at the top of the starter.



FS-44	FS-64
40-watt	100-watt

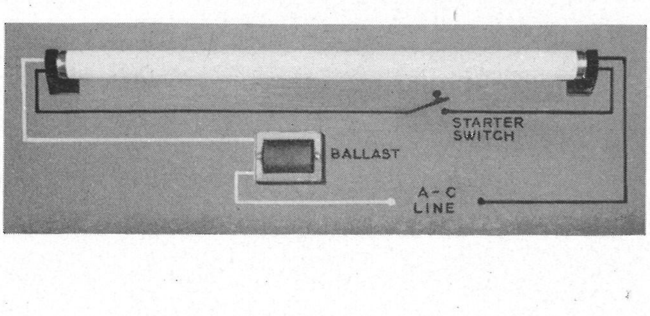
Thermal-switch Starters. On starting, the ballast, starter heating element and lamp cathodes are all in series across the line, since the contacts of G-E thermal-switch starters are normally closed. The cathode preheating current thus also heats the bimetallic strip in the starter and the contacts open. The inductive kick then starts the lamp, the normal operating current thereafter holding the thermal switch open.

G-E thermal-switch starters use some energy during lamp operation, (FS-44—½-watt; FS-64—1½ watts) but their design insures more positive starting by providing (1) an adequate preheating period, (2) a higher induced starting voltage, and (3) characteristics inherently less susceptible to line voltage variations. For these reasons, the FS-44, for example, gives best all-around performance of 40-watt lamps, being especially useful under adverse conditions such as d-c operation, low temperature, and varying voltage.

Preheat Cathode Starting Switches

The function of the starter switch is to complete a separate circuit so a preheat current can flow through the filament cathodes and heat them momentarily; after a few seconds the starter circuit is opened and the lamp lights. The simplest concept of a starter switch is shown in the illustration below where a push-button is held down for a second or two and released, and manual starters of this type are oftentimes used for desk-type fluorescent lamps.

The types of starters described above represent several designs for accomplishing the operation automatically. Other types of starters have been developed,



but the prime function of every type is the same. The ballast in the main circuit limits the current flow through the cathode filaments, otherwise they might be heated almost instantaneously like an ordinary filament lamp; the limited current passed by the ballast heats the filament more slowly (usually a second, as compared with .0001 seconds for a filament lamp) and several seconds elapse before the starting operation is complete. A small .006 Mfd. condenser is used across the switch contacts which aids in starting but is primarily useful to shunt out line-lead harmonics which may cause radio interference.

The Watch-dog reset starter is an improved glow switch and is recommended over the simple glow switch. The latter type will continue to attempt to start a lamp even when it has become deactivated. The result is that the lamp will blink on and off repeatedly, and unless the lamp is removed or replaced, will continue until the starter itself fails. The Watch-dog starter, which may be either a manual or automatic reset device, prevents this annoying blinking and prolongs the life of the starter.

BALLAST AND LAMP OPERATING CHARACTERISTICS

Supply Voltage

Fluorescent lamps are designed and rated as to light output and electrical characteristics at a given lamp wattage, and these are the same for each individual lamp regardless of the voltage of the circuit on which it is used. The ballasts, on the other hand, are designed for specific circuit voltages and their function, besides serving as a choke, is to raise or lower the circuit voltage, so as to provide the wattage required by the lamp.

Since variable voltage conditions are encountered on most lighting circuits, it is necessary that ballasts and lamps perform satisfactorily over a reasonable range of circuit voltage; this range is specified on each ballast. Fluorescent lamps are designed to give best all-around performance within this range. Since line voltage is a factor in starting reliability, voltages lower than recommended may result in unsatisfactory starting.

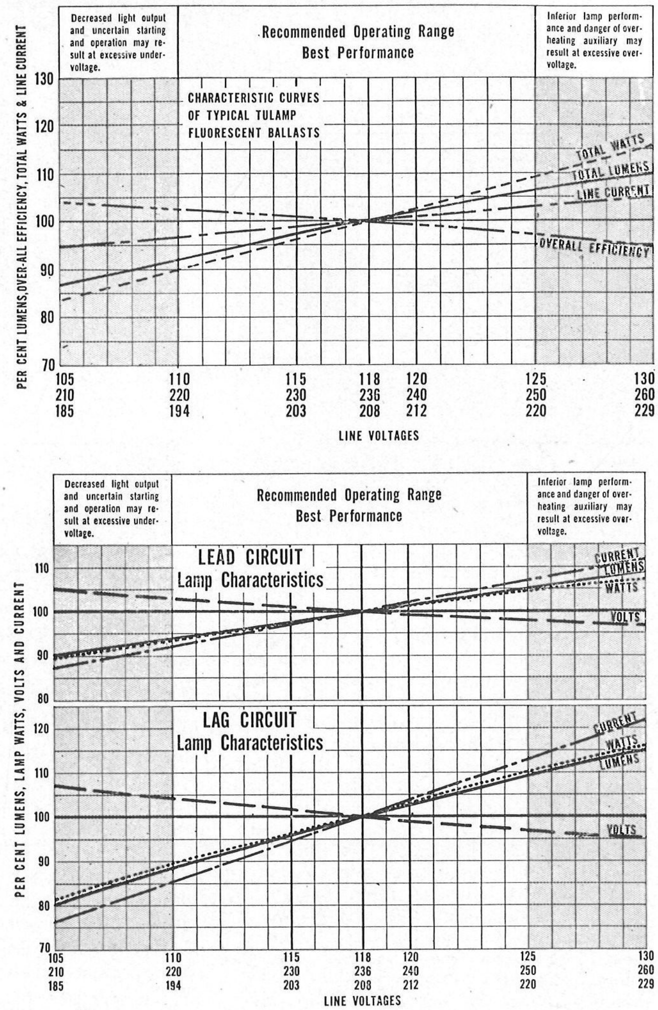
The changes in lamp characteristics with variations in circuit voltage are given in the accompanying charts. In general, one per cent variation in line voltage will change the lumen output only about one per cent. On a Tulamp ballast, there is a difference in characteristics on the lead and lag components—the variation on the "lead" lamp being approximately one-half that of the "lag" lamp. These differences between lead and lag characteristics for the 40-watt lamp are also given in the lower set of curves. These curves, for all general purposes, apply with minor departures to the other sizes of lamps; the variation in light output for the 100-watt lamp, however, is approximately one-half that shown by the curves.

It will be noted that the over-all efficiency of fluorescent lamps decreases as the line voltage is raised above normal. The increased line voltage causes the choke to pass more current to the lamp. This lowers the resistance of the arc column resulting in a lower voltage drop across the lamp itself. The input watts to the lamp are slightly increased and therefore the lumens increase over a certain range. In this condition, however, the higher current density produces the short ultraviolet radiation less efficiently; consequently, the luminous efficiency of the lamp decreases.

Hot-cathode fluorescent lamps with present types of auxiliary equipments are not adapted to flashing or dimming applications.

Ballast Operating Temperatures

The conventional ballast is enclosed in a container filled with a heavy impregnating compound which congeals around the choke coils and condenser. This serves to radiate heat and by its compactness, to eliminate or minimize noise or hum. The wattage loss in the ballast creates heat and suitable ventilation must be provided in fixture design or in places where ballasts are installed so that the temperature is kept within safe limits. If the temperature rises too high, the capacitor will fail and cause excessive heating



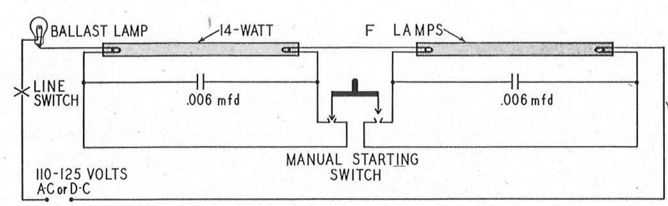
Characteristic curves of a 40-watt fluorescent lamp operated on a tulamp ballast.

and eventual failure of the transformer winding. Excessive temperature may also result from over-voltage operation.

The temperature of a ballast measured on the case should not exceed 194° F, with continuous operation and with the starter switch short-circuited; this condition may occur in practice and represents the condition of maximum wattage absorption by the ballast. Capacitors are more susceptible to damage by high temperature, and the safe limits depend on the type; however, in no case should the operating temperature exceed 167° F for any type of capacitor.

Resistance Ballast Operation

The relatively low lamp voltage of the 14-watt lamps (41 volts) combined with the excellent regula-



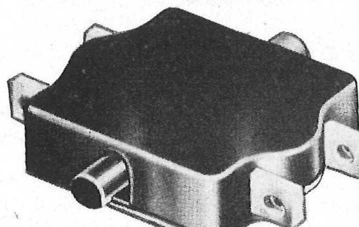
The 14-watt two-in-series circuit.

tion of the tungsten lamp ballast used, makes it possible to operate 2-in-series on nominal 110—125-volt a-c or d-c circuits. This use was the first application of the sequence starting of two lamps in series and has been applied to some extent for desk lamps, portable lamps for home use and similar uses. A special small incandescent lamp in an S-11 outside white bulb with an intermediate screw base is used instead of the conventional choke type of ballast. It is rated at 60 volts and ½ ampere. The resistance of this lamp, operating at low efficiency, changes over a wide range for a given change in current, and therefore provides better regulation than is practical with a choke type ballast.

A manual starting switch is used to preheat the electrodes and this specially designed switch combines the regular on-and-off contacts as well as the momentary make-and-break-starter circuit. The total wattage of two 14-watt lamps and ballast is about 45 watts on alternating current and 38 watts on direct current. This scheme provides a fairly efficient and inexpensive method of operation of fluorescent lamps and has the advantage of light weight, no ballast noise and basically high power factor. The stroboscopic effect is the same as for single lamp operation.

Turn Type
G-E Cat. No. 95X266 for two lamps.
G-E Cat. No. 95X292 for one lamp. ▶

Push-through Type
G-E Cat. No. 95X708 ▼



G-E manual starting control switches.

Direct-current Operation

While fluorescent lamps are designed for a-c operation, they may be used on d-c circuits if the proper series resistance is used in connection with a suitable inductance coil and starting switch. Failure to provide the necessary resistor equipment will result in failure of the lamp and/or accessories. The series resistance consumes about as much wattage as the lamp itself, and therefore, the over-all efficiency of light production will be much less than normal a-c operation. Resistors especially designed for this service are available, and are so constructed that excessive temperatures will not be reached.

Because of somewhat more difficult starting conditions on direct current, useful lamp life may be impaired because of failure to start. Lumen maintenance may likewise be somewhat less favorable. On the other hand color quality and total light output of lamps compare favorably with a-c operation and problems of power factor and stroboscopic effect are, of course, eliminated.

Because direct current flows in only one direction through the tube, lamps of 36 inches or longer may develop a considerable dim region at one end of the tube. This may be corrected by equipping installations with line reversing switches. A switch suitable for 240-volt inductive circuits should be used, and should be of a type which opens the circuit for an instant before reversing it. Present glow-switch starters are not recommended for operation on direct-current circuits. The suitable starting switches available for the cases where manual starting is necessary are indicated in the accompanying table. The table likewise gives the resistor values required.

Lamp Watts	D-c Lamp		Watts Loss at Voltage Shown	Resistance Required in Series with G-E Ballast No.						Ohms per Volt†
	Amps.	Volts		58G562*		58G690**		58G699***		
				120 V.	240 V.	120 V.	240 V.	120 V.	240 V.	
6	0.125	48	9	....	....	551	....	....	....	8.0
8	.140	57	9	....	....	425	....	....	....	7.1
14	.34	41	24	200	....	207	....	....	....	2.9
15 (T-8)	.26	58	16	206	....	213	....	....	....	3.8
15 (T-12)	.29	52	20	202	....	209	....	....	....	3.4
20	.31	65	17	145	....	152	....	....	....	3.2
30‡	.29	103	40	....	440	....	447	....	....	3.4
32‡	.37	86	57	....	....	....	391	....	....	2.7
40‡	.35	114	44	....	....	....	335	....	....	2.8
100‡	1.27	79	204	....	....	....	....	....	124	0.8

* D-c auxiliary with built-in thermal switch. ‡ Use line reversing switch (G-E catalog No. 95X289).

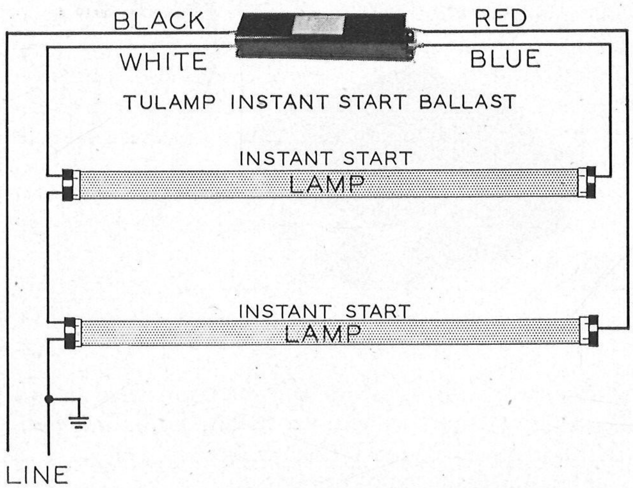
** Use FS-44 thermal-switch starter for 32- and 40-watt lamps and manual starting switch for 118-volt d-c operation of other lamp sizes with this ballast (G-E catalog No. 95X292 for one lamp, 95X266 for two lamps).

*** Use FS-64 thermal-switch starter.

† If actual line voltage is more than 5 per cent from value listed, the resistance required may be corrected by adding or subtracting the number of ohms indicated for each volt difference. The resistance should be within about 10 per cent of the value shown.

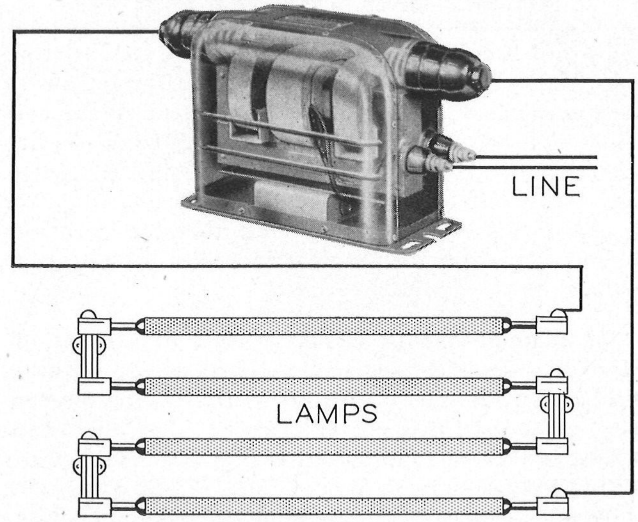
INSTANT-START CIRCUITS

For Multiple Operation of Slimline and Instant-start Lamps



Instant-start two-lamp ballast and multiple circuit for instant-start and Slimline lamps.

For High-voltage Series Operation



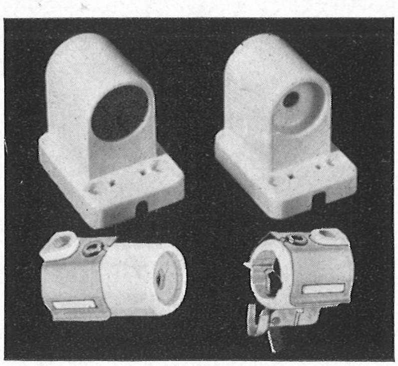
High-voltage, cold-cathode transformer and series circuit.

The Instant-start Ballast Circuit

The instant-start ballast is designed to start lamps without preheat, by virtue of delivering a high starting voltage and normal operating voltage after the lamps are started. Lamps for instant-start circuits have filament type cathodes, specially designed in order to obtain normal life under the higher impact voltage. Since no preheat circuit is required, instant-start lamps need only one terminal at each end, as in the Slimline types. A specially designed instant-start lamp with a bipin base is available for installations using the conventional type of lampholders; these lamps, however, have the base pins short-circuited inside the end cap and, therefore, will not operate on preheat ballast circuits.

A characteristic of the instant-start circuit is the difficulty of starting under conditions of high humidity. To overcome this shortcoming, instant-start lamps are provided with a thin metallic strip running lengthwise of the lamp; this produces a capacitive action which assures starting under all conditions.

Instant-start lamps have filament-type cathodes, and lamp life is dependent upon the number of starts.



Slimline Sockets

Slimline lamps are instant-start, hot-cathode lamps with single-pin base. This type of lamp operates at relatively higher lamp voltage and lower current. The drawing above shows a typical two-lamp instant-start circuit.

Series Circuit Operation of Lamps

Fluorescent lamps of all types may be operated on either multiple or series circuits, although when operated on series circuits, lamps especially designed for this service are recommended. Such lamps may be either of the hot- or cold-cathode types. High-voltage cold-cathode series circuits have long been the practice in the electric sign field.

Series transformers are rated in milliamperes, that is, they are designed to pass a certain maximum current depending on the current rating of the lamps used. The voltage rating ranges up as high as 15,000 volts—the actual voltage depending on the number of lamps or feet of tubing used on the circuit. In order to safeguard against the hazards of high-voltage operation, specially designed sockets or lampholders are required. These must be fool-proof from the standpoint of electrical shock hazard when renewing or replacing lamps.

One advantage of series operation where long runs of continuous lamps or tubing are employed is the simplification of the interior wiring since distribution circuits need be brought only to transformer locations.

The General Electric Company manufactures a complete line of transformers for high-voltage luminous tubing applications. The range of sizes is from 2000 volts to 15,000 volts with ampere ratings from 12 to 60 milliamperes. It also supplies a full line of phosphor-coated fluorescent tubing in standard lengths in eleven tube sizes ranging in diameter from 8 to 25 millimeters. By various combinations of glass and fluorescent phosphors, 17 colors are available to the sign manufacturer for electrical advertising and cold-cathode lighting purposes.

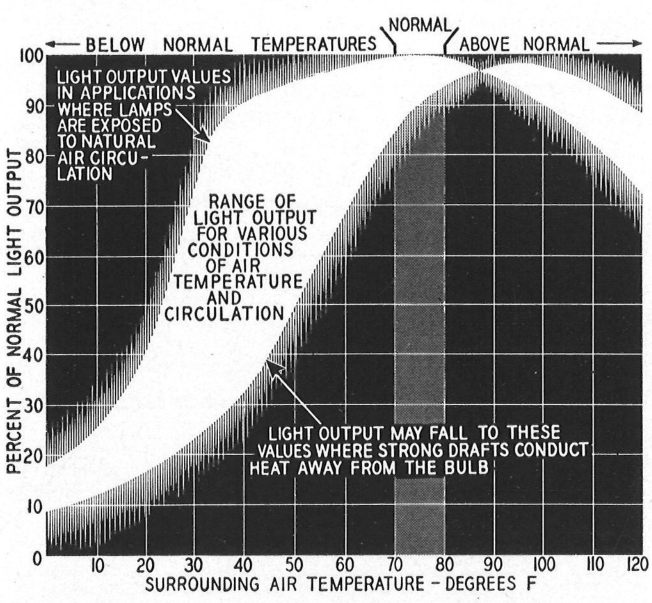
Lamp Temperature and Lamp Efficiency

The more common sizes of bare fluorescent lamps operate most efficiently at normal room temperatures of 70° to 80° F, where the temperature of the glass tube itself is 100° to 120° F. At lower surrounding temperatures the mercury vapor condenses and the activating ultraviolet radiation is reduced. At higher temperatures the vapor pressure is increased and some of the ultraviolet radiation is shifted from 2537A to longer wavelengths; also there is increased reabsorption of the 2537A radiation by the mercury vapor.

Both of the above circumstances reduce the light output of fluorescent lamps, the amount depending on specific conditions of use. In ordinary rooms of livable room temperature, and in conventional types of fixtures this problem is unimportant since the light output will be relatively unaffected. In very hot weather and in hot locations like boiler or furnace rooms, lamp bulb temperatures may reach the point where the light output falls off perceptibly. In these instances, the danger of overheating ballasts perhaps is more significant.

The drop in light output when operated in cool or cold temperatures is usually more important in practice because this condition is likely to be more generally encountered. The performance of lamps in refrigerated cases, in outdoor use during winter months, and for similar applications is important to the satisfactory use under these circumstances.

The accompanying curves will give a general picture of the effect of lamp temperature on light output.



Fluorescent lamps operate at highest light output when the bulb temperature is between 100° and 120°F. This condition occurs when the surrounding air in natural circulation is between 70° and 80°F.

Drafts conduct heat away from the bulb and in extreme conditions of draft the bulb temperature may be little greater than the air temperature—a condition realized when lamps are first turned on. The lower limits shown represent measurements of light output made immediately after turning on the lamps and before the bulbs were warmed up.

In common usage the values in the upper range would normally apply.

These are laboratory observations and do not describe many influencing factors in practical installations. The curves are carried down to zero, though most lamps cannot be depended on to start below 50° F. (See low-temperature starting.) The 100-watt lamp maintains its light output down to about 30° F at which point the light output drops sharply; this lamp will start reliably under most conditions of temperature down to zero degrees, and for this reason would seem to be a likely choice for outdoor service in cold weather.

The adverse effect of low surrounding temperature can be offset to a great extent by enclosing the lamp. This can be accomplished in a variety of ways, including the use of enclosing tubes, etc. It should be remembered, however, that enclosing lamps operating in normal room temperature will likely raise the bulb wall temperature to the extent that light output will be decreased. Even in open fluorescent luminaires the mutual heating of lamps mounted on close spacings may raise the ambient temperature and reduce the light output unless proper consideration has been given to heat dissipation.

To what extent the light output will fall off under different conditions of surrounding air temperature is difficult of precise prediction under practical installation conditions. Normal light output is conditioned upon maintaining the bulb itself within a certain range of temperature. This range varies with the different bulb sizes and wattage—one criterion being the watts per square inch of bulb surface provided in the design of the lamp. The actual bulb wall temperature is dependent upon the circulation of air about the bulb, how well it may be shielded, or enclosed.

The lower curve was obtained by measuring the light output immediately after the lamps were started when the bulbs were at the same temperature as the surrounding air. This would seem to be the lowest limit of light output, because in operation, the bulbs would warm up somewhat. The upper curve is for lamps operating exposed in "still" air.

Low-temperature Starting of Fluorescent Lamps

From the standpoint of starting, no special restrictions need be applied where surrounding temperatures are not below 50° F and providing the circuit voltage is within the recommended range. Satisfactory starting should be obtained at temperatures considerably below 50° F by (1) keeping the line voltage up, preferably in the upper half of the ballast range, and (2) using manual starting switches or thermal-switch starters. Such starters are available for 40- and 100-watt lamps. In applications involving the 40-watt size, satisfactory starting can be secured down to 0° F by using the lamp specially designed for low-temperature starting. The FS-44 starter should be used. This lamp should not be used for general service, however, because of its shorter life and inferior lumen maintenance characteristics.

The life of the 40-watt low temperature lamp is estimated at about 60-per cent of the ratings given for the standard type.

LAMP LIFE AND DEPRECIATION

Normal Failure

The small filament-type cathode at each end of a fluorescent lamp is coated with an active compound of barium or strontium from which there is an electrical emission when the cathodes are heated for starting and during operation. This material is gradually used up during the life of the lamp and is especially used up during starting. Therefore, a longer life will be obtained if the lamps are allowed to operate continuously instead of being turned "on" and "off" frequently. However, rated life should be obtained on the average if lamps are operated for normal periods of 3 or 4 hours.

When this active material is used up at one end or both, the lamp will no longer operate but will simply blink "on" and "off," and there may be quite a shimmering effect of the light during the period that it remains lighted. Most lamps fail in this manner.

Average Life

Published values of lamp life are determined by life testing a selection of lamps each month from each factory. Precise test procedures are followed. Circuit voltages are closely regulated, the starters used deliver proper preheat and the ballasts are accurately rated for the designed lamp voltage and current. Under these specified test conditions, average life and the mortality rate can be determined, though it will be noted that some lamps fail before rated life is realized, while others may live considerably longer than average life.

In actual installations the life obtained may be more or less than published values, depending on the departure from standard test conditions. Where lamps are turned on and off frequently or where the lamps blink several times before starting due generally to a poor starter or low voltage, the life will be shortened; in installations that burn continuously as in many industries, a life of 10,000 hours or more may be experienced, although the depreciation may be so severe that most economical operation is not obtained.

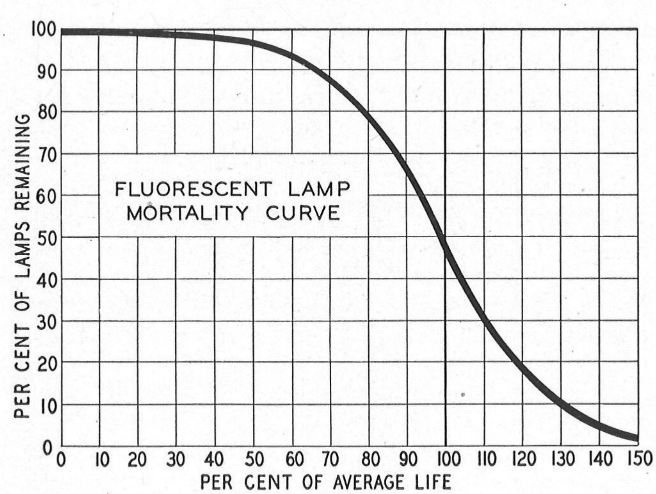
Life Ratings of Fluorescent Lamps

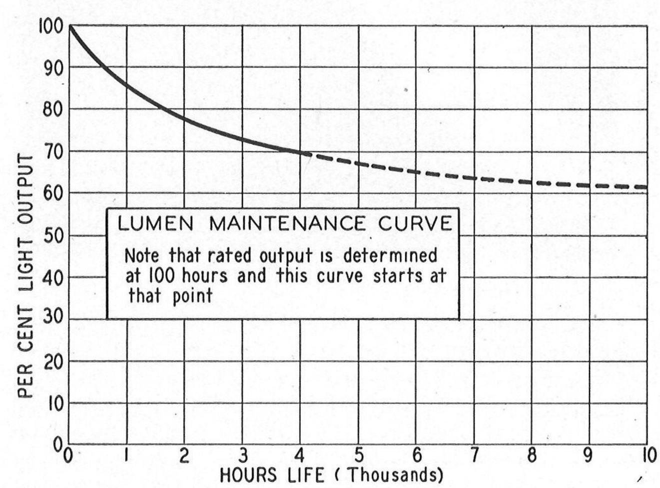
Lamp	Burning Hours per Start	Rated Average Life (Hours)
6- and 8-watt T-5	3	2500
13-watt T-8	3	2500
14-watt T-12	3	2000
15-watt T-8 30-watt T-8	3 6 12	2500 4000 6000
15-watt T-12 20-watt T-12 40-watt T-12 All Slimline lamps	3 6 12	2500 4000 6000
40-watt T-17 60-inch (Low brightness)	3	2500
100-watt T-17	3 6 12	3000 4500 6500

Light-output Depreciation

Fluorescent lamps blacken rather uniformly throughout the length of the tube during life. This is usually not very noticeable unless a lamp which has burned for a considerable time is compared with a new one in front of a light source. However, this more than any other cause results in a depreciation of light output during life.

The light output decreases rather rapidly during the first 100 hours of operation and the loss may amount to as much as 10 per cent. Therefore, for rating purposes, the 100-hour value is used. The light output may depreciate 25 to 35 per cent on the average for average operating conditions by the end of rated life. The light output during life averages approximately 80 per cent of the 100-hour value.



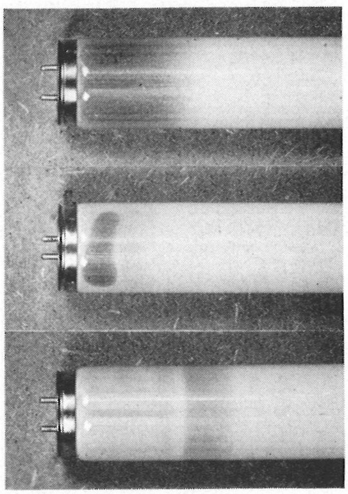


Lamp Appearance

At the end of life the lamps usually show a dense blackening at either one end or both. Also, there may be dark rings slightly brownish in color at one end or both. However, on the average, there should be little indication of either blackening or rings during the first 500 hours of operation.

Heavy end-blackening early in life indicates that the active material on the cathodes is being sputtered off too rapidly, and may be due to:

1. **Frequent starting of lamps—life is based on number of starts.**
2. **Starters operating improperly, causing**
   - **(a) Either insufficient or too long a preheat period**
   - **(b) Lamps to blink "on" and "off"**
   - **(c) Ends of lamp to remain lighted**
   - **(d) Several starting efforts each time lamp is started**
3. **Omission of or a short-circuited starting compensator in lead circuit of two-lamp ballast.**
4. **Improper ballasts or ballasts not meeting specification requirements.**
5. **High or low voltage—for best results circuit voltage should be within ballast rating.**
6. **Improper wiring of units.**



Normal End-Blackening

The normal blackening which may develop at either one end or both usually extends from the base for a distance of 2 or 3 inches. This is typical of a normal failure and usually develops quite rapidly near the end of lamp life. Lamps showing this condition and still operating can be removed from service with little loss in lamp life.

Certain starting and operating conditions may cause a lamp to blacken prematurely and result in shortened lamp life, as noted above. Normal end-blackening should not be confused with a mercury deposit which sometimes condenses around the bulb at the ends. This mercury condensation appears to be more common with the 1-inch diameter lamps than with the 1½-inch sizes. It is often visible on new lamps but should evaporate after the lamp has been in operation for some time. However, it may reappear later when the lamps cool.

Frequently dark streaks appear lengthwise of the tube due to small globules of mercury collecting on the lower (or cooler) part of the lamp. Mercury condensation is quite common on lamps in louvered units due to the cooling effects of air circulation around the louvers.

Mercury may condense at any place on the tube if a cold object is allowed to lie against it for a short period. Such spots near the center section may not again evaporate. When condensation occurs in this manner, rotating the lamp 180 degrees in the lampholders may give a more favorable position for evaporation or may place the spot in a less conspicuous place from an appearance standpoint.

Near the end of life some lamps may develop a very dense black spot, shown in the center photo about ½ inch wide extending almost half-way around the bulb, centering about 1 inch from the base. This is quite normal but should a spot develop early in life, it is an indication of excessive starting or operating current. This may be due to a ballast off-rating or to an unusually high circuit voltage.

Rings or bands slightly brownish in color sometimes develop at either end or both. These are usually located about 2 inches from the base at either end or both, but have no effect on lamp performance. The lower photo illustrates the appearance.

Lamp Performance in Service

To secure the best performance of fluorescent lamps it is important that the user understand how to properly maintain his fluorescent installation. There are certain factors which affect the performance of fluorescent lamps that were not encountered with incandescent filament lamps, and some of these new elements related to satisfactory service are within the control of the customer.

For example, if a filament lamp does not light when current is applied, the one conclusion is that the lamp is burned out or defective. No such conclusion should be formed in the case of the fluorescent lamp. A fluorescent lamp, though perfect in all respects, may not start or operate properly through no fault of its design or manufacture. Specifications based on the attainment of best lamp performance govern the design and construction of auxiliary equipments.

Frequency and Stroboscopic Effect

Operation of fluorescent lamps is possible and practicable on 50 cycles and auxiliaries are available for this frequency. The lamp itself will operate on 25 cycles, and 25-cycle Tulamp ballasts for 40-watt lamps are available on special order. However, at this frequency the flicker is likely to be unsatisfactory unless special precautions are taken in installation and circuit arrangement.

Every lamp, when burned in the usual manner on alternating current, has a non-uniform light output caused by the cyclic variations in current. This effect is, of course, increased at lower frequencies. In electric discharge lamps where practically no energy is stored, as it is in the hot tungsten in filament lamps,

Flicker* of Fluorescent Lamps
(Operated on 60-cycle circuits)

Daylight	55	Green	20
White	35	Pink	20
Daylight (Tulamp Auxiliary)	25	Red	10
White (Tulamp Auxiliary)	16	40-watt Filament Lamp	13
Blue	90	100-watt Filament Lamp	5
Gold	25		

* Per cent deviation from mean light output. (Approx.)

the light drops almost to zero along with the current between each half cycle. Fluorescent powder, however, except for the blue, has a persistence of glow or phosphorescence which helps to reduce flicker, the reduction being dependent on the phosphor used. With lamps burned on two or more phases or with a Tulamp transformer the lamps operate out of phase and the fluctuation in light output is further reduced and becomes comparable to the variation in low wattage filament lamps.

Swirling

This refers to a pronounced and irregular variation in the light quite noticeable as one looks directly at stationary objects, and does not refer to the high-frequency stroboscopic effect (which is noticeable when observing a fast-moving object), which results from normal variations of light output on alternating current. Swirling may appear in several different forms, all apparently related as to cause. These effects are often referred to as "spiraling," "snaking," "fluttering," etc.

A new lamp may swirl when first placed in service. This will usually clear up after the lamp has been operated for a short period or turned "on" and "off" a few times. One of the chief causes of swirl is starting the lamp without properly preheating the cathodes. This may be due to a starter which is not performing properly, starting the leading lamp of a two-lamp ballast without a starting compensator, high-voltage starting, or starting the lamp with improper auxiliary equipment.

A swirl may suddenly develop at some time during the life of any lamp in normal service, and then clear up quickly. Lamps showing a persistent tendency to swirl should be replaced. Further investigation may be necessary if successive lamps continue to develop this condition in the same lampholders.

Color Quality

In passing judgment on variation in color, great care must be used to avoid illusions, as lamps of exactly the same color may appear quite different in various locations of a given installation. These illusions are usually due to effects from fluorescent lamps of other colors, or differences in reflector finishes or from colored paints used for decorative purposes. Always interchange the lamps before forming a conclusion where differences of color are involved.

The eye is quite critical in color comparison, and the slight differences within the manufacturing tolerances of both white and daylight lamps may be discernable, although the differences are seldom objectionable.

Cathodes—The cathodes are short in length and should withstand a considerable amount of rough handling without breaking. However, it is sometimes possible to break these by a severe side blow. A simple test will show whether or not the cathodes are intact. Test each end of the lamp separately by connecting the two base pins in series with a 60-watt 115-volt filament lamp on a 115-volt circuit. If the cathodes are intact the filament lamp will light and the end of the fluorescent lamp will glow. The 60-watt test lamp should be used with lamps from the 14- to 40-watt sizes. For a small diameter or miniature fluorescent lamp, use a 25-watt 115-volt test lamp and for the 100-watt size use a 200-watt 115-volt test lamp. The purpose of the several sizes of lamps mentioned is to limit the current to the value for which the cathode filaments are designed. This allows the cathodes to heat up sufficiently to produce a fluorescent glow at the end. This test shows not only an intact cathode circuit but the glow indicates the presence of active electrons. Absence of the fluorescent glow, even though the cathode heats, is an indication of a lamp that has leaked air.

Burned-out Cathodes

An abnormal circuit or operating condition is necessary to burn out a cathode. In the normal operation, the ballast will limit the current to a value below that required to burn out a cathode or cause any fusing of the metal. Electrodes may be examined by viewing the end of the bulb against a pinhole of light which casts a shadow of the cathode on the bulb wall. In this way it can be observed whether the cathode is intact.

If one end of the lamp is inadvertently placed across a 115-volt circuit, the cathode may burn off at both leads with little fusing of the metal. The stem press may also crack, resulting in an air leak. Broken lampholders, lampholders with starter sockets attached and surface-mounted on metal, one strand of a stranded conductor touching a grounded fixture, and improper wiring, are common causes of either momentary or definite grounding which may result in burned-out cathodes. Also, operation on direct current without the necessary additional resistance required, is a common cause.

Breakage

Base Pins—These pins are able to withstand a reasonable pressure without breaking. However, a considerable force can be exerted on these pins if an attempt is made to turn the lamps in the lampholders without first making certain that the two ends are seated properly. If a lamp does not turn readily when it is being inserted, remove the lamp again and reinsert into the lampholders.

Broken Base Insulation—Here again the base insulation has sufficient strength to withstand a reasonable service. However, if the lamp is dropped or severely bumped on the end it is possible to break this insulation and render the lamp useless.

Starting Difficulty

Starting difficulties may be due to a number of other causes than the starter itself. In general, any difficulty in starting may result in premature end blackening and short lamp life.

A starting compensator in series with the starter in the leading branch of a two-lamp ballast is necessary for all circuits requiring starters except for the 100-watt lamp. Starting compensators are usually built into the ballast housing. If the compensator is omitted or if the radio interference condenser becomes short-circuited there will be insufficient cathode heating when the lamps are started. This "cold" starting is quite likely to result in short lamp life as previously mentioned.

Anything that results in repeated starting efforts tends to reduce lamp life. Various causes of starting difficulties are mentioned at the bottom of the page.

Under and Over Voltage

Lamps with low-voltage ballast equipment are designed for operation on circuit voltages of from 110 to 125 volts inclusive, and in some cases, may operate satisfactorily on circuits as low as 105 or as high as 130 volts. Similarly, ballasts designed for high-voltage service should operate satisfactorily on circuits from 220 to 250 volts with possible satisfactory operation as low as 210 or as high as 260 volts.

If lamps are used on higher than rated voltages, the operating current becomes excessive and may not only overheat the ballast but may cause premature end blackening and early lamp failure. If lower voltages are applied, the current may be too low for satisfactorily preheating the cathodes and the lamps may flash "on" and "off" without starting. Thus, either too high or two low voltage operation is injurious to the lamp.

Radiant Heating Effects

Confusion is sometimes expressed at the assertion that fluorescent lamps produce cooler footcandles than do incandescent lamps. While a kilowatt-hour represents an over-all heating effect of 3414 BTU regardless of how consumed, the lesser sensation of heat from fluorescent lamps lies in the fact that (1) they generate more lumens per watt of energy consumed than do filament lamps, and (2) less radiant energy is emitted than by filament lamps of the same wattage. Both of these factors are evaluated when light sources are compared on a "total radiant energy per lumen" basis. The chart on page 60 shows the total radiant energy to be 18.8 watts (light plus radiated heat) for a 40-watt white fluorescent lamp or 8.7 watts per 1000 lumens. Comparable values for a 200-watt general service incandescent lamp are 160 watts radiated or 43 watts per 1000 lumens. Thus it is said that the sensation of heat from fluorescent lamps is only about one-fifth that from filament lamps for the same amount of light delivered.

Lamp Blinks "On" and "Off"

This may simply be a normal lamp at the point of failure. On the other hand, if the lamp is new or if it has not been in service long there are a number of factors that might cause this action. This difficulty may be due to the starter, and this can readily be replaced. It is possible that the lamp may be at fault, and lamp replacement is the next logical step. Changing either the lamp or starter may only temporarily correct the trouble if there is a borderline cause of difficulty for some other reason.

Low circuit voltage, low ballast rating, low temperature and cold drafts may individually be the cause of difficulty of this nature, or several of these may be contributing factors.

If two-lamp ballasts are involved, there is a possibility that the individual starter leads from the two pairs of lampholders have been criss-crossed. When this is the case, the two lamps may start promptly if both starter switches open simultaneously. However, if one lamp starts, the other lamp may blink "on" and "off" for a long period of time or may not start at all. This sort of trouble is generally easy to locate because after one lamp starts only one end of the other lamp will light up before the starting effort is made. Also, one lamp will not make a starting effort unless the other is in the lampholders. Thus, by testing each of the two lamps separately, this wiring fault can be easily detected.

Lamp Makes No Starting Effort or Starts Slowly

Be certain that the lamp makes proper contact in the lampholders. The lamp can be checked by testing it in another circuit, as there may be an open circuit in the lamp. Too, it is possible that the starter has reached the end of life and should be replaced.

If necessary, a voltage check should be made from one lampholder to the other. This can be done with a voltmeter or with a test lamp (220 volts, 100 watts). It should be remembered that there are two connections to each lampholder, and but one of these at each lampholder should be alive. Hence, there are four possible ways of checking these contacts to find the live two. If no voltage indication can be found, next check the circuit leads to the lampholder. If there still is no voltage indication, check the circuit connection. There is also a remote possibility of an open-circuited ballast.

Ends of Lamp Remain Lighted

In a new installation it is, of course, possible for the circuit to be incorrectly wired.

If the installation has been in operation, the trouble may be due to a short-circuited condenser in the starter, or it is possible that the switch contacts are welded together. In either case, it is necessary to replace the starter. Starters which have been in service for some time can fail in this manner. In the earlier designs of the "No Blink" starter the ends remained lighted until the lamp was replaced. In the newer manual reset types, such as the FS-20, FS-30, FS-40, FS-100 and FS-102, the cathode circuit is opened when the lamp fails to light.

Radio Interference

The performance of the mercury arc of a fluorescent lamp at the electrodes is associated with an electrical instability which sets up a continuous series of radio waves. There are three ways in which these waves may reach the radio and interfere with reception:

1. Direct radiation from the bulb to the radio aerial circuit.
2. Direct radiation from the electric supply line to the aerial circuit.
3. Line feedback from the lamp through the power line to the radio.

The direct radiation from the bulb diminishes rapidly as the radio is separated from a lamp and this effect can be controlled by proper positioning of the radio and its aerial. The table shows the extent and comparative amount of bulb radiation for various sizes of fluorescent lamps. It will be seen that if the aerial is at least 9 feet from the lamp, interference by bulb radiation is negligible.

Extent of Bulb Radiation
(Values are relative)

Lamp	Aerial 2 ft. from Lamp	Aerial 4 ft. from Lamp	Aerial 6 ft. from Lamp	Aerial 8 ft. from Lamp	Aerial 10 ft. from Lamp
40- or 100-watt	100	47	9	4	0
30-watt . .	90	43	8	1	0
20-watt . .	75	35	7	0	0
15-watt . .	55	26	5	0	0

In case the radio must remain within the bulb radiation range it will be necessary to take the following precautions:

1. Connect the aerial to the radio by means of a shielded lead-in wire with the shield grounded, or install a "doublet" type aerial with twisted pair leads.
2. Provide a good ground for the radio.
3. Aerial proper must be out of bulb and line radiation range. The use of a correct antenna system will usually help reduce radio interference by providing a better station signal strength.

Interference from line radiation and line feedback can best be minimized by the proper application of line filters at each lamp or fixture. A simple form of filter is the 3-section capacitor (G-E Catalog No. 25F214). One such unit per fixture (or for each 8 feet of lamps in a cove) will reduce line noise approximately 75 per cent. For the cases where it is desirable to completely eliminate line noise, the inductive-capacitor type (G-E No. 67G400) is recommended. This filter has a current-carrying capacity of 2 amperes which is, for example, about the load of four 40-watt lamps.

Where only one or two radios are located near a fluorescent installation and the aerial circuit has been properly shielded from bulb and line radiation, a single line filter located at the radio power outlet will suffice.

Where radios located in buildings adjoining the fluorescent installation are receiving line feedback type of interference, it is practical to install a single filter such as the 25F214 at each panel box feeding fluorescent lamp circuits.

Where it is necessary to filter each lamp or fixture, the filter should be located as close to the lamps as possible. This precaution should be taken because of line radiation between lamp and filter.

Lampholders improperly spaced resulting in poor contact with lamp base pins can also generate interference, as can fluorescent fixtures improperly grounded. Failure to ground the neutral of branch circuits (as required in the National Electric Code) is an additional cause. If the service lines are not properly grounded, filters will be much less effective.

Fluorescent equipments destined for home or other use where radios are likely to be present should have the proper radio interference filter in each fixture.

FLUORESCENT LAMP DEVELOPMENTS

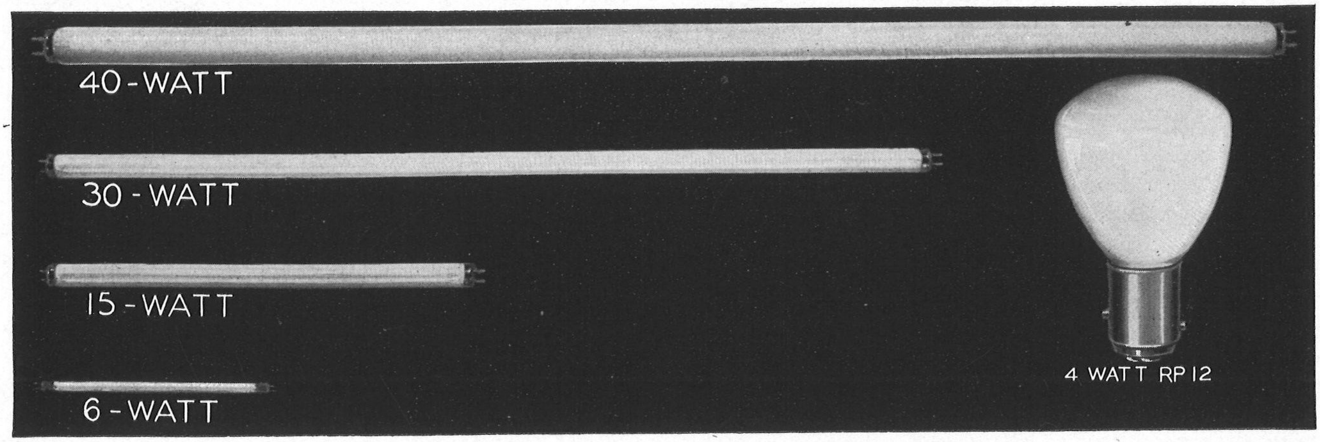
The principle of the fluorescent arc, the field ahead in the chemistry of phosphors and the wide latitude for the development of lamps of various physical sizes and operating characteristics, suggest that this most versatile type of lamp will, in the future, find many new fields and widespread uses not presently developed.

The Slimline and Circline lamps are examples of ideas in lamp design to meet application needs, so potential that eagerness for their announcement could not patiently await manufacturing facilities. Other lamp designs are crowding the minds of lamp and application engineers. Serious deliberation and well-balanced thinking are necessary to achieve orderly progress and prudent designs; otherwise, the business of lighting will be cluttered with a miscellany of lamp types, ballasts and special circuits whose economic concept might not prove very lasting or substantial. Yet with a new product with as broad a horizon as fluorescent lamps, one must always be alert and receptive to all new ideas.

The latest of new ideas demonstrating the versatility of these lamps is the development of a new phosphor to produce the ultraviolet rays of sunlamps. Such lamps will become available as manufacturing facilities permit.

The germicidal lamps and 360BL lamps, briefly described on the following page have been listed for the past several years, yet their use has been restricted largely to wartime needs, and the broader fields of application remain to be explored.

"BLACK LIGHT" (360BL) FLUORESCENT LAMPS



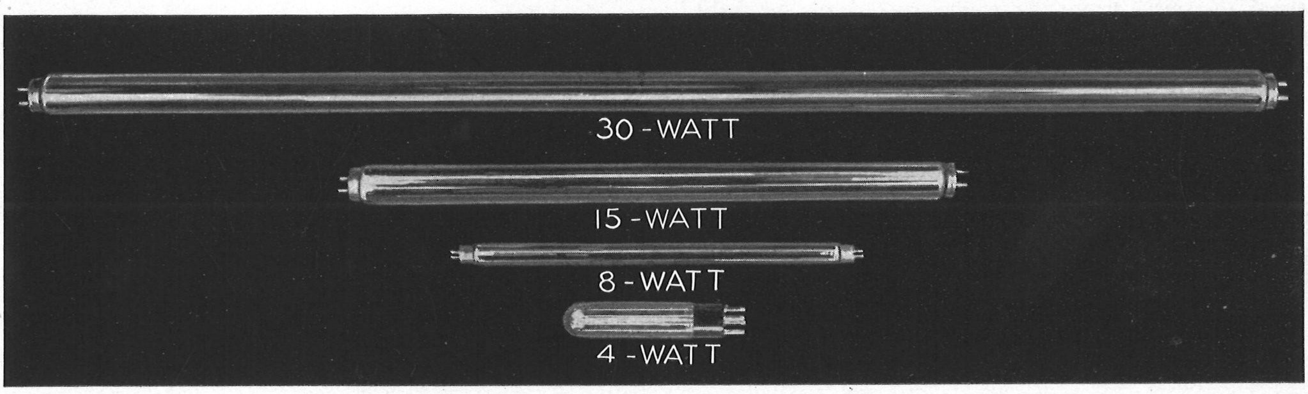
Fluorescent lamps containing a special phosphor whose radiation peaks around 3600A in the near-ultraviolet region of the spectrum are now available. Designated as "360BL" lamps, these sources are similar to comparable sizes of standard lamps except for the phosphor; they operate from standard auxiliary equipments. They can be used for blueprinting and for activating luminescent materials such as on fluorescent maps, markers, sketches, directional signs, laundry markings, etc.

Some visible light is produced. Supplementary filters for absorbing the visible light are available.

The RP-12 bulb shown is also a "360BL" lamp designed to operate on 12-16 volt and 24-28 volt D.C. circuits for fluorescent instrument dial lighting on airplanes.

The wattage ratings are 3 and 4 watts respectively for the two voltage classes.

GERMICIDAL LAMPS



These lamps radiate most of their energy at the 2537 line which is very near the wavelength most effective in destroying bacteria.

Three of the germicidal lamps are similar in construction to 8-, 15-, and 30-watt fluorescent lamps except for omission of the phosphor and use of No. 9741 glass which transmits the shortwave ultraviolet. Auxiliary equipments for these germicidal lamps are identical with those for standard fluorescent lamps of corresponding size. A 4-watt germicidal lamp having a bent-U tube and a radio-type base is also available. It uses G-E ballast 58G825 and FS-5 starter. Germicidal lamps are being employed in hospitals, barracks and general interiors, as well as sterile storage cabinets and the like.

These sources produce shortwave ultraviolet radiation which activates fluorescent phosphors. They must be used with caution and full understanding that the radiation emitted is dangerous to living organisms and that direct exposure to the eyes even for a few seconds should be avoided.

FLUORESCENT SUNLAMPS

The development of a new phosphor for converting the 2537A radiation of the arc to a broader band of longer wavelengths in the ultraviolet, corresponding to the vital ultraviolet rays of natural sunlight, is indeed a most important element of progress. This will permit the listing of sunlamps in sizes corresponding to standard fluorescent lamps, which operate on the same ballast circuits, and which can be combined in installations with standard lamps for illumination purposes.

These lamps produce little visible light, but are highly efficient sources of suntan radiation, the 20-watt lamp having an E-Viton rating of approximately 40,000, while the 40-watt size produces 100,000 E-Vitons. These low-wattage suntan sources, while competitive with older types of sunlamps will have the advantage of lightweight portability and casual use not possible with other types. This aspect should permit the wide extension of the benefits of artificial sunlight to millions of people, in offices, schools and work places, by the simple means of including a small proportion of these tubes as a part of the fluorescent lighting system.

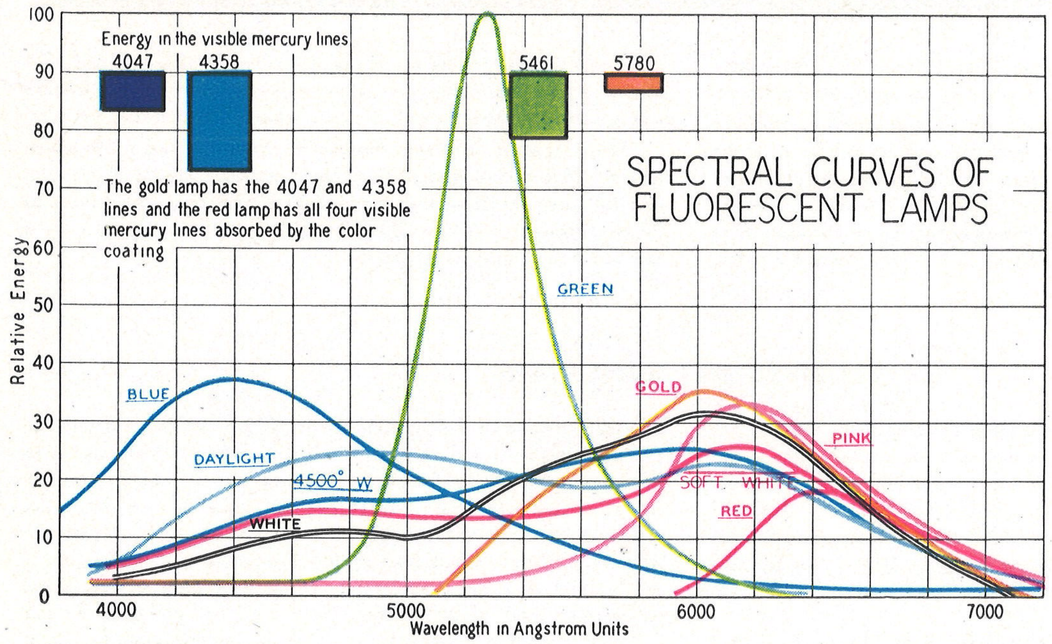
COLORS AND COLOR QUALITY

The fluorescent lamps opens up an entirely new realm in color and color quality of light production. With filament lamps, the production of colored light was by means of absorption filters; while amber, orange and red could be produced with fair efficiency, blues and greens required an absorption of from 85 to 99 per cent of the light from the less efficient filament lamp. An efficiency of 1 or 2 lumens per watt was accepted. With the fluorescent lamp, colored light is produced directly by choice of phosphor; the green phosphor, for example, produces green light at an efficiency of 70 lumens per watt. Blue, pink and amber have an efficiency of 25 to 30 lumens per watt; red is presently low at about 4 or 5 lumens per watt. White light is a mixture of all colors and is obtained by blending in proper proportion the phosphors that in themselves produce colored light. Obviously, therefore, almost any degree of "whiteness" or almost any tint or saturation may be obtained. The colors available in white and colored lamps are largely a matter of standardization and attendant economics. The line of colors available at any time will always be conditioned upon public demand and preference.

The demand for colored lamps has not been great, and while people react tremendously to colored light, the possibilities have not yet been explored. As far as "white" light is concerned, good reproductions of natural daylight from the warm sunset to the cold blue-white of north skylight have been achieved. Hundreds of different white light lamps are possible, and hundreds would be needed to duplicate all of the variations in natural daylight from day to day, from season to season, from one latitude to another; and even more complicated, the daylight that comes indoors which is tempered by orientation, window draperies, and interior painting. It is probably a mistake to predicate judgment of desirable standard white lamps on natural daylight, though this is the most obvious procedure since certain spectral standards of noon sunlight and north skylight had long been established. Misjudgments of color appearance of materials come not only from differences in color quality of the light, but from the wide difference in the light intensity or footcandles under which comparisons may be made.

It is not likely that standard, low-cost fluorescent lamps will match natural light precisely. They will always be closely approximate and there is little point, except perhaps in scientific circles, of trying to prove the proximation. Fluorescent lamps are worthy of new creative standards of color and color quality appraisal.

At present, in the interest of standardization and manufacturing economy, four different "white lamps" are listed—namely, "daylight" (6500°), the 4500° white, the 3500° white and the "soft white," a warmer-toned white. Many others are possible and may, whimsically, be demanded. One thing seems certain—and that is that there seems to be no urgently valid reason for more than a few standard "white" lamps which can be massed-produced, stocked and sold at the lowest possible cost. It is perhaps too early in our new experience in freedom from older restrictions and habit in production, appraisal and handling of spectral qualities of artificial light to consider that present lamps are just a contemporary step toward a better understanding of color. The spectral distribution of present standard fluorescent lamps is given in the accompanying chart. These curves are plotted to the same scale for a given wattage so that comparisons may be made of energy distribution necessary to achieve the variations in white and colored lamps. A study of these curves in relation to the eye sensitivity curve will reveal the reason for the wide differences in lumens-per-watt efficiency in the production of colored light.



Fluorescent Lamp Curves. To show the outputs from equal wattages of the various colors the curves (left) are plotted to the same relative energy scale. To avoid confusion only the continuous part of the spectrum is shown in all cases. The energy contained in the four visible mercury lines is shown by the separate rectangular areas. Except in the case of the red and gold lamps, the energy in the mercury lines should be added to the continuous spectra when plotting the resultant spectral distribution obtained by combinations of different colored lamps.

LAMP DEPARTMENT

GENERAL ELECTRIC COMPANY

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