Compact fluorescent lamps

A. Bouwknegt

The development of very stable phosphors with a narrow band emission opened the way to a further miniaturization of fluorescent lamps. A discussion is presented of the present possibilities to reduce lamp dimensions to a degree that makes them suitable for home lighting. Reduction of length is essential, and on the basis of experimental data the balance is considered between this desired reduction in length and the accompanying effects such as loss of efficacy and increase of ballast volume. This leads to an optimum discharge diameter, which is between 10 and 15 mm, depending on the level of luminous flux. Lamps with this diameter must be bent in order to arrive at an acceptable length. Two types of compact fluorescent lamps, designed for the home lighting area, are described. A few remarks are made about their possible applications and their economics.

Introduction

Since their introduction in the late 1930's, fluorescent lamps have found widespread application for the interior lighting of offices, schools, industrial buildings, and similar premises. In these cases their specific features, such as high efficacy and long life, could be exploited to the full. However, despite these advantages, fluorescent lamps were less successful in the domestic area. There, the dimensions of the light source, requiring bulky luminaires, were a serious disadvantage, and the most widely used light source remained the small, simple, inexpensive, but relatively energy–hungry incandescent lamp.

The above picture will change in the near future. Firstly, because increasing energy consciousness among light users is leading to a growing interest in efficient light sources, which makes fluorescent lamps an interesting proposition. Secondly, because it is becoming apparent that recent progress in lamp technology—especially in the field of phosphor development[1–7]—is opening the way to a more extensive miniaturization of fluorescent lamps than was possible only a decade ago. So fluorescent lamps will become competitive with the ubiquitous incandescent lamps. In this paper attention is focused on the theme of this miniaturization. First, a general discussion is given, indicating new possibilities and limitations. Next, two types of newly developed compact fluorescent lamps are described, these being designed specifically for application in domestic and social areas.

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New phosphors, the key to miniaturization

Lamp miniaturization means the reduction of lamp dimensions, especially the length, while maintaining the same level of luminous flux. Thus, miniaturization implies a higher density of ultraviolet radiation impinging on the phosphor coating.

Recently, three highly efficient narrow band phosphors have been developed which show emission peaks in the blue, the green, and the red part of the spectrum[1–7]. If a mixture of these phosphors is used in fluorescent lamps, a combination of high lamp efficacy and good color rendering is obtained, whereas the color temperature can be varied between 2500 K and 6000 K by changing the phosphor mix. Moreover, and this is of vital importance, it was recognized that these new phosphors showed a remarkably high stability in intense ultraviolet radiation[1] occurring for example in lamps with a small diameter. This stability results in lamp maintenance and efficacy values that cannot be achieved with the conventional halophosphate phosphors. Figure 1 illustrates this, for lamps with an internal diameter of only 10 mm. As a consequence, miniature fluorescent lamps with high efficacy, good maintenance, and good color rendering, can now be constructed. In all the following considerations, the use of these new phosphors is presumed.

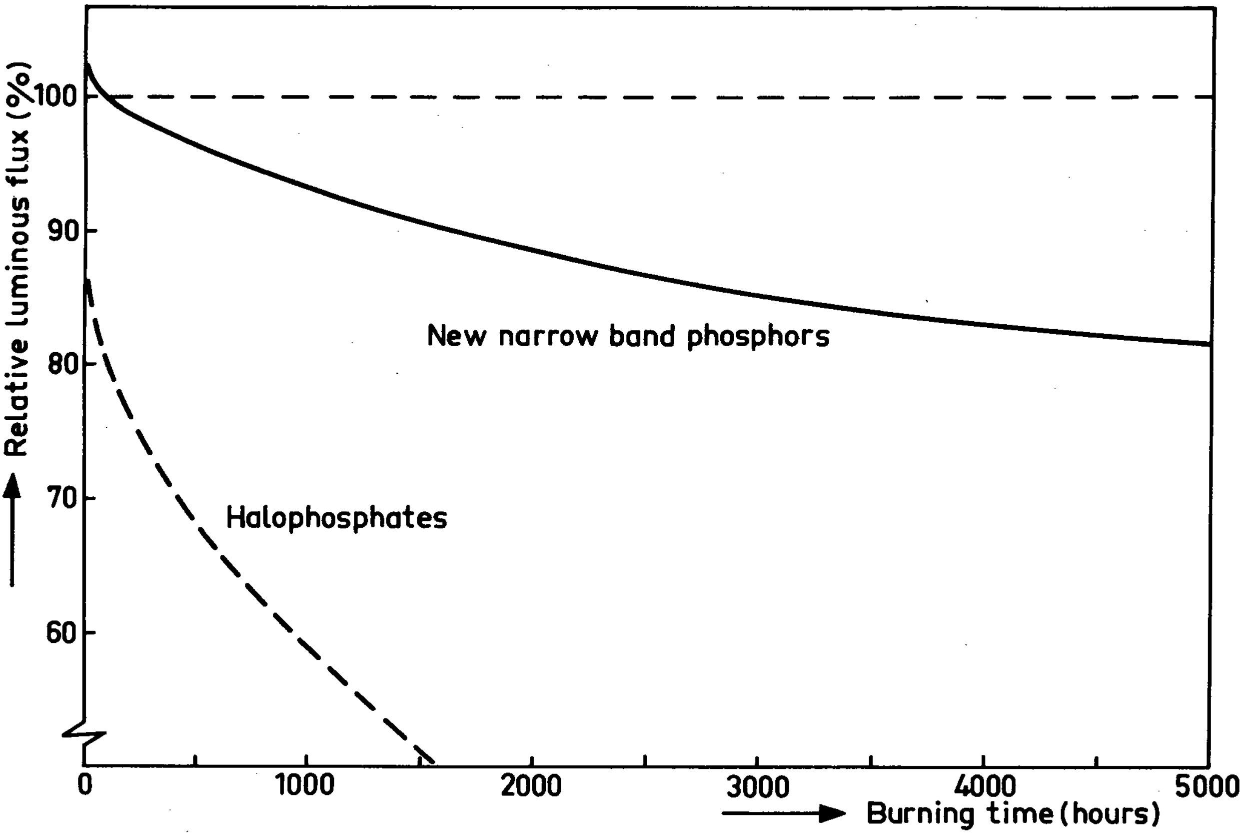


Figure 1. The relative luminous flux of miniature fluorescent lamps as function of the burning time. Lamps coated with the new narrow band phosphors are compared with the same lamps coated with the conventional halophosphates. Discharge diameter 10 mm, current 180 mA. All luminous flux values are related to the 100-hr value of lamps with the new phosphors.

Increased power dissipation per unit of lamp length

Reducing the length of a fluorescent lamp—while keeping the luminous flux constant at the same time—implies a higher power dissipation per unit of discharge length. This higher power dissipation can be achieved by raising the lamp current, but also by increasing the electric field strength in the discharge. The consequences of both these possibilities are considered.

Higher power dissipation by raising the current. If the lamp length is reduced by raising the current, while keeping the luminous flux and the diameter constant, this strongly influences the relative levels of power dissipated in the three parts of the system, namely the discharge column, the electrodes, and the ballast. The power dissipated in the column increases only slightly, due to the reduced discharge efficacy, but that in the electrodes increases almost proportionally to the current, and that in the ballast more than proportionally, if the latter is of conventional design. As a consequence, the efficacy of the lamp-and-ballast system is reduced. In addition, there is an increase in ballast volume, which is also more than proportional to the current. So lamp miniaturization does not always lead to system miniaturization!

The conclusion is that the possibility of reducing lamp length by raising the current is limited by the unwanted effects of a decrease in the lamp and system efficacy, combined with an increase in ballast volume and weight.

Higher power dissipation by raising the electric field. This case is more complicated. In principle, there are three options for raising the field strength:

1. Reduction of lamp diameter.
2. Addition of Ne of He to the discharge gas.
3. Use of a recombination structure, as recently proposed[8,9].

As combinations of the above possibilities are also possible, there is obviously a wealth of opportunities. The problem lies in making the choice.

The complexity is reduced if one considers Fig. 2. There the efficacy of the discharge column, η_d, is plotted against its electric field strength, E_d, for a fixed value of the discharge current (200 mA). The points represent experimental observations on a number of discharges in which the field strength is raised in different ways.[10] The drawn line is the relation between optimum η_d and E_d as indicated by model calculations on the discharge efficiency, made for a wide range of gas mixtures and discharge diameters.[11,12] Experiment and calculations are linked

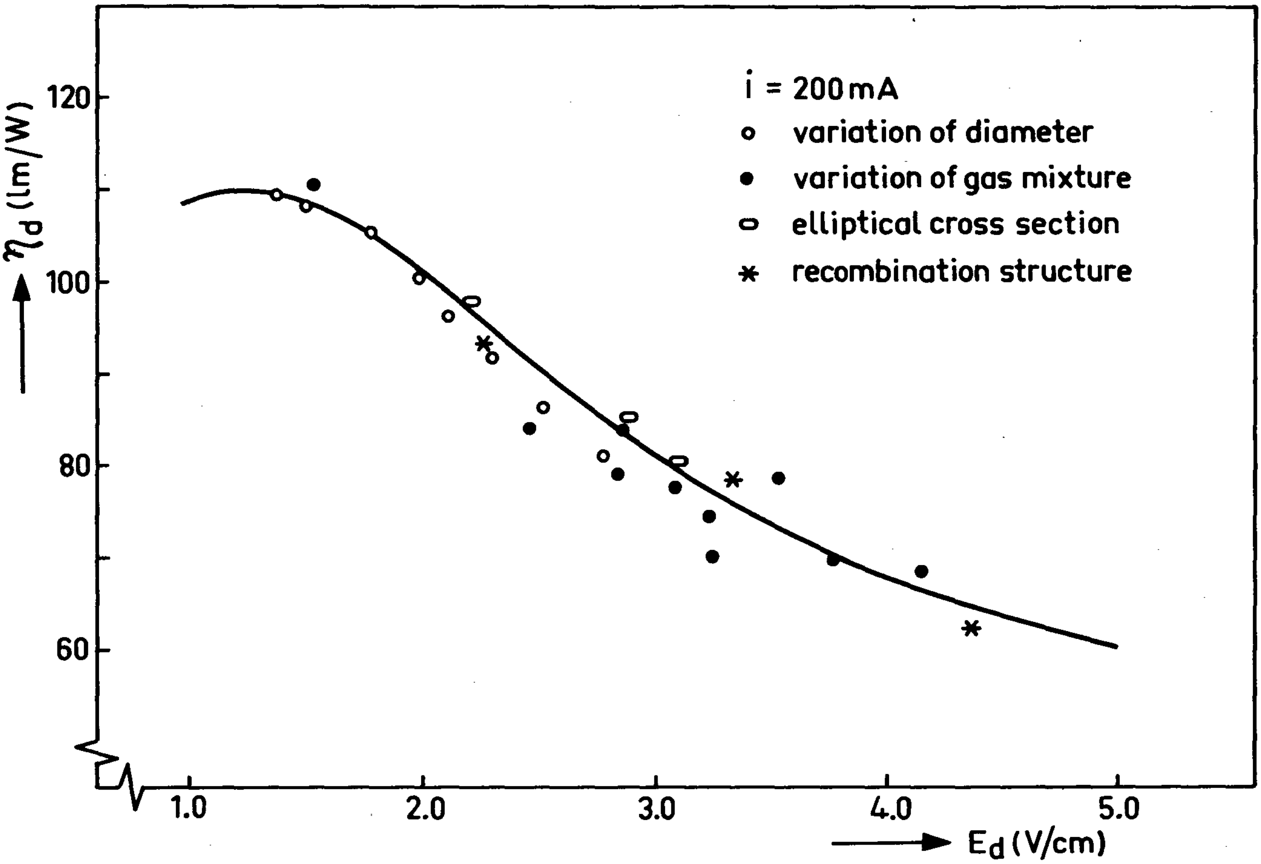


Figure 2. Efficacy of the discharge column as function of its electric field, for different Hg-rare gas discharges, all operated at 200 mA. The points are experimental observations. The drawn line gives the relation indicated by model calculations of the discharge efficiency. The efficiency calculations are linked to the experimental efficacy values at E_d = 1.8 V/cm.

at E_d = 1.8 V/cm. Similar curves have been found for other discharge currents.

The relation between η_d and E_d, as revealed in Fig. 2, shows that the means chosen to obtain an increased field strength in the gas discharge is of secondary importance, if judged with respect to the efficacy of the discharge column. This fact is rather surprising, in view of the many physical variables that are changed in the observed discharges; there are changes in diameters and current densities, circular and elliptical cross sections, different mixtures of rare gases, and also recombination structures.

If the field-raising means is judged with respect to the lamp efficacy, electrode losses must be included in the considerations. In general, these are higher for the lighter rare gases. From this point of view a reduction of diameter and the use of recombination structures as a field–raising means are to be preferred. The technological problems with electrode life in the lighter rare gases must also be mentioned in this respect.

It is clear from the considerations in the italicized headed sections above that both the increase of current and of electric field strength will reduce the lamp and system efficacy. Is there an optimum balance between these two? An answer to this question has been sought for a reduced set of possibilities: lamps with circular cross-sections, filled with 400 Pa Argon. Within this set the question is narrowed down and becomes: Is there an optimum diameter?

Choice of diameter for miniature Hg-Ar discharges

In order to arrive at a well-founded choice of the diameter for miniature lamps, an extensive experimental investigation was made. In the experiments, the lamp diameter d, the lamp current i, and the wall temperature, were varied,[10] and an analysis was made for the field $6 < d < 20$ mm, $100 < i < 400$ mA, for luminous flux values Φ between 300 and 1500 lm, at the optimum wall temperature. This is about 47 °C for lamps with an internal diameter of 10 mm. The analysis leads to the following results:

1. One may consider a set of lamps with varying diameter, but fixed values of luminous flux and lamp length. It is found that in this set both the lamp efficacy and the system efficacy reach a maximum for certain diameter values. These values depend on the luminous flux chosen, but not on the length. The efficacy maximum, especially that of the system, is not very pronounced, and in consequence the efficacy criterion is not a very selective one for a diameter choice. If the luminous flux varies between 500 and

1500 lm, the diameter for optimum system efficacy varies between about 9 and 15 mm, while the values for optimum lamp efficacy are about 3 mm higher.

2. An upper limit is often set to the lamp voltage by light output stability requirements. For conventional small inductive ballasts this limit is about half the line voltage. In the case of a set of lamps with varying diameter, but fixed values of luminous flux and lamp voltage, a smaller diameter will lead to a lower lamp length, but also to a lower efficacy, a higher current, and a more voluminous and heavy ballast. The analysis indicates that for this reason it is not wise to choose a diameter value lower than 9 to 10 mm.

There are a few other points that may limit diameter reduction. These include:

1. The technological limitations. The electrode dimensions, for example, put a practical lower limit on the lamp diameter.

2. The heat production and heat transport possibilities, especially in the neighborhood of the electrodes.

3. The lamp maintenance, decreasing with the increased phosphor loading for smaller lamp diameters.

4. The mercury pressure control. This is an important point for the PL lamp, to be described in a following section.

Keeping all the above considerations in mind, a good choice of internal diameter is about 10 mm for lamps with lower values of luminous flux Φ, say $\Phi <$ 1000 lm. For Φ values between 1000 and 2000 lm a better choice is 13–15 mm.

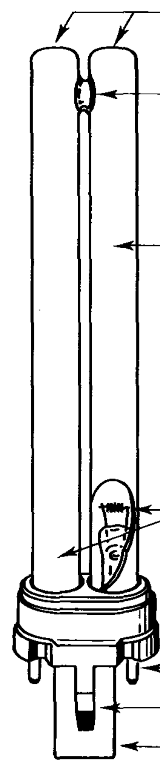


Figure 3. A PL-lamp. Starter and capacitor are integrated with the discharge tube, and mounted in the lamp cap.

Desired properties of miniature fluorescent lamps, necessity of further length reduction

The next step after the choice of the discharge diameter is the choice of the proper values of length and current for any given value of luminous flux. At this point a more quantitative listing of the requirements to be met by miniature lamps for home lighting may be useful. The most relevant requirements relate to:

1. *Luminous flux.* The most commonly used flux levels in Europe are between 400 lm and 1000 lm, which are the levels of incandescent lamps between 40 W and 75 W. Somewhat higher levels are required in the USA.

2. *Length.* An investigation of possible applications showed that the lamp length should not exceed about 20 cm; a much lower value is preferred.

3. *Efficacy.* The system efficacy of the lamp and ballast should be more than about three times the efficacy of an equivalent incandescent lamp; otherwise the lamp becomes less interesting with respect to energy saving, reduced heat production, and costs.

4. *Lamp voltage.* To ensure a stable light output the lamp voltage should not exceed half the line voltage, if simple small inductive ballasts are to be used.

5. *Ballast.* Small lightweight ballasts are desired, with low energy dissipation. For a conventional ballast this means low current values.

It is clear from the above requirements that items 3 and 5 require high voltage, low current lamps, with 4 imposing a limitation on the lamp voltage. However, the length requirement in item 2 points in the opposite direction. An examination of the experimental data shows that fulfillment of items 3 to 5 will lead to an unacceptable lamp length, even at moderate levels of luminous flux. So some form of bending of the lamp is necessary. This leads to the proposal of two types of compact lamps, to be indicated as the PL lamp and the SL lamp.

Description of the PL lamp

A sketch of a PL lamp is given in Fig. 3. The lamp consists of two half tubular fluorescent lamps arranged in parallel, only a few millimeters apart, and connected by a small bridge through which the discharge passes from one lamp half to the other. In this way the lamp length is reduced to a little more than half the discharge length and with this reduction the requirements of the foregoing section can be met.

An essential part of the PL construction is the top of the lamp. A serious problem in miniature lamps, not mentioned up to now, is the control of the mercury pressure. This is determined by the temperature of the coldest spot of the lamp wall, where mercury droplets will condense. The optimum temperature of this cold spot, at which the lamp produces its

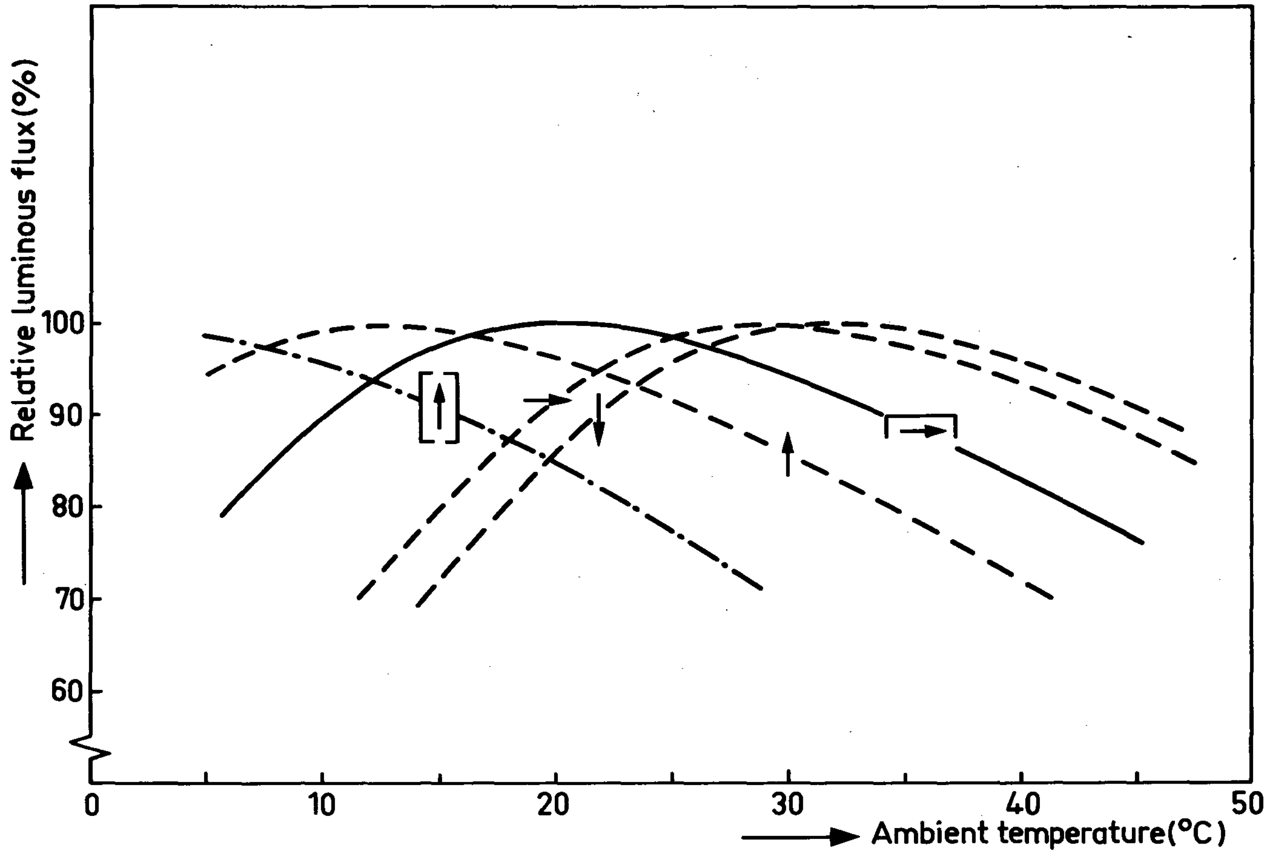


Figure 4. Relative values of luminous flux as function of ambient temperature, for three free-burning lamp positions and two luminaire situations of PL lamps. The points of the arrows indicate the positions of the top of the lamp.

maximum luminous flux, is about 47°C in 10 mm fluorescent lamps. In general, this temperature is greatly exceeded in straight miniature lamps, particularly if they are mounted in compact luminaires. As for the PL lamp, the top acts as an appendix to the discharge vessel. Its wall temperature is essentially lower than that of the discharge vessel, because of the locally reduced energy dissipation—no discharge!—and the increased cooling surface. By choosing the proper top length, the lamp can be adjusted to its optimum working point. The presence of this pressure-controlling lamp top is an advantage of the PL construction over other possible folded lamps, for example, the well-known U-shaped lamps.

The small distance between the two lamp halves is a desirable feature from the application point of view, for the effective lamp volume is near to its minimum value. On the other hand, this small distance causes some loss of light. However, this loss is small, being only about 4 percent as compared with equivalent straight lamps.

The PL lamp is single-ended, and the lamp starter (a glow-switch with parallel capacitor) is integrated with the lamp in its cap. This integration makes it possible to match the lamp and the starter. The cap, G23, is of the plug-in type, the central part acts as a guide post and retention device, and at the same time forms the housing of the starter. The wiring of this integrated two-pin PL lamp is of course much simpler than that of a straight fluorescent lamp, and the non-professional consumer is not confronted with a complex lamp-plus-starter system. The ballast has to be mounted in the luminaire. Due to its special cap, the PL lamp cannot be interchanged by mistake with an incandescent lamp in an existing luminaire that contains no ballast.

The relation between the luminous flux T of the lamp and the ambient temperature T_{amb} will depend on the burning situation—closed or open luminaire—and on the burning position—top up or down, or horizontal position. The top length is adjusted in such a way that the lamp will operate near its optimum if it is burning horizontally in a half open luminaire, open side down, at an ambient temperature of 20°C. This burning situation will be met quite frequently in practice. A few relations between 0 and T_{amb} are given in Fig. 4 for the three free-burning positions and for two luminaire situations.

A list of the properties of a family of three PL lamps is given in Table 1, as an example. This lamp series is designed for countries with a line voltage of 220 V, as used in Europe. In that case the lamp voltage can be varied over a fairly wide range, and a

Table 1. A series of PL lamps for 220 V line voltage. All lamps can be operated on one type of ballast. Two PL7 and PL9 lamps, connected in series, can also be operated on one single ballast.

lamp	l^1 (mm)	Φ (lm)	V_{la} (V)	i (mA)	W_{la} (W)	η_{la} (lm/W)	$\eta_s{}^2$ (lm/W)
PL7	111	410	45	180	6.9	59	37
PL9	143	570	60	170	8,7	66	46
PL11	212	890	90	155	11,4	78	61

¹ Length: measured from top to pen-base, see Fig. 3.
² η_{syst} depends on the ballast design.

family of lamps can be designed which all operate on one single ballast type and differ mutually by a factor 1.5 in luminous flux.

The color temperature of PL lamps is 2700 K (color coordinates x = 0.465, y = 0.414), i.e. about the same value as for incandescent lamps, and the color rendering is good, with the index R_a = 82.

The SL lamp

Further integration of lamp and ballast. In the SL lamp the integration of the discharge tube, starter and ballast is completed, for they are built together to form one single lamp unit. This further integration clearly has its advantages. A direct connection to the line voltage is possible, and the integrated product can be interchanged with incandescent lamps in many existing luminaires. There is an optimum matching of lamp and ballast. A disadvantage, however, is that at present the integration still results in a relatively voluminous and heavy product, due to the presence of the ballast. In order to keep the ballast weight low, it is necessary to choose the lowest possible lamp current, in combination with a high lamp voltage. If the discharge tube is folded once, the total length of the tube and ballast will not be below 20 cm. In order to fulfil this length requirement, a further reduction must be made by bending a second time. This is especially the case for high line voltages, such as the 220–240 V used in Europe. The appearance of such a doubly folded lamp is of course closer to rotational symmetry than that of a PL lamp.

Description of SL lamp. A sketch of an SL lamp is given in Fig. 5. The ballast is situated partly between the legs of the doubly folded discharge tube, below it are the glow switch starter, the capacitor, and a thermal fuse, all housed in a base encapsulation. A conventional cap of the screw-in type (E27 in Europe, E26 in the USA) or the bayonet type (B22 for the UK) makes the lamp interchangeable with incandescent lamps. The discharge tube is surrounded by an outer bulb which can be opalized or have a prismatic structure.

The control of mercury pressure cannot be as simple as in the case of a PL lamp. Heat is not only produced by the discharge tube inside the lamp, but also by the ballast, and its removal from the interior is hindered by the outer bulb. The temperature of the discharge tube therefore becomes much too high to

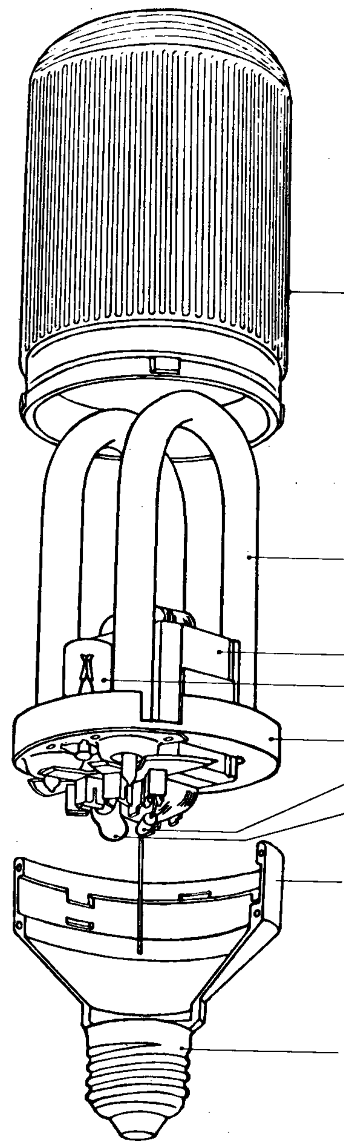


Figure 5. Exploded view of an SL-lamp. Ballast, starter and the folded discharge tube are integrated in one single unit.

obtain an optimum light output, and it is necessary to reduce the mercury pressure inside by applying an amalgam. This amalgam will not only reduce, but also stabilize the mercury pressure to a certain extent, thus broadening the range of ambient temperatures in which the lamp operates near to its optimum by a factor of almost two.[13,14] The amalgam is of the type Bi In-Hg with In-Hg as an auxiliary amalgam,[14] and is applied in one of the exhaust tubes of the discharge tube.

To give an impression of the lamp properties, a list of a series of SL lamps is given in Table 2, by way of example.

The color characteristics of the SL lamp are the same as those of the PL lamps.

Table 2. A series of SL lamps for 220 V line voltage. Lamp diameter 72 mm.

lamp	height (mm)	Φ (lm)	W_{la} (W)	η (lm/W)
SL9	148	425	9.0	47
SL13	158	600	12.8	47
SL18	168	900	18.7	48
SL25	178	1200	25	48

Application fields and economics of PL and SL lamps

The PL and SL lamps have been developed for application in the domestic and social sphere, homes, hotels etc., where at present the incandescent lamp is the most commonly used light source. In the following, the application possibilities will be considered in greater detail.

To begin with, the PL lamp is well suited for many applications in which T5 4, 6 and 8 W fluorescent lamps have been used up to now. An advantage, as compared with these lamps, is the simpler wiring in the luminaire, due to the single-ended shape, and the integration of the lamp and starter. Moreover, PL lamps have a higher luminous flux-to-length ratio, which may also be of interest for luminaire designers. Additionally, in many cases where the smaller types of circular lamps are used at present, PL lamps will offer a welcome alternative.

More important, however, is a more innovative class of applications. Three characteristic properties of PL lamps as compared with incandescent lamps with the same luminous flux are their small size in one dimension, their low heat production, and their long life. The exploitation of the combination of these lamp properties offers new opportunities for luminaire designs. Very "thin" or "flat" designs become possible in cases where at present the dimensions and heat production of incandescent lamps put restrictions on miniaturization of the luminaire design. A few applications which may be mentioned are all kinds of downlighters, many task-lighting elements such as desk lamps and hobby lamps, pendant lamps, and small decorative wall lighting elements. In all these cases we are thinking of luminaires, designed especially for the new lamp geometries. An example is given in Fig. 6.

From this point of view the SL lamp has a complementary field of applications. It is designed especially for the replacement of incandescent lamps in existing luminaires, in which the somewhat larger lamp dimensions and the higher weight of the integrated fluorescent lamps are not restrictive. Advantages with respect to incandescent lamps are the much lower energy consumption and the lower heat production. Moreover, in cases of large-scale use in hotels and similar buildings, the longer life will reduce relamping costs considerably.

This last point touches the subject of the economics of the new compact fluorescent lamps. A simple presentation of the general behavior of the accumulated costs as a function of time is given in Fig. 7 for a compact fluorescent lamp and an incandescent lamp. Distinct differences between these two are the energy consumption and, as a consequence, the energy costs, the lamp life, and the lamp prices. A crucial factor is the influence of the energy price, especially for higher wattages. This price differs from

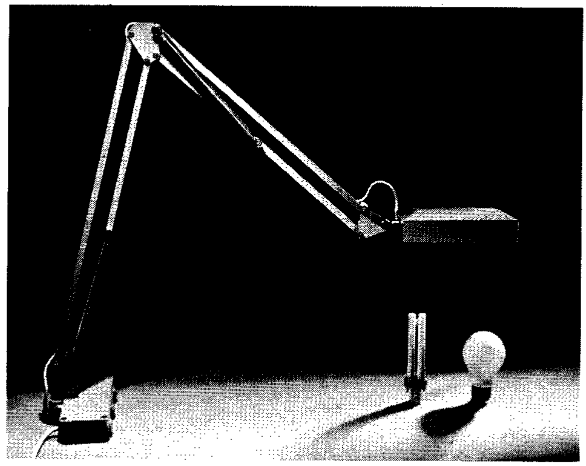
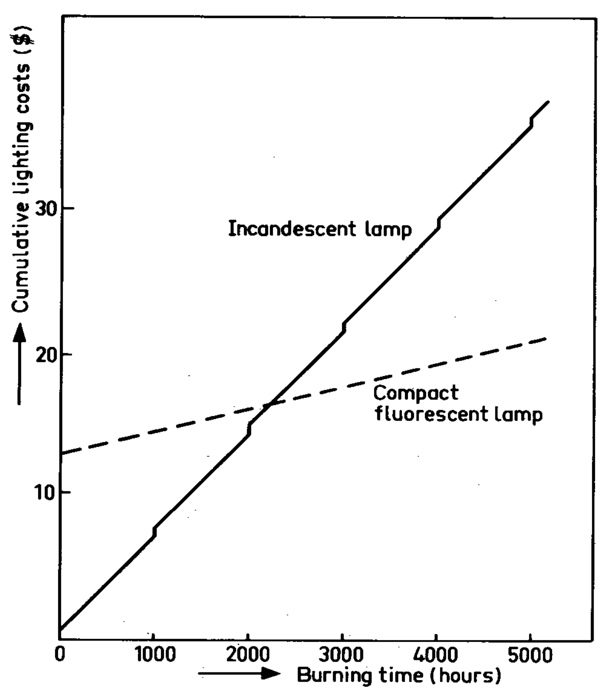


Figure 6. Example of a PL application in which the characteristic lamp properties—"thin" form and low heat production—are exploited. Two PL7 lamps are mounted in this desk lamp, for comparison a PL7 lamp and an incandescent lamp are shown on the table.

Figure 7. General behavior of total lighting costs as a function of burning time, for a compact 18 W fluorescent lamp and a 75 W incandescent lamp. The assumed energy price is $0.08 per kilowatt-hour in this example.



country to country, but will certainly increase in the near future. At present it is already so high in Europe, that even for a 10 W–500 lm compact fluorescent lamp unit, the accumulated costs are below that of the equivalent incandescent lamp, at a lamp price of $15 and a life of 5000 hours!

Conclusions

Miniaturization of fluorescent lamps to a degree that makes them suitable for the lighting of domestic and social environments came within reach after the development of very stable phosphors. An analysis of experimental data showed that a discharge diameter of about 10 mm is well suited for lamps with a luminous flux of up to about 1000 lm, while the preferred diameter shifts to 13–15 mm for flux values up to 2000 lm. Straight lamps with these diameter values are still too long from the application point of view. Bending of the discharge tube into two parallel parts is necessary if the lamp and ballast are separated and preferably into four parts if complete integration is intended.

Two types of compact fluorescent lamps have been described. In the first, the PL lamp, only the discharge tube and starter are integrated, while the discharge path is folded once. In many cases the lamp will require new types of luminaires, and due to its very "thin" form and low heat production as compared with incandescent lamps, it offers interesting prospects for innovative designs. Complementary to the PL lamp is the SL lamp, in which the discharge tube, starter and ballast are integrated in one single product. This more voluminous lamp is intended for use in existing luminaires, in which it can replace incandescent lamps.

The high efficacy and long life of both lamps, as compared with incandescent lamps, will reduce energy and replacement costs to such an extent that notwithstanding the higher lamp price, more economic lighting can be achieved.

Acknowledgment

The author wishes to acknowledge the enthusiastic and inventive cooperation with many colleagues in the lamp development department during the development of the compact fluorescent lamps described in this paper.

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DISCUSSION

E. E. HAMMER:* The author has presented some interesting information and discussion concerning compact fluorescent lamps which is very relevant today, particularly for the residential marketplace. Although we have noted improved lumen maintenance characteristics associated with the narrow band phosphors, we have not experienced such depreciation effects with our halophosphate system. Could the author comment on the actual 3000 hour lumen maintenance value associated with the halophosphate sample in Fig. 1? Additionally, what maintenance values would these two phosphors have if operated in standard F40T12 type lamps at 3000 hours? Was the mercury vapor pressure held constant in generating the data for Fig. 2? In an attempt to better understand the fundamental relationship of mercury vapor pressure with relative luminous flux, could the author plot this Fig. 4 relationship as a function of bulbwall coldspot temperature, or amalgam vapor pressure, whichever is appropriate?

R. G. YOUNG:† The author has done a fine job in describing his two compact lamp designs and the reasoning behind them.

That the discharge column efficacy vs electric field strength for many different physical variables results in a single curve is unexpected. The data is for 200 ma. Where and how high are the peaks for 300 and 400 ma?

Table 1 for the 220 V line voltage version of the PL lamp series suggests that 600 lm is about the maximum obtainable with this style if designed for a 120 V circuit. Any comments?

Although the SL design is a complete lamp, with ballast, it seems to have lower efficacy than the PL style for the higher outputs. Is this solely because of the outer bulb light absorption? How long does it take for the lumen output to reach equilibrium after each cold start?

J. SHURGAN:‡ The paper presents a very good and detailed analysis of what would be required and what has been achieved by the author in fabricating two types of compact fluorescent lamps.

Does the 5000 hour life rating reflect the actual lamp or is it

* General Electric Company, Cleveland, Ohio.
† Westinghouse Electric Corporation, Bloomfield, New Jersey.
‡ Duro-Test Corporation, North Bergen, New Jersey.

more a function of the starter in the SL lamp? Also, have there been any lumen maintenance studies for these lamps? Quite possibly there may be an additional advantage in the relatively slow drop in light level later in life compared to the darkening of incandescent bulbs for the same period. There may also be some difference in light output regulation with supply voltage compared to the exponential change to be found in incandescent lamps. Has the author any measurements to that end?

REBUTTAL

AUTHOR: I will reply to Mr. Hammer first.

The experiments with the 10 mm lamps coated with the halophosphate phosphors were not continued beyond 2000 hr life. From the observations made we can estimate, by extrapolation, the maintenance value at 3000 hrs, which is about 55 percent. The maintenance values of the same phosphors applied in F40 T12 lamps is 91 percent at 3000 hrs, the corresponding value in these lamps coated with the newly developed phosphors is 95 percent.

The data generated in Fig. 2 were obtained by measuring lamp properties as a function of wall temperature, which was controlled by mounting the lamps in a water bath. The lamp efficacy goes through a maximum, from this maximum value we derived the efficacy values of the gas discharge in Fig. 2. The bulb wall temperature at the efficacy maximum is not constant, but depends on the lamp being considered. For example it will increase if one decreases the discharge diameter.

The plot of the relative luminous flux as a function of the bulb wall coldspot temperature for a PL 9 lamp, operated on an inductive ballast at a line voltage of 118 V, equals within experimental error the central curve of Fig. 4 shifted by 27°C. The top shifts from 20°C ambient temperature to 47°C mercury cold spot temperature in that case.

In response to Mr. Young, the prime interest of the author was not the position and height of the peaks in Fig. 2, but more the situation at higher field values. So the available experimental data in the peak area is not sufficient to draw conclusions. The theoretical calculations may give a rough indication; they suggest a shift of the peak of about −10 percent in the electric field and −3 percent in efficacy peak height at 300 mA, and about twice these values at 400 mA.

The PL lamp in Table 1 has a lamp voltage of 60 V, which is indeed about the maximum voltage for 120 V circuits, if conventional ballasts are used. Higher luminous flux values can be obtained by raising the lamp current.

The efficacy of an SL lamp is somewhat below that of a comparable PL lamp. One of the causes is indeed the absorption of light in the outer bulb. But also the presence of the ballast between the "legs" of the discharge tube will cause some losses, and additionally a small part of the generated light is absorbed in the bottom of the integrated lamp construction.

It will take about 1 minute to reach a luminous flux value of 80 percent of the optimum value after a cold start, which is considered as satisfactory for most lamp applications.

In reply to Mr. Shurgan, the value of 5000 hr burning time of the SL lamps in Fig. 7 has only been used for comparing the lighting costs of an SL lamp with those of incandescent lamps. The life of the actual SL lamps, as given in Table 2 is about 7500 hrs, the maintenance values at 7500 hrs are between 73 and 78 percent. The light output regulation is comparable with that of conventional fluorescent lamps; for the lamps quoted in Table 2 a 10 percent variation in supply voltage will cause about 15–20 percent variation in light output.