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Electrical Lighting Design

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Abstract

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With respect to. these problems a number of questions must be asked.

ELECTRICAL LIGHTING DESIGN

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by

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CHAPTER I

INTRODUCTION

The writer, having worked in the electrical field, has observed that once in a while there will be work in lighting design comes to the office, although the place where the writer has worked does not have anything related to lighting design. For example, a lighting design is needed for our new office building or lighting around the vicinity of the power substations. Of course, this electrical lighting design must be the responsibility of the electrical section which is the section where the writer has worked. It is impossible to avoid this responsibility, even though we have never had experience in this field before.

The procedure in electrical lighting design may not be difficult, but the difficulty is the lack of training in lighting design. Only this training can help one make a decision in the problems which will be confronted by the designer. This is the reason why the writer is very interested in choosing "electrical lighting design" as a topic for this research.

This research will be the first step in helping the writer to become prepared to cope with the problems confronted in electrical lighting design. After years of work in the future, it should be obvious that the training and experience gained by the writer will be valuable.

I. LIGHTING PROBLEM

In any given space for lighting design, each space presents a unique lighting problem which must be studied. These problems can be considered as physical characteristics of the space and its occupancy and usage.

With respect to these problems a number of questions must be asked.

1. What are the actual seeing tasks? The answer to this question will allow one to determine recommended illumination levels from Appendix A. The recommended illumination levels can be divided into two categories:

a. Interior illumination. The illumination levels recommended are different depending on the need of illumination for each actual seeing task. For example, the minimum recommended illumination level for general offices is 30-foot candles but for reading rooms in libraries, is 70-foot candles.

b. Exterior illumination. There are also differences in recommended illumination levels. But, in some cases, the surroundings must come into consideration. For example, the minimum recommended illumination level for bulletin boards and poster panels (light surfaces) is 20-foot candles in the dark surroundings, but is 50-foot candles in bright surroundings. The reason is that, if the background is dark, only the small amount of illumination level will give enough visibility, like a white thread on a black cloth. On the contrary, if the background is bright, the amount of illumination level must be greater in order to give enough visibility, like a white thread on a white cloth.

2. Is the usage uniform or are different areas utilized for seeing tasks of varying severity? A department store is a very clear example for this. The circulation in the department store requires low-level illumination (30 F. C.), while merchandising areas and show cases require up to 500 F. C. The indicated solution for such a problem is a general lighting system which will provide 30 F. C. of uniform lighting, and supplementary local lighting in restricted areas.

3. How should the lighting equipment be? The lighting equipment should be unobtrusive, but this does not mean invisible. Fixtures can be chosen and arranged in various ways to complete the satisfaction.

4. How can the proper quantity and quality of light be established? After selecting the type of fixtures and determining of the recommended illumination levels, these levels must then be adjusted for reductions in visual caused by high brightness ratio and direct and indirect glares and many other factors which will be discussed in Chapter IV. Consideration of these interrelated factors and if utilized

properly, yield illumination of adequate quantity and good quality.

5. Will the area be used during both daylight hours and at night, and, if so, are the seeing tasks the same? A schoolroom which has a large daylighting contribution need not be as well artificially illuminated if the room's nighttime use will be as a meeting room rather than a classroom.

II. RESOURCES FOR THIS RESEARCH

1. The Library of the University of Northern Iowa was a great help in finding the information for electrical lighting design.

2. Electrical manuals and handbooks.

3. Edison Company, which gave information on lighting design.

CHAPTER II

RELATED TECHNICAL INFORMATION

I. LIGHT AND COLOR

Light is defined as "visually evaluated radiant energy", (Illuminating Engineering Society, 1966, p. 1-1), and can be interpreted as a form of energy which permits us to see. Light travels in the form of waves, passing through free space at the rate of 186,300 miles per second. When traveling through a transparent medium the speed is reduced according to the optical density of the medium.

Color is defined as a mental phenomenon and is the product of a process which includes the physical cause, the physiological functions of the eye, and the psychological factors that influence the appearance of color. Color and light are almost synonymous words, but light does not become a perceptible image until its nature as radiant energy is translated by the eye and brain into images of form and color. In this process, adaptation and environment play important parts, while observer interpretation is the final factor that determines the color "seen". (Williams, 1965, p. 1).

II. ELECTROMAGNETIC SPECTRUM

If light is considered as a wave, similar to an alternating current wave or radio wave, it has a frequency and a wave length. The visible light comprises only very small part of the wave energy forms and this part of energy produces visual sensation and makes possible to our sight. Color is determined by wave length, starting at shortest wave length (highest frequency) with violet, we proceed through the spectrum of indigo, blue, green, yellow, orange, and red to arrive at the longest visible wave length (lowest frequency).

When energy is produced over the entire visible spectrum in approximately equal quantities from a light source such as the sun, the combination of the colored lights produces white. If a source produces energy over only a small section of the spectrum, its characteristic color light will be produced, such as blue-green mercury lamp and the yellow sodium lamp.

See Fig. 1, Electromagnetic Spectrum, page 6a.

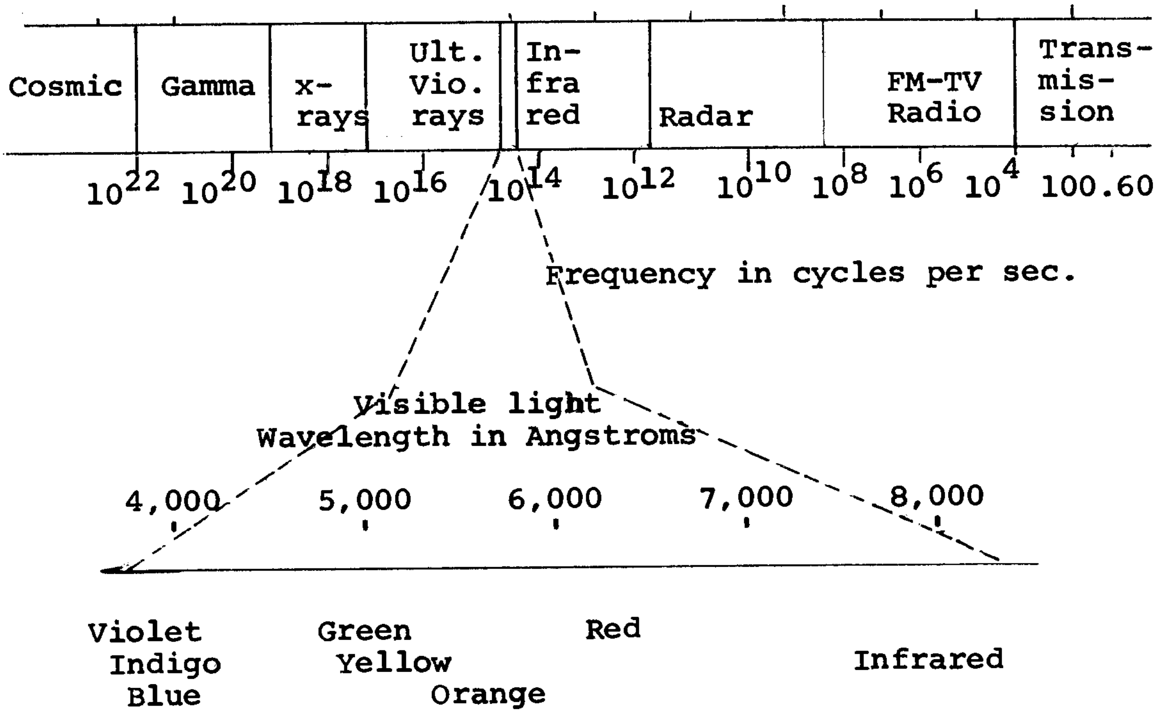


Fig. 1 Electromagnetic Spectrum

III. THE VISIBILITY OF THE NORMAL EYE

The objective measurements of light depend upon establishing fundamental units and upon the response of an instrument as sensitive to every wavelength of light as is the normal eye. The normal eye has a different response to different wave lengths.

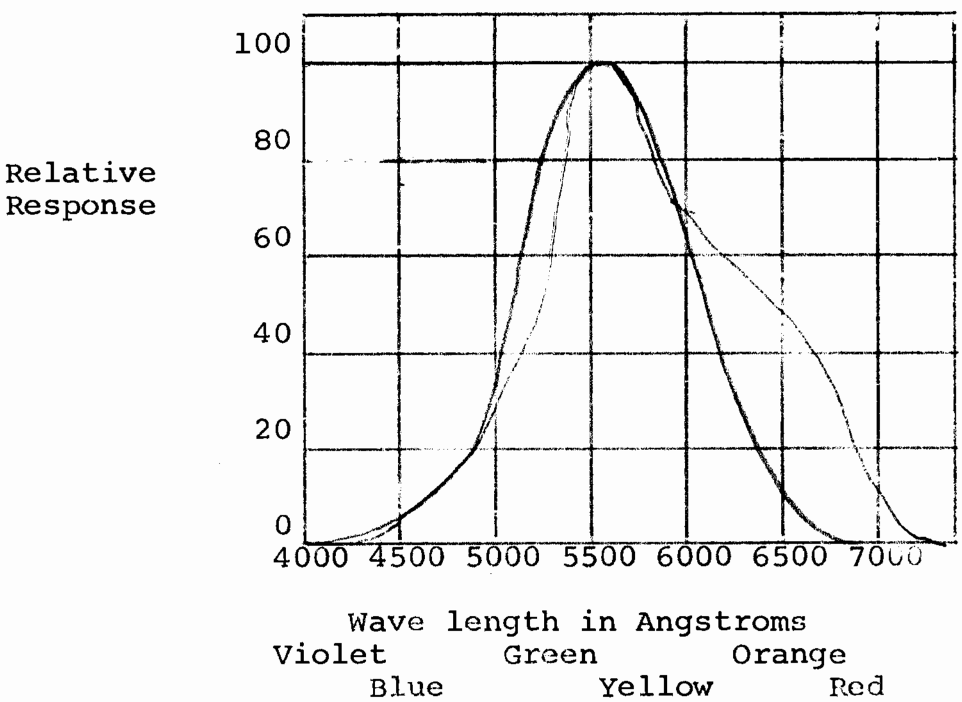


Fig. 2 Visible curve for the normal eye

(Allphin, 1959, p. 19)

The curve shown is so arranged that unity will occur at a wavelength of maximum visibility. The color allocation on the scale represents the usual accepted classification. It will be seen that the blue and red ends of the spectrum contribute little to visibility.

IV. COLOR TEMPERATURE

Different whitenesses of light are often identified by their color temperature ratings, expressed in degrees Kelvin (^{o}K). These ratings represent a match or near comparison of a color of light to that of standard black-body radiator. This radiator glows in a color ranging between dull red and bright blue, as determined by the temperature (^{o}K) to which it is heated. At a temperature of 800^{o} K the emitted light is dull red, but as the temperature goes up, the proportion of shorter wavelength energy increases, until at 8,000-9,000^{o}K the light is weak blue, changing ultimately to a bright blue at temperatures above 50,000^{o}K. Thus, incandescent lamps with a color temperature rating of, say, 2,800^{o}K provide a yellowish light compared to lamps with a higher rating, say, 3,400^{o} K.

See Fig. 3, Color Temperature Scale, page 9.

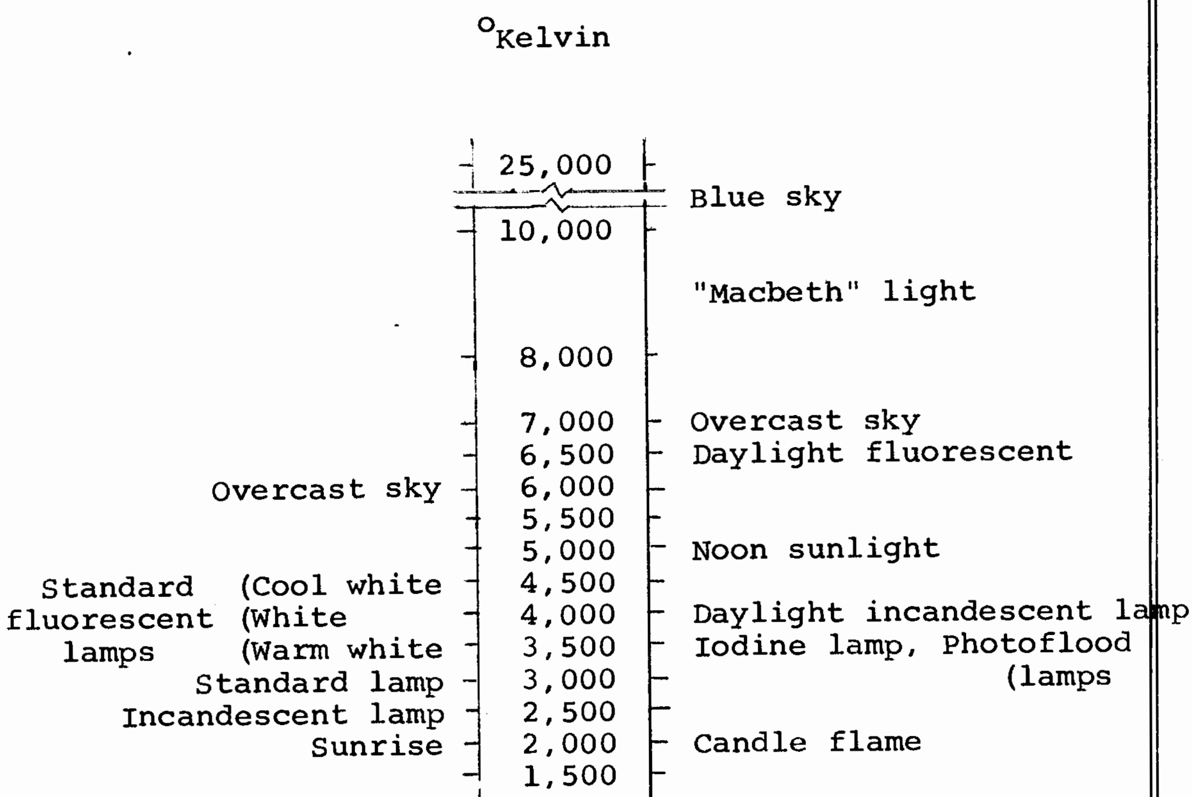


Fig. 3 Color Temperature Scale

(McGuinness, 1967, p. 333)

V. BLACK BODY RADIATION

Black body is a light absorbing body, when heated, it will first turn deep red, then cherry red, then orange until it finally becomes blue-white hot. The color of the light radiated is thus related to its temperature. Therefore, by developing a black body color temperature scale, we can compare the color of a light source to this scale and assign it an approximate "color temperature".

The design of black body radiators is founded upon the fact that a small hole in the wall of a total enclosure behaves as though it were an absolute black surface. Outside light passing through the small opening will be totally absorbed by internal reflections, providing the reflectance factor of the inside surface is low. When the material enclosing the space is heated until it glows, the internal emitted light will be absorbed as heat because of internal inter-reflections. The amount of light entering or leaving the enclosure through the opening is too small to affect the internal temperature. The light that passes out of the small opening in the surface will, therefore, exactly match the light received on the interior surface of the enclosure. When a body, such as described, absorbs all the radiation incident upon it, it is known as a "black body" and the light emitted through the small opening is known as "black body radiation".

CHAPTER III

ELECTRICAL THEORY

According to common accepted electrical theory, all matters consist of very small particles, or charges, of electricity. The kind of charge known as electrons can be made to flow from one part of a body to another part. The path cover which electrons flow is an electric circuit.

I. OHM'S LAW

The importance of ohm's law depends on the relation of current, voltage and resistance.

Current is a flow of electrons through a circuit. The practical unit is the ampere. One ampere is a rate of current flow of one coulomb per second.

Voltage is a force which causes a flow of electrons through a circuit. This electric force is measured in volts.

Resistance is the opposition of the material of an electric circuit to the flow of electrons through the circuit. The opposition is called resistance and is measured in ohms.

Ohm's law expresses the relation of these three components as:

$$\text{Volts} = \text{Amperes} \times \text{Resistance}$$
$$\text{OR} \quad E = I \times R$$

Thus, when we know any two of these three quantities, we can find the third quantity.

II. ELECTRIC POWER AND ENERGY

Electric power:

Power is an amount of work done in a unit of time. The unit is watt (W) or kilowatt (KW). One kilowatt is equal to 1,000 watts.

In direct current electric circuit, the power in watts may be found by using the relationship between voltage in volts, and current in amperes.

$$\text{Watts} = \text{Volts} \times \text{Amperes}$$

OR

$$W = EI$$

$$= (IR) \cdot I$$

$$= I^2R$$

In alternating current electric circuit the power may not be equal to the product of the current and voltage, but power generally is the product of current, voltage, and a power factor which measures the effect of a phase difference between current and voltage.

Electric energy:

The amount of electric power consumed in a certain time is usually measured in kilowatt-hours (KWHR). This energy can be formed by multiplying the power (KW), by the number of hours (HR), which is the period of time that power is applied. Kilowatt-hours = Kilowatts x Hours

III. PHASE

The relationship between values of a voltage and current with the same frequency is called phase.

If the voltage and current pass through zero, maximum and minimum values at the same time, they are in phase.

If the voltage and current pass through zero, maximum and minimum values at different times, they are out of phase.

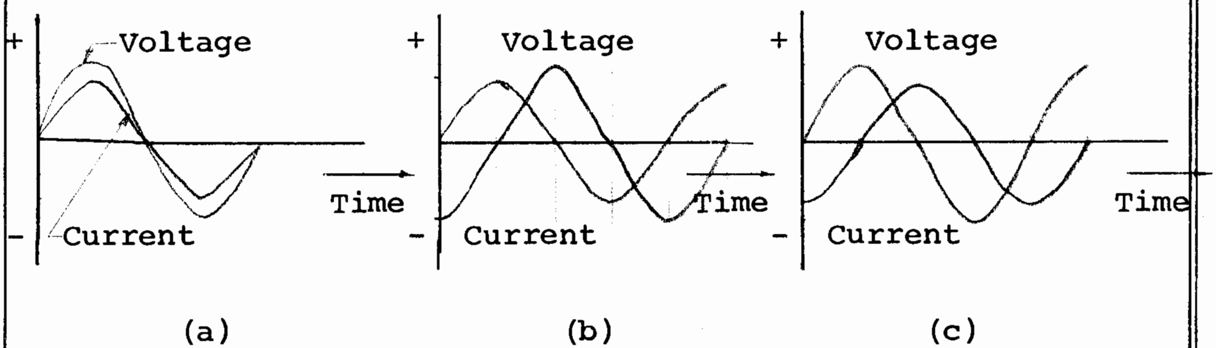


Fig. 4 Phase relationship, (a) unity power factor, current and voltage are in phase, (b) lagging power factor, voltage lagging current, (c) leading power factor, voltage leading current.

IV. A. C. CIRCUIT COMPONENTS

Inductance, (L) opposes the change in magnitude of an alternating current The unit of measure is the henry. Inductive reactance, X_L, impedes the flow of current, is measured in ohms. In an A. C. circuit, this reactive component will cause the voltage to lead the current by 90^o.

Capacitance, (C) opposes the change in magnitude of an alternating voltage. The unit of measure is the farad. Capacitive reactance, X_C, impedes the flow of current, is is measured in ohms. In an A. C. circuit, this reactive component will cause the voltage to lag the current by 90°.

Impedance, (Z) is the total opposition to the flow of alternating current due to resistance R, inductive reactance, X_L, and capacitive reactance X_C. The unit of measurement is in ohms. It is the vector sum of these components.

$$Z = \sqrt{R^2 + (|X_L| - |X_C|)^2}$$

Resistance, Inductance and Capacitance in an A. C. circuit.

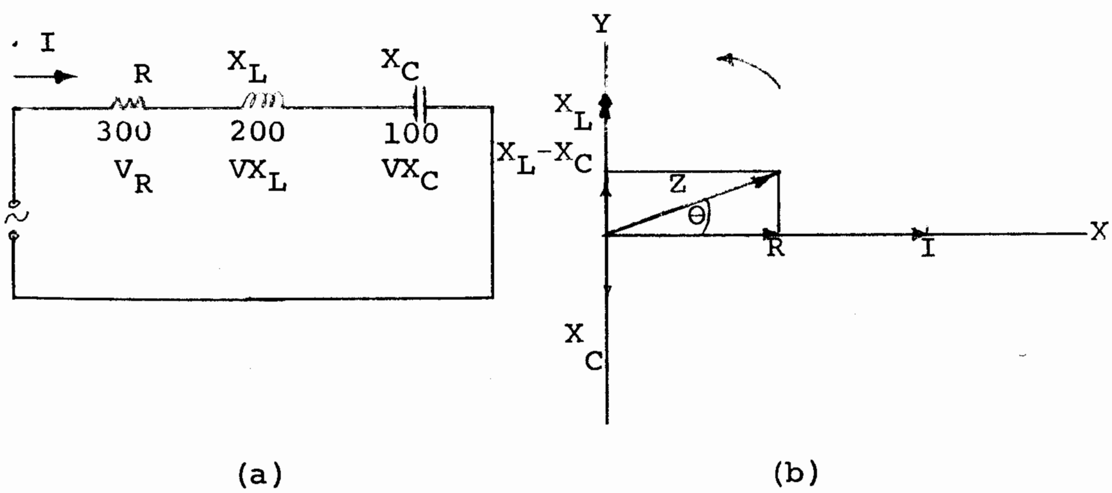


Fig. 5 (a) Simple series A. C. circuit components, (b) vector diagram of series RLC circuit.

From the vector diagram, let axis X is represented current I. Since voltage drop across resistance R (V_R) is in phase with the current, therefore, R is in the same axis as I. Voltage drop across inductive reactance (V_{X_L}) leads current by 90° which make X_L leads R by 90°, and voltage drop across capacitive reactance (V_{X_C}) lag current by 90°;

therefore, X_C lags R by 90°. Total resistance of the circuit which is called impedance is equal to the algebraic sum of those vectors and is represented by vector Z.

$$\text{Thus,} \qquad Z = \sqrt{R^2 + (|X_L| - |X_C|)^2}$$

V. POWER FACTOR

Power factor is the ratio of true power to apparent power. From Fig. 5(b), the angle between vector Z and vector R is the angle θ and represents the phase displacement between the current and voltage resulting from the reactive components. Cos θ is equal to the power factor and also equal to $\frac{R}{Z}$.

The true power in this circuit will equal the apparent power times the power factor for cos θ.

$$\text{True power} = \text{Apparent power} \times \cos\theta$$

$$\cos\theta = \frac{\text{True power}}{\text{Apparent power}}$$

It is usually expressed as a percentage. Power factor is equal to 100% only when current and voltage are in phase.

Thus, in an A. C. electric circuit,

$$\text{Watts} = \text{Volts} \times \text{Amperes} \times \text{Power factor}$$

$$W = EI\cos\theta$$

$$I = \frac{W}{E\cos\theta}$$

From this question, if power factor is low, current will be high, but if power factor is higher, current will be lower; therefore, high power factor is preferable in order to get lower current which will be resulted in the reduction of wire size.

A fluorescent lamp ballast with a high power factor has the condenser built into the ballast. Such a ballast costs more than a ballast with a low power factor, but it may be preferable in order to hold down wire sizes.

CHAPTER IV

ILLUMINATION

One of the most adaptable instruments in seeing is the human eye. In the bright sunlight, one could read the book with some discomfort, and in the bright moonlight one could read the same book too, but with some effort. The reason is that the bright sunlight could provide much more illumination level on the page than the moonlight.

I. GLARE

The light applied can be divided into quality and quantity considerations. The most obvious contribution to poor quality is that of glare, which can occur as direct brightness from a lamp or fixture of a reflected image in some surface, such as the top of a table.

Glare can be divided into three types:

1. Distraction glare which "draws the eyes" away from the work toward the source of glare (Allphin, 1959, p. 143).

2. Discomfort glare which defines itself. It is hard to give the specific value between comfort and discomfort of individuals.

3. Disability glare which interferes with most effective seeing. It can be evaluated by measuring the reduced visibility resulting from loss of contrast within the task.

II. BRIGHTNESS CONTRAST AND BRIGHTNESS RATIOS

Contrast is the basis of most seeing, when contrast within the task is high, seeing is easiest. For example, white thread on black cloth is more visible than white thread on white cloth, and black ink on white paper is also more visible than black ink on blue paper. But if there is high contrast outside the task, it can be a disadvantage. The size of the pupils will be automatically changed when we change brightness in the field of view. A bright light causes the pupils to become smaller. So, if a worker often looks up from his brightly lighted work to an area which is much less brightly lighted, then looks back to his work, the pupils of his eyes frequently change size. Thus, discomfort and, later, fatigue can result.

To achieve a comfortable brightness balance, it is desirable and practical to limit brightness ratios between areas of apprecable size from normal viewpoints as follows:

1 to 1/3 between task and adjacent surroundings.

1 to 1/10 between task and more remote darker surfaces.

1 to 10 between task and more remote lighter surfaces.

20 to 1 between luminaires (or fenestration) and surfaces adjacent to them.

40 to 1 anywhere within the normal field of view.

These ratios are recommended as maximums, reductions are generally beneficial. (McGuinness, 1967, p. 380).

III. DELIVERING LIGHTING QUALITY

By hanging a bare 500 watt incandescent lamp close to the work on a lathe, a high level of illumination provided on such a work is enough, but the glare would be so great as to be temporarily blinding. It is obviously seen that the need for quality in lighting is important.

In lighting design, fixtures should be so designed as to put the light where it is needed, without presenting high brightnesses toward the eyes. In order to give a comfortable brightness pattern, the light is needed also on walls and ceiling, but not only on the working area. At the present time most industrial fixtures are designed to allow some of the lumens to escape upward, which provides a lighter ceiling and therefore, a more comfortable visual environment.

IV. LIGHT MEASURING UNITS

The units concerned in measurement of light are:

Quantity	Unit	Abbreviation
Intensity of light	Candlepower	cp.
Amount of light	Lumen	L
Level of illumination	Foot-candle	Ft-c.
Brightness of a surface	Foot-lambert	Ft-L.

Candlepower, (cp) is the unit of intensity of the light source. A light source of one candlepower will produce a light intensity of one foot-candle on a surface one foot away from the light source. The intensity, in foot-candles, on the surface will vary inversely as the square of the distance from the light source.

A theoretical point source has equal distribution of light in all directions. Filaments of lamps are not true point sources. Furthermore, the base of the lamp stops light from passing. As a result, candlepower distribution curves for lamps are irregular. The intensity usually is a maximum directly under the center of the lamp and diminishes as the angle increases away from the vertical. (Merritt, 1966, p. 23-25).

Lumen, (L) is the unit of light quantity.

Foot-candle (ft-c) is the unit of light intensity. It equals the number of lumens per square foot on an area.

Foot-lambert, (ft-L) is a measure of the brightness of a diffusing surface when 1 lumen per square foot is reflected from the surface. When the illumination on a diffusely reflecting surface is known, the brightness of the surface can be found by using a factor called the percentage of the light that is reflected by the surface. If a surface with a reflectance of 20 percent is illuminated by 100 ft-c, its brightness is 100 x 0.2 = 20 ft-L.

V. ILLUMINATING CALCULATION

In lighting design systems, it is usually more practical to provide an average illumination level with a reasonable degree of uniformity throughout the room by using "The Lumen

Method". If illumination at specific task locations is required, a "Point-by-Point Method" must be used.

A. The Lumen Method

1. General Calculation

a. From the definition of foot-candle which is defined as the number of lumens falling on one square foot of surface. If all the light leaving the lamps reached the working plane which means that there were no losses:

$$\text{foot-candles} = \frac{\text{lamp lumens}}{\text{area in square feet}}$$

b. Because all of the lamp lumens do not reach the working plane due to losses, such as, some of the lumens will be absorbed in the reflecting, refracting, or transmitting materials of the fixture, and some will be absorbed by the room surfaces. They must be multiplied by a "coefficient of utilization" (c. u.) which represents the portion that reaches the working plane. Thus, the formula will be:

$$\text{foot-candle (initial)} = \frac{\text{lamp lumens x coefficient of utilization}}{\text{area in square feet}}$$

This is the initial illumination, that is, when the installation is brand new.

c. As they are used, the output of the lamps falls off a little and, more importantly, the lamps and fixture surfaces collect dust and dirt, so the illumination does not remain at the initial level. In designing for the average illumination, the initial foot-candles must be multiplied by maintenance factor (m. f.). Thus, the lumen formula becomes:

$$\text{foot-candles (average maintained)} = \frac{\text{lamp lumens x c. u. x m. f.}}{\text{area in square feet}}$$

d. The lamp lumens generally are expanded into a number of fixtures x number of lamps per fixture x lumens per lamp, this is for convenience. Therefore, the formula becomes:

$$\text{foot-candles} = \frac{\text{number of fixtures x lamps per fixture x lumen per lamp x c. u. x m. f.}}{\text{width of room x length of room}}$$

OR

$$\text{number of fixtures} = \frac{\text{foot-candles x width of room x length of room}}{\text{lamps/fixture x lumens/lamp x c. u. x m. f.}}$$

2. Determining the coefficient of utilization

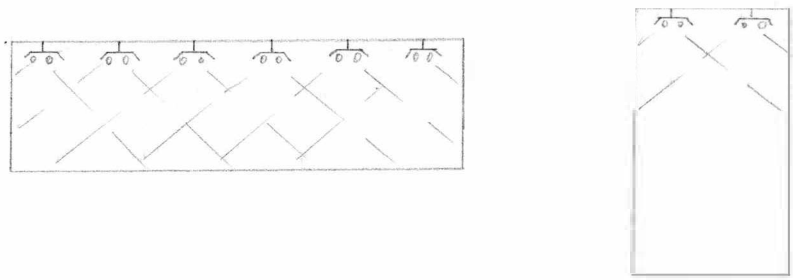
The coefficient of utilization depends on three factors: the characteristics of the fixture, the proportion of the room and the reflectances of principal surfaces in the room.

a. Classification of fixtures. If the fixture catalogs do not designate the classification of fixtures, the designer must make his own decision based on the light distribution of fixtures.

Upward light	Downward Light	Classification	For room ratio consider to be
0 to 10%	90 to 100%	Direct)	
10 to 40%	60 to 90%	Semidirect)	Direct
40 to 60%	40 to 60%	General Diffuse)	
60 to 90%	10 to 40%	Semi-indirect)	Indirect
90 to 100%	0 to 10%	Indirect)	

(This allows some overlapping in classification. (Allphin, 1959, p. 151).

b Room ratio is the proportions of the room which can help in considering the coefficient of utilization



(a) (b)

Fig. 6 A greater proportion of light is absorbed on the walls of a tall, narrow room, (b) than a wide, low-ceilinged room (a).

By considering Fig. 6, one can see that the utilization of light is affected by the shape of the room. The same type of fixture is used on the same spacing in both rooms, but the walls in the high, narrow room will absorb a greater percentage of the lamp lumens; therefore, fewer of them will reach the working plane and the illumination will be less.

For direct lighting: Room ratio = $\frac{w \times l}{h\ (w + l)}$ where

w = width of room l = length of room,

h = mounting height of fixtures above working plane

For indirect lighting: Room ratio = $\frac{3 \times w \times l}{2 \times h\ (w + l)}$ where

h = ceiling height above working plane.

The fixtures send most of the light to the ceiling in indirect lighting, so the ceiling is considered to be the light source, from a standpoint of room ratio.

In some fixture information, instead of room ratio letters of the alphabet were used and each letter represented a certain range of numerical value. The room ratio can be converted into room index according to the table shown below:

Room Ratio	Room Index
0.60	J
0.80	I
1.00	H
1.25	G
1.50	F
2.00	E
2.50	D
3.00	C
4.00	B
5.00	A

(Allphin, 1959, p. 153)

c. $\text{Reflectance} = \dfrac{\text{Brightness of surface in ft-L}}{\text{Illumination on surface in ft-c}}$

Brightness can be measured with a foot-candle meter.

Ceiling reflectance. Usually, ceilings are white which can be assumed to have a reflectance of 80 percent. If the ceiling is to be colored, it must use the reflection factors shown below:

White	83%	Brown	40-20%
Gray	70-44	Green	55-20
French gray	40	Olive green	20
Dark gray	19	Azure blue	55
Ivory white	80	Sky blue	37
Caen stone	78	Shell pink	54
Ivory	71-63	Pink	70-50
Pearl gray	72	Cardinal red	20
Buff	70-40	Red	40-15
Buff stone	20		
Tan	50-30		

(McGuinness, 1967, p. 388).

Average wall reflectance. If there are blinds, it must be decided whether calculations will be based on the blinds being open or closed. An average wall reflectance must be determined where maximum precision is required which involves a decision in treating the windows.

For example, if the wall has

	Area	Reflectance	Weighted average
Upper wall surface	600	0.7	600 x 0.7 = 420
Lower wall surface	400	0.2	400 x 0.2 = 80
Doors	80	0.4	80 x 0.4 = 32
Windows	250	0.1	250 x 0.1 = 25
			1,330 557

Therefore, the average reflectance of the total wall area = $\frac{557}{1,330}$ = 0.42.

3. Determining the maintenance factor

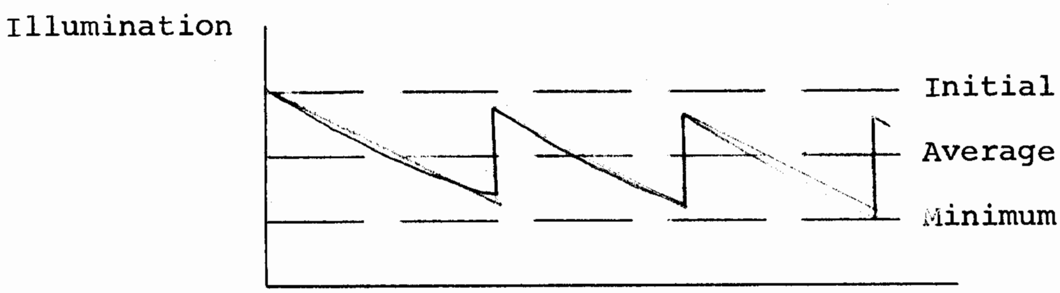


Fig. 7 Depreciation due to dust and dirt on lamps and lighting fixtures.

From Fig. 7, the illumination does not remain at the initial level. The lamps fall off a little in output as they are used and, more importantly, the lamps and fixture surfaces collect dust and dirt. The second peak is lower than the first one, and the third peak is lower than the second, because lamps are all new at first. If group replacement is used, the peaks will be less at each cleaning until the point of group replacement is reached. Then the peak will return almost to its original value.

For example, suppose the initial illumination is 80 ft-c, and maintenance factor of 0.7 is assumed. This would make the average illumination 0.7 x 80 = 56 ft-c. However, since the average is halfway between the initial and the minimum, the minimum would be 32 ft-c.

If particular illumination level is desirable for a certain task, then the level should not be below this at any time. The installation should be such that the desired minimum level will be reached just before the equipment is cleaned.

More realistic maintenance factors are now being developed, and fixture catalogs will state whether the recommended maintenance factors are based on average or minimum foot-candles.

4. <u>Maximum spacing</u>. Spacing factor called, maximum spacing, recommended spacing or spacing ratio appears in fixture data. The greatest distance which should be used between fixtures can be found when multiplied: spacing factor x the mounting height.

If maximum spacing factor = 1, and the mounted fixture is 10 feet above the floor, therefore, the greatest distance between fixtures = 1 x 10 = 10 feet.

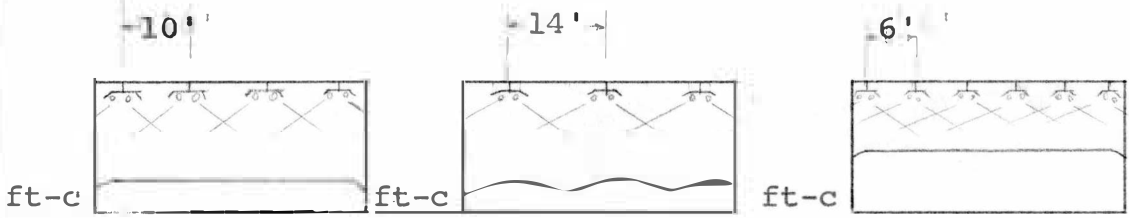


Fig. 8 Effect of Fixture Spacing on Uniformity of Illumination.

If the fixtures are placed too far apart, the illumination level will be non-uniform. But, if the more illumination is desired, the fixtures can be put closer together than the greatest distance.

5. Step in design by the lumen method

a. Determine the foot-candles of illumination

b. Select fixture with the required lumen output

c. Decide mounting height

d. Estimate reflectance

e. Determine room ratio

f. Determine coefficient of utilization and maintenance factor

g. Compute number of fixtures required

h. Determine maximum spacing.

6. Sample of calculation

The floor plan of a general office 45 ft. wide and 88 ft. long, with a 10½ ft. ceiling is assumed. The lighting is to be from direct-indirect fluorescent lamp. Lamp color is to be cool white.

See Fig. 9, Floor Plan and Fixture layout, page 28.

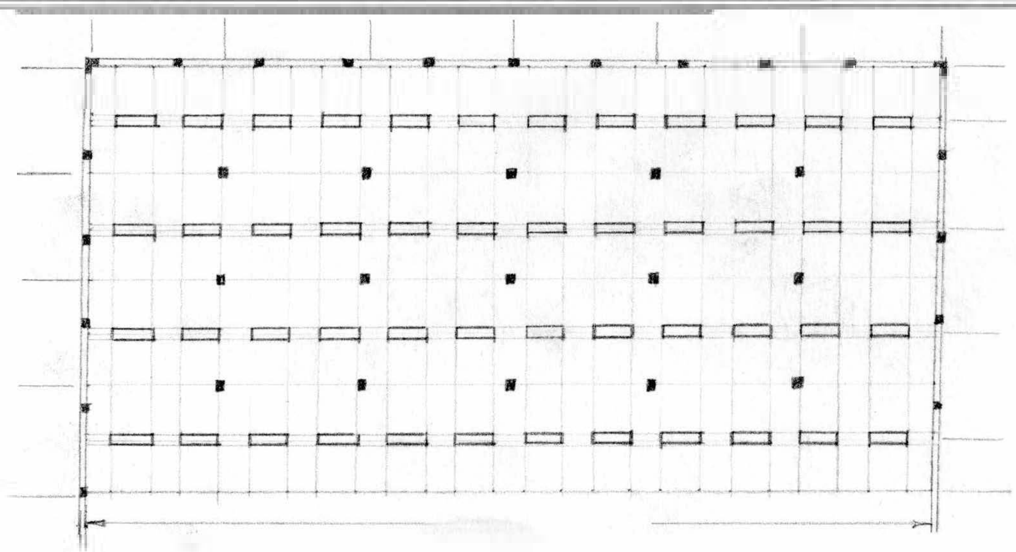


Fig. 9 Floor Plan and Fixture Layout

Assume that Fixture No. 35 from Appendix B, with direct-indirect fluorescent lamp as required is chosen, and will be suspended on 6" stem in order to spread upward light across ceiling. These stems, together with depth of canopies and fixtures, will result in a mounting height of 9½ ft. above the floor.

If the ceiling is white, ceiling reflectance will be approximately 80%. (See reflection factors, page 24.)

Wall reflectance will average 30%. It is estimated the average of the floor and desk-top reflectance will be 20%. Maintenance factor is expected to be good.

From Appendix A, recommended minimum foot-candles for general office is 30 ft.-c

Since Fixture No. 35 gives 45% upward light and 35% downward light, therefore, according to the classification of fixtures (p. 21), this fixture is considered to be indirect type in order to find the room ratio.

For indirect lighting: Room ratio = $\frac{3 \times w \times l}{2 \times h\ (w + l)}$

$$= \frac{3 \times 45 \times 88}{2 \times 10.5\ (45 + 88)} = \frac{11,880}{2,793}$$

$$= 4.3$$

Where h = ceiling height above working plane,

Maximum spacing = 1.2 MH
= 1.2 x 9.5
= 11.4 ft.

From Appendix B (Fixture No. 35): If floor reflectance were 10%, for a room ratio of

4, coefficient of utilization = 0.59
5, coefficient of utilization = 0.63

therefore,

difference of room ratio = 1, diff. of c.u. = 0.04
difference of room ratio = 0.3, diff. of c.u. =
0.04 x 0.3
= 0.012

Thus, the room ratio - 4.3 c.u. - 0.59 + 0.012 = 0.602.

However, the floor reflectance is not 10%, but 20%. From Appendix B, find the multiplying factor for 20% floor reflectance. Select the multiplying factor at room ratio of 4, which is the nearest value.

At 10% reflectance floor, multiplying factor = 1.00
At 30% reflectance floor, multiplying factor = 1.12

therefore, difference of reflectance floor

= 20%, diff. of multiplying factor = 1.12

= 10%, diff. of multiplying factor = $\frac{0.12 \times 10}{20}$

= 0.06

therefore, multiplying factor for 20% floor reflectance

$$= 1.00 + 0.06$$

$$= 1.06$$

Thus, the actual coefficient of utilization = 0.602 x 1.06

$$= 0.64$$

From Appendix B (Fixture No. 35), since maintenance factor is expected to be good; therefore, m f. = 0.75.

If lumens per lamp are 2,550, and there are two 40W lamps per fixture, the information needed is:

Recommended minimum ft-c	=	30.00
Coefficient of utilization	=	0.64
Maintenance factor	=	0.75
Width of room - ft.	=	45.00
Length of room - ft.	=	88.00
Maximum spacing - ft.	=	11.40
Lumens per lamp	=	2,550.00
Lamps per fixture	=	2.00

Number of fixtures

$$= \frac{\text{foot-candles x width of room x length of room}}{\text{lamps/fixture x lumens/lamp x c.u. x m.f.}}$$

$$= \frac{30 \times 45 \times 88}{2 \times 2{,}550 \times 0.64 \times 0.75} = \frac{118{,}800}{2{,}448}$$

$$= 48.$$

Therefore, the number of 4-ft. fixtures which can be used in a continuous row lengthwise in this room is 12 for each of 4 rows.

Dividing the 45-ft. room width by 4, gives 11 ft. 3 in for the spacing between rows. Since this is less than maximum spacing, which is 11 4 ft. or 11 ft. 4 8 in , the illumination will be uniform. The fixture layout is also shown in Fig. 9.

B. Point-by-Point Method

If the illumination at specific points is desired, the method for determining average illumination in large areas cannot be used, but calculations are made by point-by-point method.

1. Calculation with point sources. To determine the illumination at definite points in installations (either interior or exterior) where:

a. There is little reflection of light from the surroundings,

b. Where the distance from the source is at least five times the maximum dimension of the source (Illuminating Electrical Society, 1966, p. 9-22).

Foot-candles (on plane normal to light ray) = $\frac{I}{D^2}$

where: I = candle power of source in direction of ray

D = distance in feet from source to the plant.

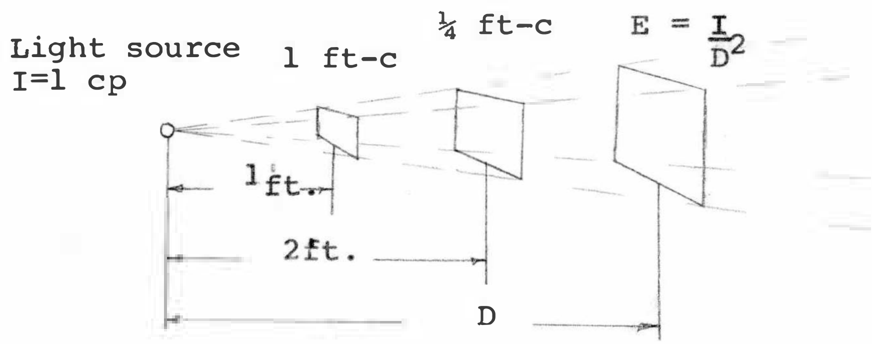


Fig. 10 Illumination on the normal plane

If the surface to be illuminated is not normal to the light rays, in calculation we have to project the light ray to the normal position (perpendicular to the surface on which the illumination is to be determined).

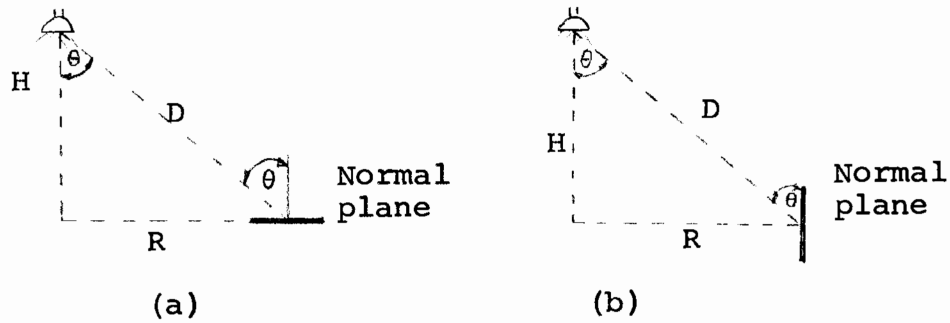


Fig. 11 Illumination on the inclined plane, (a) horizontal plane, (b) vertical plane.

$$\text{Foot-candles (on horizontal plane)} = \frac{I \cos \theta}{D^2}$$

$$\text{foot-candles (on vertical plane)} = \frac{I \sin \theta}{D^2}$$

where: H = vertical mounting height of the light source above the plane of measurement

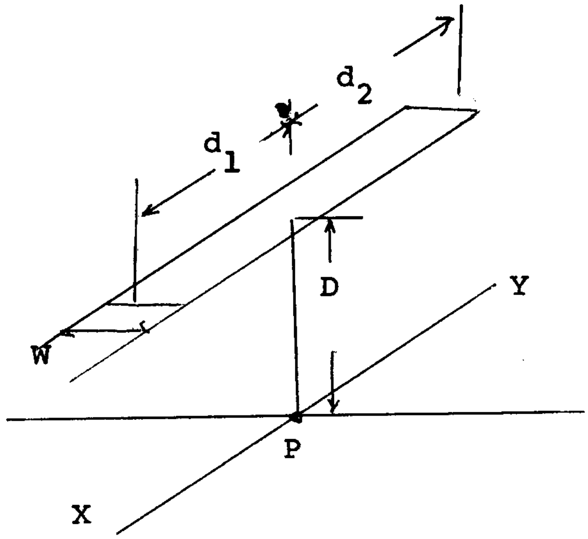
R = horizontal distance from the light source to the point whose illumination is being computed

D = actual distance from the light source to the point

I = candle power of the source

2. <u>Calculation with Line Sources</u>

For infinitely long sources, the following expression may be used for exactly determining the illumination at Point P lying on line XY or its extension.



Foot-candles at P - $\frac{L \times W}{2\ D}$

where: L = luminance of source in foot-lamberts

W = width of source in feet

D = distance from point P in feet.

This expression will be accurate to within 10 percent, if both d_1 and d_2 are greater than 1.5D, and accurate to within 5 percent if both d_1 and d_2 are greater than 2D.

Fig. 12 Illumination from Line Source

(Illuminating Electrical Society, 1966, pp. 9-24).

CHAPTER V

ARTIFICIAL LIGHT SOURCES

There are two general sources of light:

1. Light from incandescence
2. Light from luminescence.

These sources differ in the method of producing visible light and in the characteristics of the light produced.

Incandescent light is produced by heating a material until it glows. The light obtained is dependent upon the material used and the temperature to which it is heated to produce light.

Luminescent light is produced by some method other than the heating of a material. It may be produced chemically, as by phosphorescent reactions, or electrically, by passing an electric current through various gases and vapors (such as mercury, sodium, and neon), usually by fluorescence from ulta violet radiations. Luminescence signifies relatively "cold light" due to the fact that it has not been produced by a heating effect.

1. Incandescent Lamps

The incandescent lamp is composed of the filament wire sealed into a glass bulb and pump out the air, without oxygen, the filament can be operated at a high temperature without burning up. The efficiency of light production depends on the temperature of the filament.

Considerable research and investigation has been carried out on a variety of materials and metals in search of a suitable filament. The desirable properties of filament material are a high melting point, a low vapor pressure, high strength, high ductility, and suitable radiation and resistance characteristics. (Illuminating Electrical Society, 1966, pp. 8-1).

Efficiency of lamps relates the light output in lumens to the electrical input in watts, that is, lumens per watt (lpw).

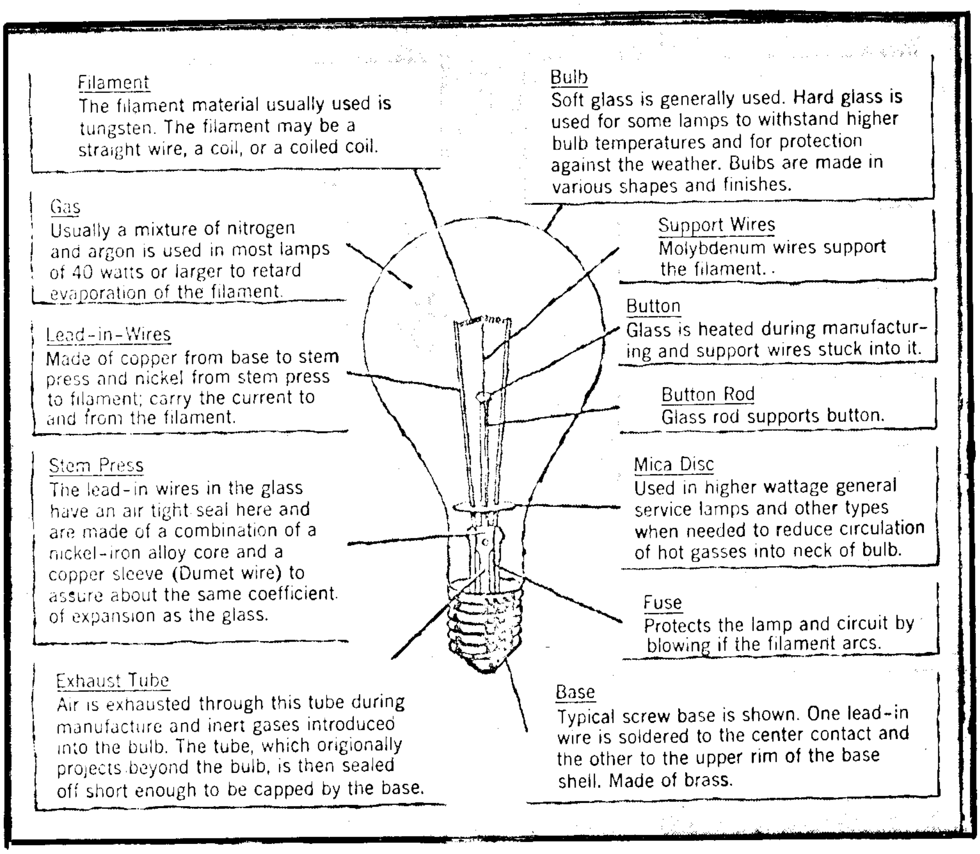


Fig. 13 Typical Incandescent lamps.
(McGuinness, 1967 p. 361)

A. The Filament

Early incandescent lamps utilized carbon and tantalum filaments, but presentday lamps use tungsten filament because it has many desirable properties for use as an incandescent light source.

Filaments are made in different forms which are determined largely by service requirements and design considerations, which is a careful balance of light output and life. Filaments designation consist of a letter to indicate the wire construction and an arbitrary numeral to identify the filament form. Most commonly used letters are:

S = a straight wire

C = a coil

CC = coiled coil. The wire is wound into a double helical coil.

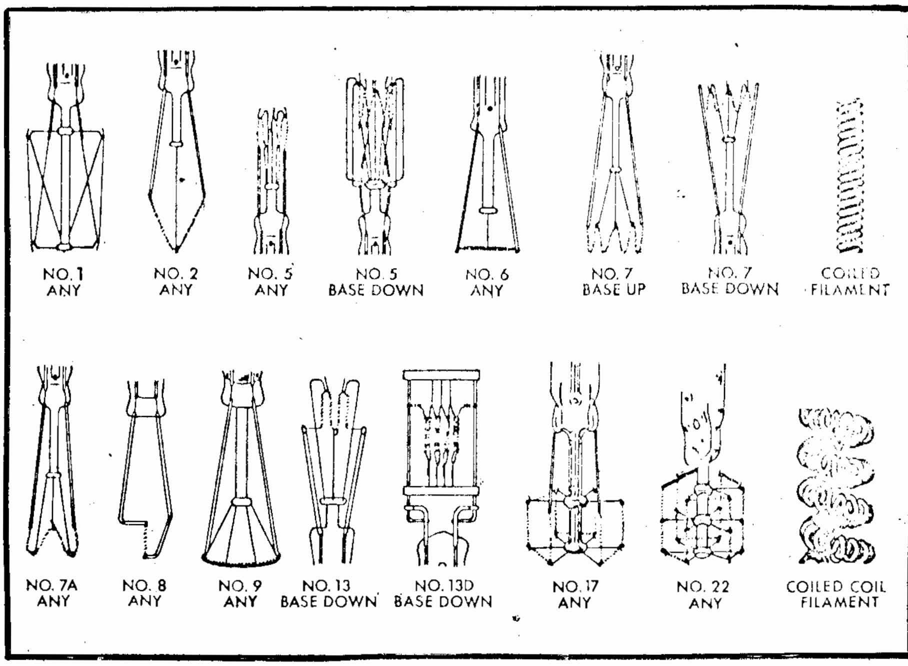


Fig. 14 Typical Incandescent Lamp Filament.

(Illuminating Electrical Society, 1966, p. 8-3)

The straight wire filament requires many supports because of its great length. Since the filament is cooled by the supports at the point of contact, so the straight wire filaments are not generally employed. Coiling the filament increases its luminous efficiency. The coiled coil, construction is formed by again coiling the original coiled filament which further increases efficiency.

B. The Bulb

1. Shapes and sizes. Bulbs are designated by a letter or letters followed by a number. The shape is indicated by letter. The number indicates the maximum in eighths of an inch.

Bulb Shape	Meaning
S	Straight side
C	Cone
GA	Globe, standard neck
F	Flame
P	Pear
G	Globe
A	Standard
T	Tubular (Lumiline)
PS	Pear, straight neck
PAR	Parabolic aluminized reflector
R	Reflector

If the bulb is designated T-8, therefore, it is a tubular bulb with diameter equal to 8/8 inch which,is one inch.

See Fig. 15 on page 38 for typical bulb shapes and designations.

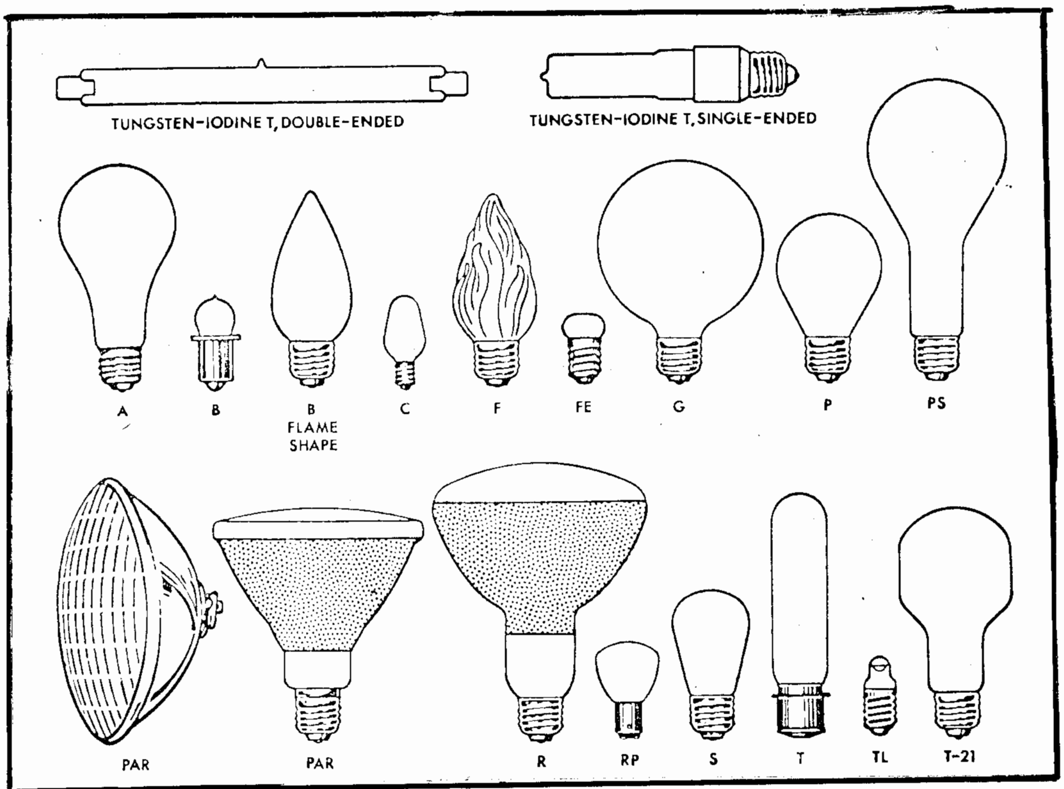


Fig. 15 Typical Bulb Shapes and Designations (Illuminating Electrical Society, 1966, p. 8-3)

2. Type of glasses

Most bulbs are made of regular lead or lime glass which is called "soft glass" and the maximum safe operating temperature is about 700° F. The other type are "hard glass" which is a heat resisting glass and the maximum safe operating temperature is about 885° F. which is needed when it is desired to have smaller bulbs with higher wattages or to prevent glass breakage caused by moisture or bugs striking lighted lamps that are used out of doors. Two specialized forms of glass are used as lamp envelopes are fused quartz and high silica, which both have high temperature resistance.

3. <u>Colored lamps</u>

Colored lamps are available in a variety of colors and many types of finishes:

a. Outside spray-coated lamps which generally are used indoors. Their surfaces collect dirt readily and are hard to clean.

b. Inside spray-coated lamps on which the pigments are not exposed to the weather so it has the advantage of permanent color and are easily cleaned.

c. Ceramic-coated lamps have the color pigments fused into the glass. They are thus smooth and easy to clean, suitable for both indoor and outdoor use.

d. Transparent plastic-coated lamps which can observe the filament directly and can be used both indoors and outdoors.

e. Natural-colored lamps which are made of colored glass. They are used largely for special applications where purity and permanence of color are desirable.

C. <u>The Base</u>

The important functions of an incandescent lamp base are:

1. Holds the lamp firmly in the socket in the electrical circuit.

2. Conducts the electricity from the circuit to the lead-in wires of the lamp.

For general lighting purposes, most lamps employ one of the various types of screw bases. Bipost and prefocus bases insure proper filament location where a high degree of accuracy in positioning of light sources is important. The conventional stem seal and lead assembly are eliminated in the bipost construction and a supporting structure that is made of one piece of channel nickel is substituted.

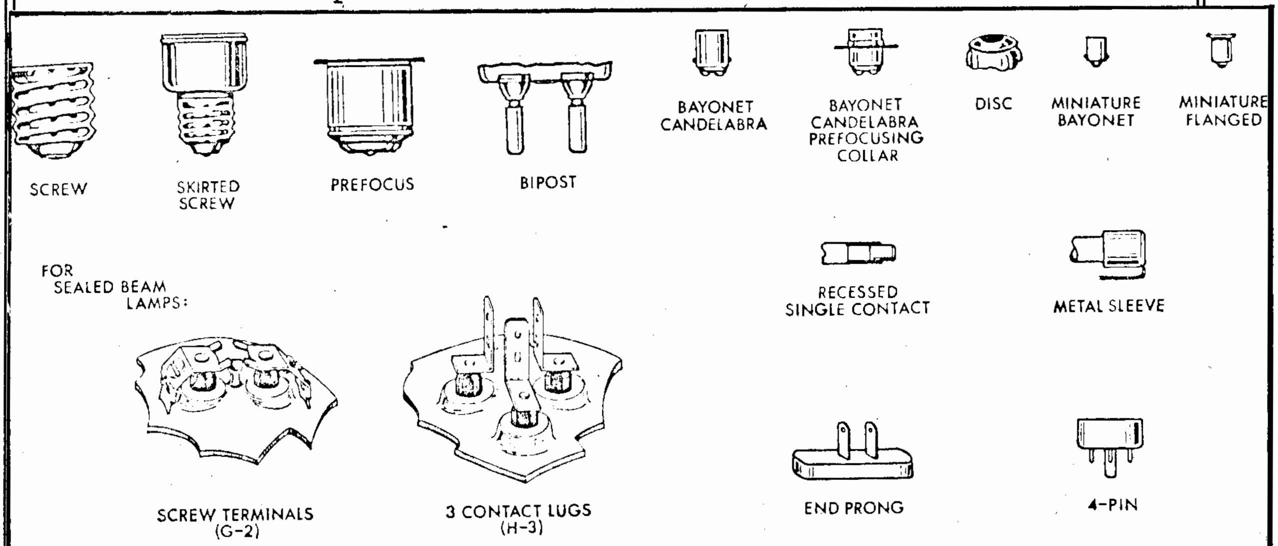


Fig. 16 Common Lamp Bases

(Illuminating Electrical Society, 1966, p. 8-4)

D. Lamp Characteristics

The operating characteristics of a filament lamp are critically dependent on filament temperature. Since temperature is proportional to the current passing through the filament and therefore to the voltage. The life output and efficiency of a lamp can be markedly altered by even a small change in operating voltage.

Lamp characteristics are given in percent of rated values; therefore, it is possible to use one chart for many types of lamps.

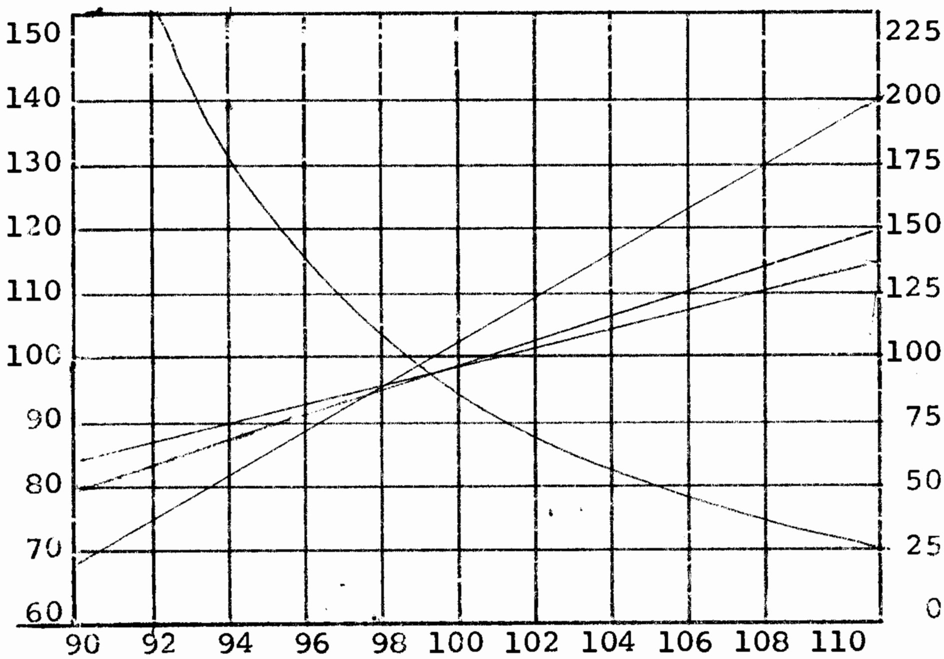


Fig. 17 Lamp Characteristics as they Change with Voltages (Allphin, 1959, p. 46.)

These charts may be shown in the following example:

Assume that a standard 60W 115V, A-19 lamp is operated on a 120V circuit. (a) What is the expected light output? (b) What is the expected life of the lamp?

(a)

1. Percent rated volts $= \frac{\text{operated voltage}}{\text{rated voltage}}$

$= \frac{120}{115}$ - 104%

2. From chart, at 104% rated volts, we can find that percent rated lumens = 116%.

3. From lamp schedule, we can find the rated light output for a 60W A-19 standard voltage lamp, rated light output = 840 lumens.

4. Expected lumen output $= 840 \times \frac{116}{100}$

$= 974$ lumens

(b)

1. Percent rated volts $= \frac{\text{operated voltage}}{\text{rated voltage}}$

$= \frac{120}{115} = 104\%$

2. From the chart, at 104% rated volts, we can find that percent life = 60%

3. From lamp schedule, normal rated life = 1,000 hours

4. Expected life of the lamp $= 1{,}000 \times \frac{60}{100}$

$= 600$ hours.

Thus, if a standard 60W 115V, A-19 lamp is operated on a 150V circuit, we may expect 974 lumens for the light output and 600 hours for the life of the lamp.

A similar procedure can be used in finding another characteristic of a lamp from any of the other curves.

In general, it is advisable to operate incandescent lamps at rated voltage, accepting balanced efficiency, output and life.

II. Fluorescent Lamps

The fluorescent lamp has almost completely supplanted the incandescent lamp in all fields except specialty lighting and residential use. This is because of its advantage over the incandescent lamp, namely:

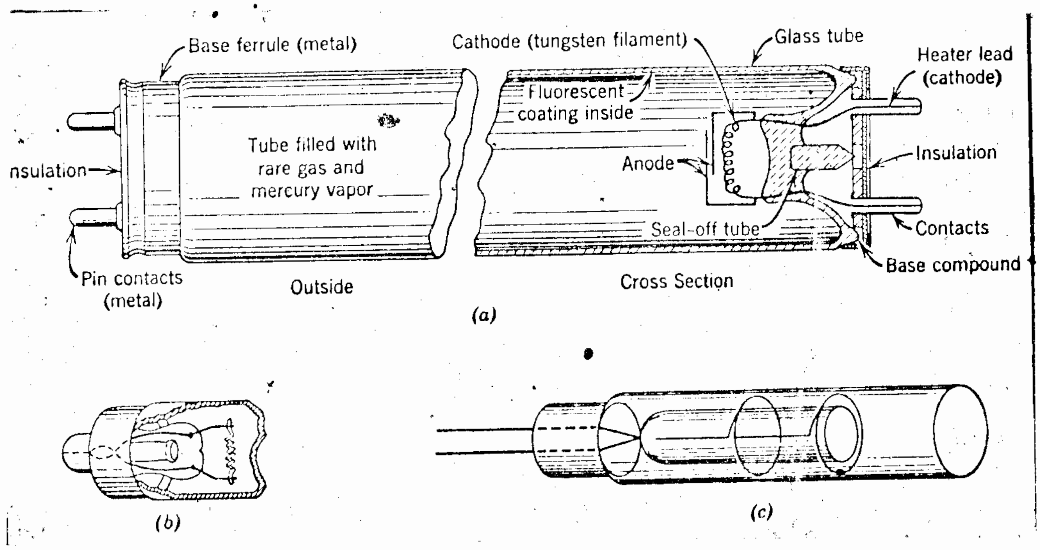
1. The efficiency of the fluorescent lamp is nearly

three times greater than an incandescent lamp.

2. The considerable range of colors can be had without loss of efficiency. For example, by choosing a blue fluorescing phospher, a blue light can be produced with a fluorescent lamp, but it would be necessary to use a blue bulb of filter with an incandescent lamp, which would absorb part of the light and reduce the overall efficiency.

The typical fluorescent lamp comprises a cylindrical glass tube sealed at both ends and containing a mixture of an inert gas, generally argon, and low pressure mercury vapor. A cathode which supplies the electrons to start and maintain the mercury arc, or gaseous discharge is built into each end. The short wave ultraviolet light, which is produced by the mercury arc, is absorbed by the phosphors with which the inside of the tube is coated and re-radiated in the visible light range. The particular mixture of phosphors used governs the spectral quality of the light output. The important function of the phosphor is to take the invisible ultraviolet energy and convert it to visible energy by lengthening its wave length.

Fluorescent lamps have a negative resistance characteristic; therefore, must be operated with a current limiting device connected in series. This auxiliary called a "ballast", limits the current to the value for which each lamp is designed. It also provides the required starting and operating lamp voltages.



Type (a) hot cathode for preheat-starting; (b) hot cathode for instant starting; (c) cold cathode for instant starting.

Fig. 18 Details of Construction of Standard Flourescent lamps. The two ends of the lamp are of identical construction.

(McGuinness, 1967, p. 365).

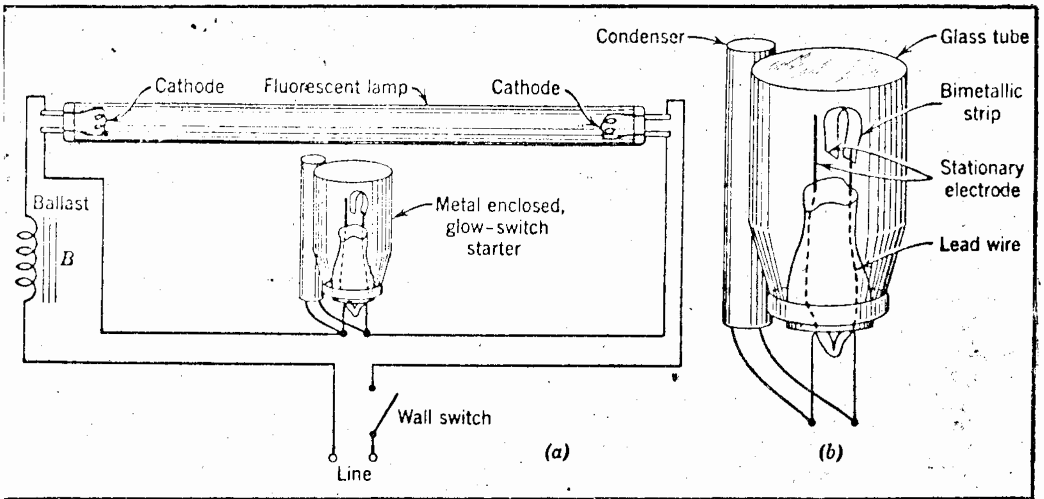
A. <u>The Electrode</u>

There are two types of electrodes:

1. Hot Cathode: Presently, most fluorescent lamps are the hot cathode type. The cathode of a fluorescent lamp are coiled-coil or triple-coil tungsten filaments coated with an emissive material, such as compound of barium, calcium, or strontium, providing abundance of free electrons when hot. There are three general classes of hot cathode fluorescent lamps defined by, circuits for which they are designed. Preheat, Instant Start, and Rapid Start.

2. Cold Cathode: The cathode is a thimble-shaped

cylinder of soft iron instead of a filament which may be coated on their inside surface with electron emitting material.



(a) operating auxiliaries and circuit connections
(b) enlarged details of the glow switch starter.

Fig. 19 Fluorescent Lamp

(McGuinness, 1967, p. 365).

Cold cathode lamps have a very long life, but they are less efficient than hot cathode lamps, and they provide less light per foot of length. They are particularly suited for use in signs, where there is need for small tubing which will be brighter and whiter than neon and which can be used in small diameters and bent into various shapes. Cold cathode lamps are used in some schoolroom fixtures and are used frequently in decorative cove lighting installations where they can be bent to follow the contour of curved surfaces. (Allphin, 1959, pp. 80-81).

B. Circuits of Hot Cathode Lamps

1. Preheat Circuit

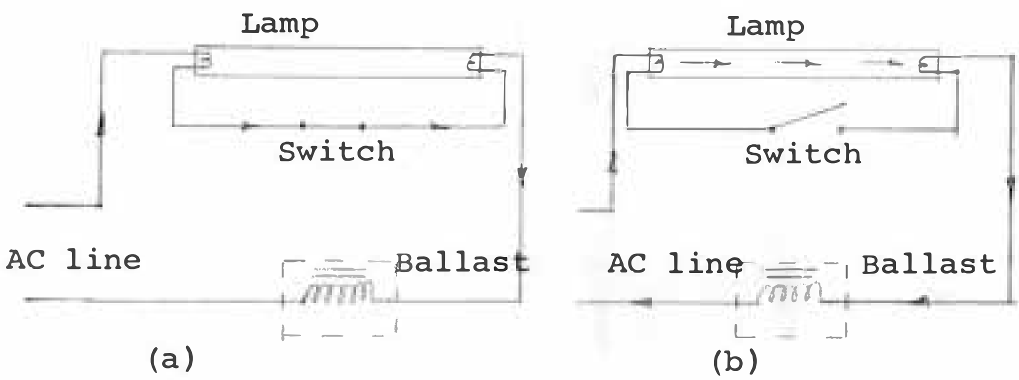


Fig 20 Simple Preheat Circuit, (a) with starting switch closed; (b) Starting Switch open.

When the switch is closed, an electric current flows through one cathode, the switch, the other cathode, and the ballast. Since it is alternating current, if it has a frequency of 60 cycles, it reverses itself 120 times in each second. The arrows as shown in Fig. 20 (b), show the direction of flow at a certain instant. At an instant 1/120 second later or earlier, the current would be flowing in the opposite direction. With the current flowing as in the illustration, both cathodes will become incandescent and will give off electrons, helped by the emissive coating. These electrons ionize the argon gas near the cathodes and make it a better conductor of electricity. When the switch is open, the current flowing through the choke coil is interrupted which causes the induced voltage in the coil greater than the voltage which has been applied. This voltage is applied across the cathodes of the lamp and causes an arc to strike between the cathodes. The heat produced by the argon arc changes the liquid mercury to vapor and the arc becomes a mercury-vapor arc. The hotter the arc, the lower its resistance, so it would run away with itself and destroy the lamp. This can be helped by using ballast limits the current to the desired value. The switch can be hand operated or an automatic switch called a "starter."

2. <u>Instant Start Circuit</u>

With instant start lamps, sufficient voltage is applied between the lamp cathodes to strike the arc without any delay. The arc current provides cathode heating. Because no preheating of the cathode is required, instant start lamps require only a single contact at each end of the lamp. Thus, the single pin lamp is used on most instant start lamps. These are commonly called slimline lamps. The ballast for instant start lamps is larger, heavier, and more expensive.

3. <u>Rapid Start Circuit</u>

Rapid start circuit will start the lamps in not over two seconds and usually, in less than one second. It uses low resistance cathodes which can be heated continuously with low loss. Therefore, the rapid start circuit is particularly suitable where fluorescent lamps are to be flashed on and off repeatedly and also are used in dimming circuits.

Rapid start cathode is triple-coiled and has finer wire than preheat cathode, which is a coiled-coil filament.

The ballast for a rapid start lamp is smaller, lighter in weight, and less expensive than the ballast for an instant starter lamp.

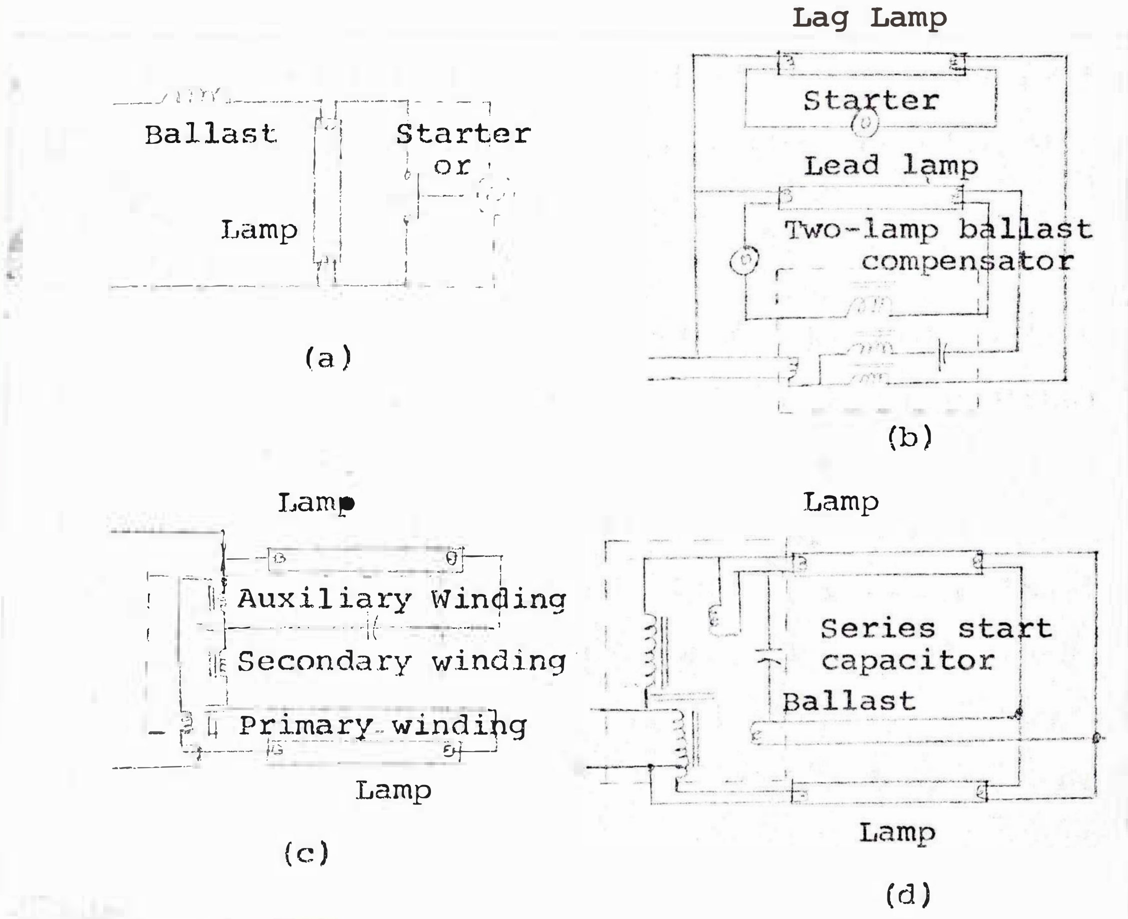


Fig. 21 (a) Simple pre-heat circuit. (b) Two-lamp lead-lag preheat, high power factor. (c) Two-lamp series sequence instant start, high power factor. (d) Two-lamp series rapid start, high power factor, the small capacitor shunted across one lamp momentarily applies nearly all of ballast secondary voltage across the other lamp.

Title?

C. Starters

The principal functions of a starter are to close the starting circuit of a preheat lamp while the cathodes heat up, and then to open the circuit. If the arc fails to start, the starter must try again. A further function in protective starters is to disconnect a lamp from the starting circuit when it fails to start after several attempts.

Bimetal switch is an important element of a starter. If two metals having different rates of expansion and contraction are welded together into a strip, the strip will bend one way when heated and the other way when cooled. A bimetal strip can be made to serve as a switch by having it make or break an electrical connection with a fixed contact.

1. Thermal Switch Starter

When the supply circuit is closed, the ballast, lamp cathodes and starter heating element are in series. The silver carbon contacts of the thermal starter shown in Fig. 22(a) are normally closed. The bimetal strip in the starter is heated by the cathode preheating current, causing the contacts to open. The induced voltage then starts the lamp, the normal operating voltage holding the thermal switch open thereafter.

If the lamp fails to start on the first attempt, the line voltage applied to the carbon resistor heats the bimetal further and causes the silver contact to move over against the third contact. This, then, the carbon resistor is shorted circuit, permits preheating current to flow through the cathodes, no current flows through the carbon resistor. Therefore, it cools and allows the bimetal strip to return to the open position and attempt to start the lamp again.

Thermal switch starters consume some power (½ to 1½W) during lamp operation. (Illuminating Electrical Society, 1966, p. 8-25).

2. <u>Glow Switch Starter</u>

The inert gas is filled the glass bulb as shown in Fig. 22(b). With the ballast of certain design, when the line switch is closed, there is no voltage drop in the ballast and the voltage at the starter is sufficient to produce a glow discharge between the contacts. The heat from the glow distorts the bimetallic strip and closes the contacts, thus, the cathode preheating begins. The bimetal cools and the contacts open in a short time later because the glow discharge is shorted circuit. The resulting transient voltage is enough to start the lamp. During normal operation, the voltage across the lamp is not enough to produce further starter glow, so the contact remains open and the starter consumes no power.

3. <u>Cutout Starter</u>

These starters are designed to prevent the repeated blinking or attempts to start a deactivated lamp, and may be made to reset either manually or automatically.

a. Manual Reset Cutout Starter

The manual reset cutout starter as shown in Fig. 22(c) uses the glow switch principle. This starter has a wire-coil heater element actuating a bimetallic arm which serves as a latch to hold a second switch in a normally closed position. After the unsuccessful repeated attempts to start an unactivated lamp, sufficient heat is developed by the intermittent flow of cathode preheating current, so that the latch pulls away and opens the starter circuit. After the lamp is replaced, the starter may be reset to operating position by pushing on the reset button.

b. Automatic Reset Cutout Starter

After the unsuccessful repeated attempts to start a deactivated lamp, a low resistance heater which is in series with the glow switch and carries the starting current as shown in Fig. 22 (d) gradually heats the bimetal and opens the circuit breaker contacts in the glow switch circuit. Then, open circuit voltage exists across a carbon resistor which is connected in parallel across these bimetallic elements. This resistor consumes negligible power (less than one watt), but produces sufficient heat to hold the circuit breaker contacts open. When the deactivated lamp is replaced, this circuit is broken and the starter automatically resets to its normal position, ready to function again.

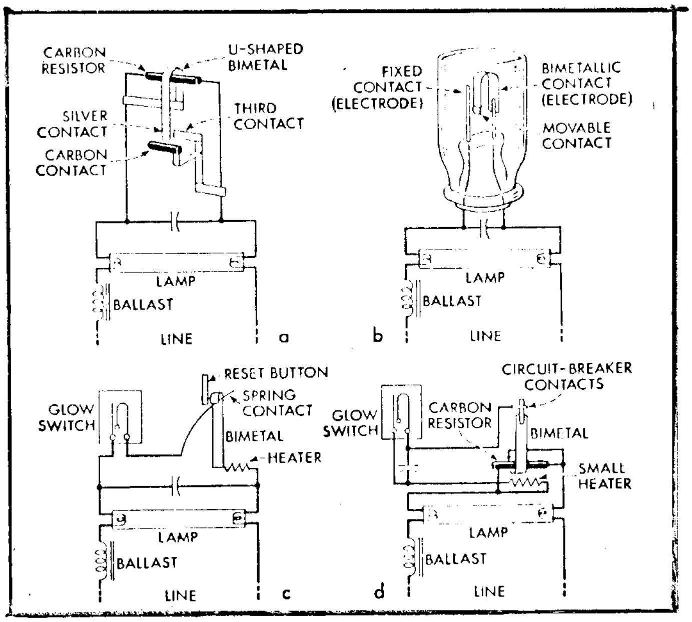


Fig. 22 Starter switches for preheat cathode circuits, (a) thermal type. (b) glow switch type. (c) manual reset type. (d) automatic reset type.

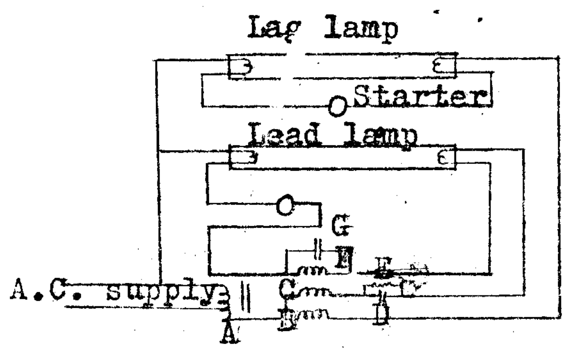
(Illuminating Electrical Society, 1966, p. 8-25)

D. Ballast Circuits

1. Lead-lag Ballast

Leading and lagging currents produced in circuits containing fluorescent lamps are important. The mercury arc inside a fluorescent lamp goes on and off 120 times per second when the lamp is operated on 60 cycles. Since fluorescent phosphors continue to glow somewhat for a little while after the arc goes out, the phosphors do not become completely dark when the current reverses. Nevertheless, there is a rapid variation in the light output. Under some circumstances, this variation in light output can produce stroboscopic effect. Modern phosphors have a long holdover period, so it is rare to have any difficulty because of the stroboscopic effect. But, if there is any, lead-lag ballast can be used to compensate this effect.

A lead-lag ballast is operated with two lamps. One of the lamps is in series with a choke coil, which will be a leading-current lamp. The lag lamp and lead lamp will operate out of phase with each other. That is, one lamp is bright while the other is dim, and vice versa.



A = autotransformer for increasing voltage
B = choke coil which causes lagging current in lag lamp
C = choke coil which, together with condenser D, regulates current in lead lamp
D = condenser which causes leading current in lead lamp
E = small resistor which bleeds off charge in condensor when lamps are turned off so workmen will not get a shock from charge left in the condensor
F = starting compensator which upsets balance of the capacative circuit and permits more current to flow, but only during preheat phase when starter is used. Compensators often omitted in low-cost ballasts
G = small condensor to suppress radio interference.

Fig. 23 Lead-Lag Ballast Diagram

(Allphin, 1959, p. 73)

2. Series ballast

If it is not necessary that lamps be operated on lead-lag ballasts, series ballasts may be used which are smaller, lighter and more efficient than lead-lag ballasts. Since the two lamps are in series, therefore, when one lamp fails, the other will go out too. This does not happen with a lead-lag ballast.

E. The Bulb

Fluorescent lamps are most commonly made with tubular bulbs. Diameter is varied from 5/8 inch (T-5) to 2-1/8 inches (T-17). Length is varied from six inches to ninety-six inches. The length includes the thickness of the standard lampholders, which are normally part of the luminaire.

Fluorescent lamps are also manufactured in the form of a circle (circline), helicoil and intermittently grooved.

All fluorescent lamps for lighting purposes, except circline lamps, have bulbs of ordinary lime glass. Circline lamps have bulbs of lead glass. Both lead and lime glass absorb ultraviolet light and transmit principally visible light.

F. The Base and Lampholder

The design of the base depends on the requirements of the circuit, because bases are not only to support the lamp but also provide a means of electrical connection.

Lampholders are designed for each base. Dimension and spacing on any particular lampholder is important because proper spacing between lampholders and luminaires must be maintained to insure satisfactory electrical contact.

G. Lamp Characteristics

Factors affecting the performance of fluorescent lamps are line voltage, ballast quality, starter type and quality (for preheat lamps), temperature, humidity, and frequency of starting.

If the voltage delivered to the lamp is too low, it may be difficult to start the lamp, particularly when the humidity is high. Also because of the smaller amount of energy in the mercury arc, the output of visible light is less. When the voltage delivered to the lamp is higher than it should be, the cathode coating will deteriorate more rapidly and lumen maintenance also suffers somewhat with higher current.

More of cathode-coating material is used up when a lamp starts than is used during the operation. Therefore, the average life of a lamp depends on how often it is started.

From the curve as shown in Fig. 24, when lamps are burned 6 hours per start, the average life is increased 25%. Continuous burning extends the life to about 2½ times normal.

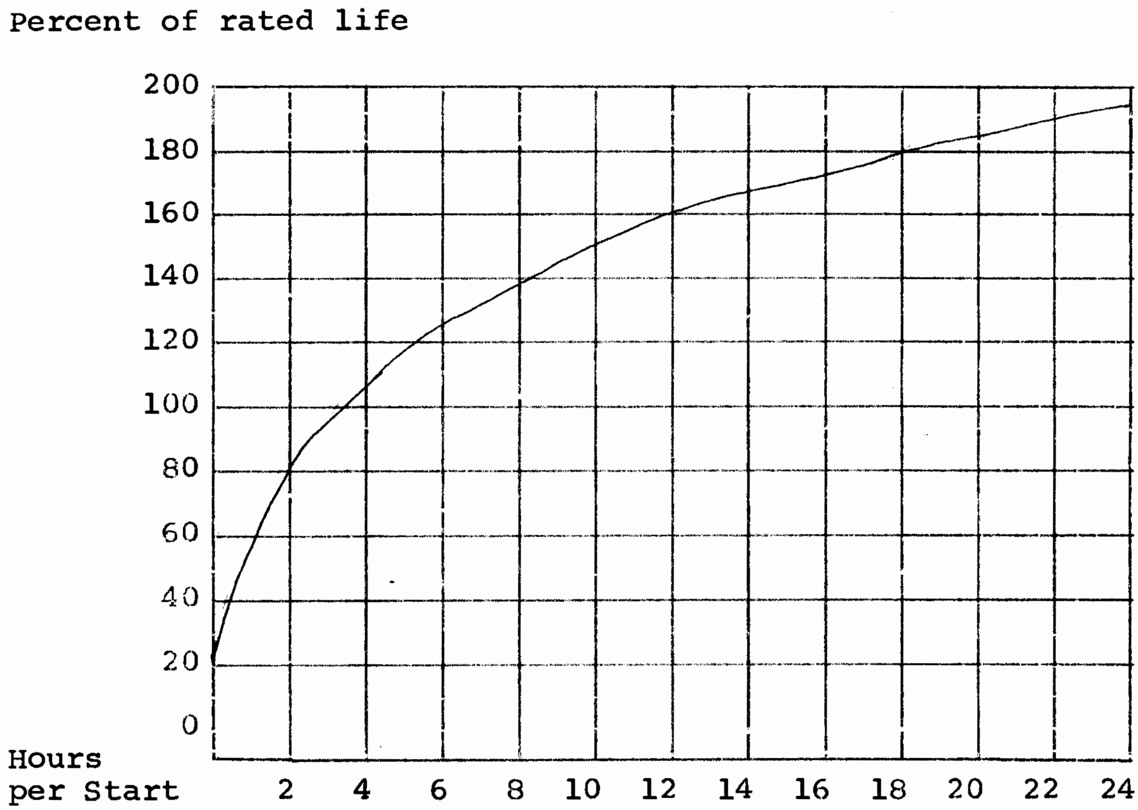


Fig. 24 Effect of Burning Periods on Life of Preheat Fluorescent lamps.

(Allphin, 1959, p. 98)

H. Effect of Temperature

A fluorescent lamp always contains a greater quantity of liquid mercury than will ever become vaporized at any one time. If any particular location is significantly cooler than the rest of the lamp all the liquid mercury will collect at this point or points. This will depend upon ambient temperature and when the lamp is lighted, lamp construction, wattage loading.

The effects of temperature on mercury vapor pressure are:

1. Effect on Light Output

In Fig. 25 as shown are the typical fluorescent lamp temperature characteristics. Exact shape of curves will depend upon lamp and ballast type; however, all fluorescent lamps have curves of the same general shape since this depends upon mercury vapor pressure.

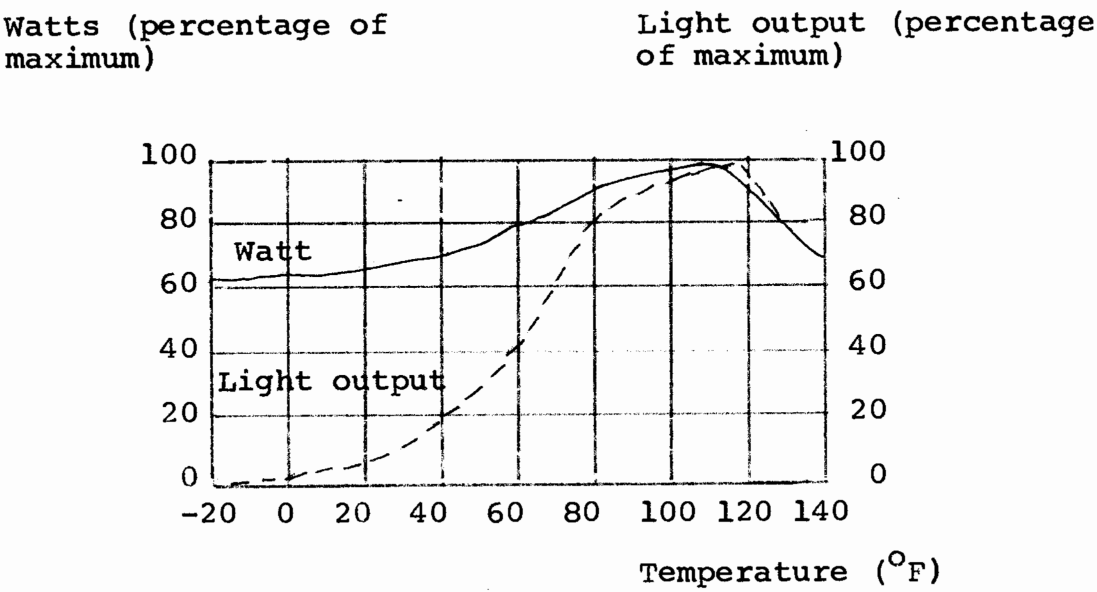


Fig. 25 Typical fluorescent lamp temperature characteristics.

2. Effect on starting

As ambient temperature is reduced, starting of all fluorescent lamps becomes more difficult. For reliable starting at low temperatures, it is necessary, therefore, to employ special lamp auxiliary components.

Ballasts are available for reliable starting in the three temperature ratings:

1. above 50° F for ordinary indoor use
2. above 0° F for normal outdoor use
3. above - 20° F for color conditions.

Very high ambient temperatures could cause difficulty with lamp starting. (Illuminating Electrical Society, 1966, p. 8-22)

3. Effect on Color

Color of light from fluorescent lamps is caused by phosphor coating on the lamp and mercury arc discharge within the lamp which each reacts independently to temperature changes.

I. Lumen Maintenance

There is some falling off of lumen output as a fluorescent lamp is used. This is because the phosphors slowly lose some ability to convert invisible ultraviolet energy into visible light.

J. Radio Interference

Electromagnetic radiation by the mercury arc in a fluorescent lamp may be picked up by nearby radio causing an audible sound. This radio noise reaches the radio by radiation to the antenna, which may be eliminated by moving the antenna farther from the lamp -- ten feet is usually enough. The radio noise is also caused by conduction over the power lines. This noise will be suppressed below the interference level by an electric filter in the line at the luminaire.

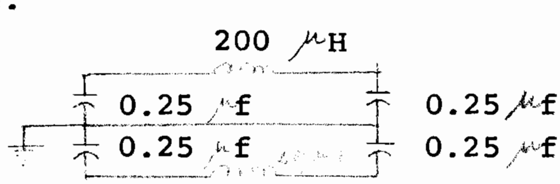


Fig. 26 Typical radio interference filter used in critical application.

K. Lamp Color

Color is a highly complicated subject, and there is wide variation in the response of people to a certain color. The list below gives some suggested applications of the seven phosphors.

Major characteristics of seven
seven shades of fluorescent "white":

Standard Cool White	Often selected for offices, factories, and commercial areas where a psychologically cool working atmosphere is desirable. Gives a natural outdoor lighting effect. The most popular of all fluorescent lamp colors.
Deluxe Cool White	For the same general applications as "standard cool white", but containing more red and therefore, more flattering to the appearance of people and merchandise. Generally chosen for all-purpose good color rendition.
Standard Warm White	For use wherever a warm social atmosphere is desirable. Close to incandescent in color, it is suggested wherever a mixture of fluorescent and incandescent is contemplated. In stores, it cuts down returns on sales of merchandise for use in homes lighted with incandescent. Its beige tint gives a bright, warm appearance to reds and yellows, brings out the yellow in green, adds a warm tone to blue.
Deluxe Warm White (Home-Line)	Similar to "standard warm white" and for the same general uses, but, with the addition of a red element which makes it more flattering to people and most objects displayed under it. Generally recommended for home or social environment applications and for commercial use where flattering effects on people and merchandise are considered important.
White	For general lighting purpose in offices, schools, stores, homes. Chiefly for use where either a cool working atmosphere or warm social atmosphere is not critical. Emphasizes yellows, yellow-greens, and oranges.

Daylight	For use in industry and work areas where one prefers the blue color associated with the "north light" of actual daylight. Makes blues and greens bright and clear, tends to tone down reds, oranges, and yellows.
Soft White	Often used for meat counter display. Its soft pink tint brings out the color of a wide range of pinks and tans, and accentuates flesh tones.

(Allphin, 1959, p. 113).

III. <u>Mercury Vapor Lamps</u>

The arc of the mercury vapor lamp is confined to a small tube of hard glass or quartz and this tube is surrounded by a larger glass bulb which

a. protects the arc tube from outside drafts and changes in temperature;

b. contains an inert gas (usually nitrogen) in order to protect oxidation of internal parts, and also maintains a relatively high breakdown voltage across the outer bulb parts; and

c. provides an inner surface phosphor coating.

In the fluorescent lamp, the arc emits most of its energy in the invisible ultraviolet region, and the energy is then converted into visible light by phosphor. But the mercury vapor lamp operates at higher pressure than does the arc in a fluorescent lamp, and that higher pressure shifts the radiation so that much of it occurs in the visible range.

When the lamp is turned on, full starting voltage is applied between the starting and operating electrodes which causes a glow discharge between them. Since the high resistance of starting resistor is connected in series with the starting electrode, so very little current flows from the starting electrode to the operating electrodes.

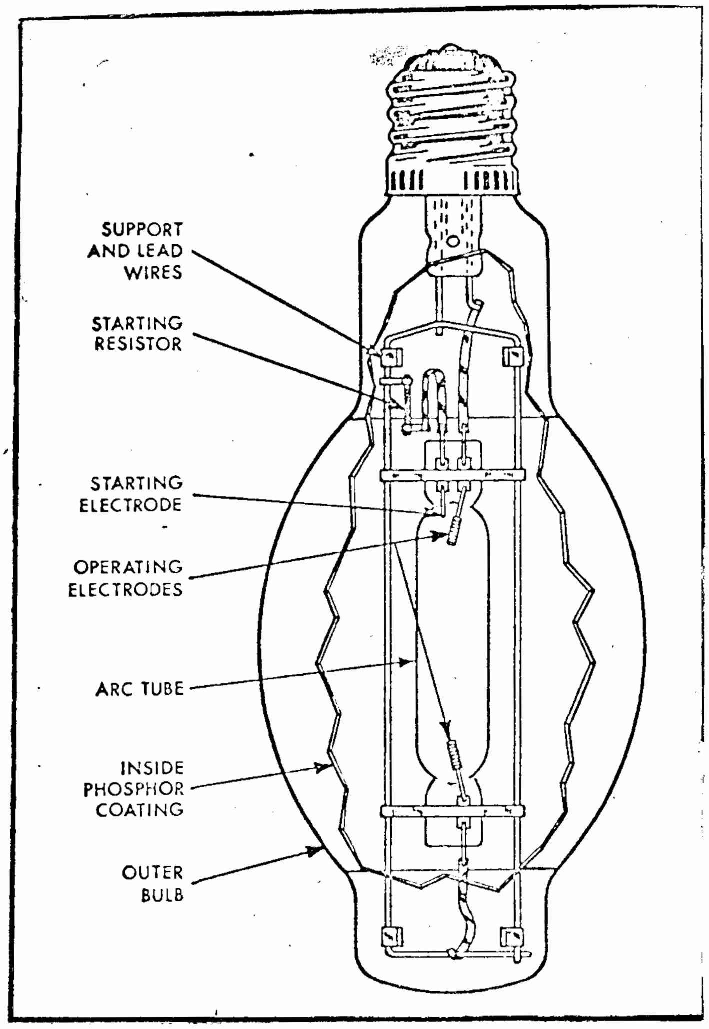


Fig. 27. Phosphor-coated mercury lamp.
(Illuminating Electrical Society, 1966, p. 8-30)

At first the arc in the argon gas gives off very little visible light. Gradually, its heat vaporizes more of the mercury in the tube. This change builds up pressure, and the arc becomes a true mercury vapor arc. The process takes from 4 to 10 minutes, and this lag must be kept in mind by the designer of an installation.

A mercury vapor lamp must be operated on a ballast because it is an arc lamp. This is to keep the current from increasing and destroying the lamp. The ballast also contains a transformer to step up when the line voltage is less than the operating voltage. Both high power factor ballasts and low power factor ballasts are available for mercury vapor lamps. Single lamp ballasts are made for all mercury lamps, and two lamp ballasts can be had in series or lead-lag type.

Self-ballasted mercury lamps are available in various wattages. These lamps have a mercury vapor arc tube in series with a current limiting tungsten filament, and do not require an auxiliary ballast as required by standard lamps.

IV. Carbon Arc Sources

Although carbon was replaced by tungsten as a filament material, some carbon lamps are used today where extremely high luminance is necessary, where large amounts of radiant energy are required and where their radiant energy spectrum is advantageous.

V. Concentrated Arc Lamps

Concentrated arc lamps use an electrical arc to heat a small piece of zirconium to molten incandescence. Light source areas vary from 0.006 to 0.110 inches in diameter. The sizes are very small which are very useful in many optical devices. Special ballasts are required to operate the lamps.

VI. Glow Lamps

Lamps using this principle do not give much light, they are low wattage, but have very long life, designed primarily for use as indicator or pilot lamps, but are also used for night lights and location markers.

VII. Electroluminescent Lamps

An electroluminescent lamp is a thin area source in which light is produced by a phosphor excited by a pulsating electrical field. In essence, the lamp is a plate capacitor with a phosphor embedded in its dielectric and with one or both of its plates translucent. Green, blue, yellow, or white light may be produced by choice of phosphor. The green phosphor has the highest luminance. These lamps are available in ceramic and plastic form, flexible or with stiff backing, and are easily fabricated into simple or complex shapes. They have been used in decorative lighting, night lights, switchplates, instrument panels, clock faces, telephone dials, thermometers, and signs. Their application is limited to locations where the general illumination is low.

CHAPTER VI

ELECTRICAL OUTLETS AND OVER-CURRENT PROTECTION DEVICES

I. Electrical Outlets

Care in determining the number and location of outlets, such as lighting, switch, convenience, and special-purpose outlets is very important. Unsightly, inconvenient, and long extension cords will be unnecessary if a sufficient number of outlets is applied. Extension cords cause a double hazard of short circuits caused by frayed cords. The location of outlets must be placed in order to serve any practical arrangement and the desired lighting.

Single switch outlets and duplex receptacle outlets are quite common in use. But there are many more wiring devices available for specific and more convenient uses. These devices do not need special outlet boxes. They fit into standard outlet boxes. Examples of these devices are:

1. Silent switches (or mercury switches) are desirable because of their quietness in operation when the handle is moved. The silent switch has a small quantity of liquid mercury that is moved against the contact points which eliminates the "clock" when the switch is turned on or off.

2. Controlling closet lights which has not been used more extensively. The light will be turned on when the door is in the open position and off when the door is in the

closed position, or, it may be the operation is reversed.

3. Outside receptacles which are weatherproof convenience receptacles. These receptacles come in single and duplex types. These outdoor devices are used for decorative lighting, Christmas lighting, for temporary yard lighting, patio or garden lighting, or any other outdoor installation.

4. Dial-set dimmer switch which gives completely variable dimming control from zero to 50% illumination or switches to full intensity.

In every lighting circuit it is necessary to be able to turn the lights on or off. Switches are used for this controlling purpose and can be classified as:

1. Single-pole switch. This switch is one that has a single contact that can be opened and closed by pushing the tumbler either up or down.

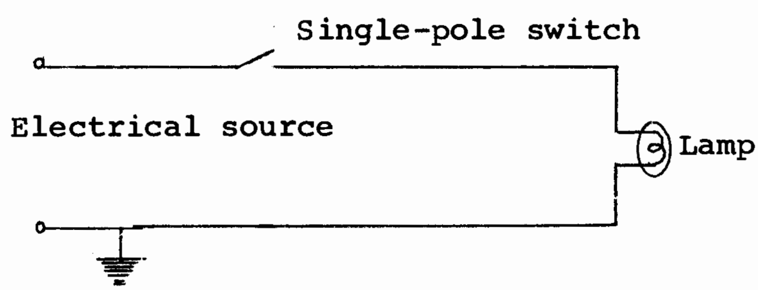


Fig. 28 Wiring diagram using a single-pole switch

The switch controls only one side of the circuit and the other side is always "live". For this reason a switch of this type should not be used on circuits located in damp places or outdoors, because there is always a possibility of danger due to grounds. A short circuit will occur in this system if an accidental ground occurs on the ungrounded wire of the supply system regardless of what position the switch is in.

2. <u>Double-pole switch</u>. This type of switch is placed into the circuit in order to break both line wires. An accidental ground between the switch and the lamp cannot cause trouble, when the switch is open. When the switch is closed, however, a short circuit will occur if the ungrounded wire of the supply system is grounded.

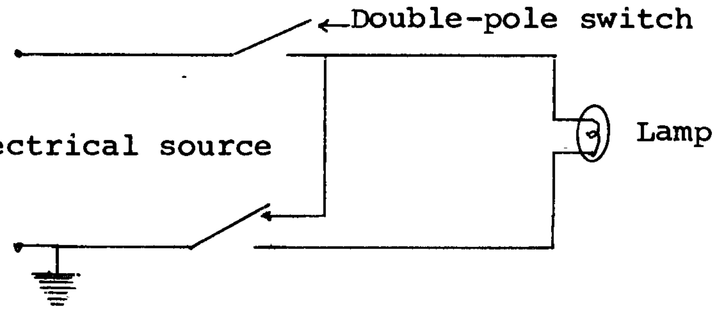


Fig. 29 Wiring diagram using a double-pole switch.

3. <u>Three-way switch</u>. Two three-way switches can be used to control a single light from two different locations. Three-way switches have three terminals for wire connections. The principle of operation is as shown in Fig. 30.

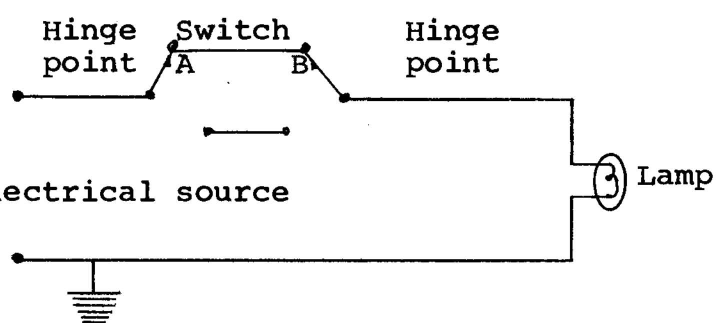


Fig. 30 Two three-way switches control a single lamp.

4. <u>Four-way switch</u>. A four-way switch has two terminals at each end. The position of the switch arm is that

either two terminals are connected directly across to the opposite terminals, or diagonally across to the opposite terminals.

This four-way switch can be used in connection with two three-way switches to control a light or a group of lights more than two locations. By adding one additional four-way switch to the circuit for each control point, the number of control points are unlimited.

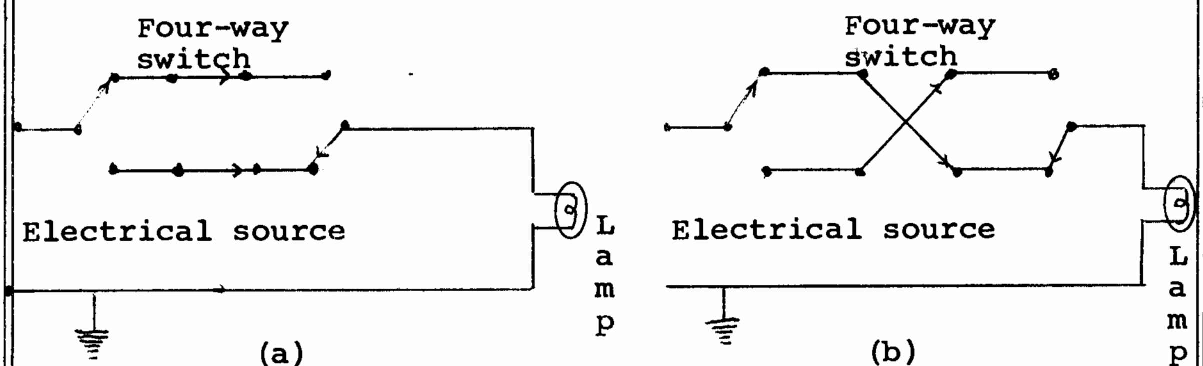


Fig. 31 One four-way switch and two three-way switches control a single lamp, (a) the circuit is open, (b) the circuit is complete.

II. Over-Current Protection Devices

When electricity flows through a conductor, heat is generated. The amount of heat depends upon the amount of electricity which flows through the wire (amperes), and the time that the electricity flows. It is obvious that if too much electricity flows in a wire, excessive heat is generated. This may be caused by short circuits or overloads which will damage the circuit and cause a fire hazard. To protect such a damage, fuses or circuit breakers are connected into circuits. The functions of fuses and circuit breakers are:

1. Provide complete protection against overloads.

2. Interrupt short circuits as quickly as possible before they have any chance to damage the wire.

3. Provide adequate time delay so that current will not be interrupted upon the starting up of loads, and permit the full safe capacity of the wire to be utilized at the same time.

A. Fuses

There are two types of fuses, the plug fuse and the cartridge fuse. The important part of the fuse is the thin strip of metal, usually zinc, that will melt when the current flow becomes too great. Contact surfaces of fuses must have good electrical connections with the fusible part of the strip. The size of the zinc strip depends on the amount of current it will carry without melting.

Generally, enclosed fuses are rated as having about 10% overload capacity (Croft, 1929, p. 186). For example, a fuse stamped 30 amperes will carry indefinitely a current of about 33 amperes. Fuses are thus so rated as to have overload capacity to insure that a fuse will, without rupturing, handle the ordinary fluctuations of current in a circuit. Furthermore, since it requires an appreciable time for a fuse to attain melting temperature, monentary currents, of intensities much greater than the fuse ratings, will not blow the fuses. It is evident then that if a conductor of a given size is protected with a fuse of a rating equal to the allowable current carrying capacity of the conductor, a margin for overload is automatically provided. If it is necessary, in order to prevent fuses from blowing, to use fuses larger than the allowable current carrying capacities of wires, obviously the wire will then be overloaded. In such a case, either the load on the wire should be decreased or the size of the wire (the load remaining the same) should be increased.

B. <u>Circuit breakers</u>.

Circuit breakers in common use are of three types:

1. Thermal type: These are designed for feeder and branch circuit protection and are simple compact devices for for use in load centers. Their operation is based on the principle of expansion of a metal strip when heated by the current in the circuit.

A strip is made of two different kinds of metal either welded or riveted together. When too much current flows to the strip the metals get hot. The heat makes the metals expand, but, since they are two different kinds of metal, one expands more than the other. Since the lower strip expands more than the upper piece, the heat strip curves upward. This bending of the heater strip allows a spring in the switch to open the contact points. The amount of current necessary to open the contact depends upon the design of the heater strip.

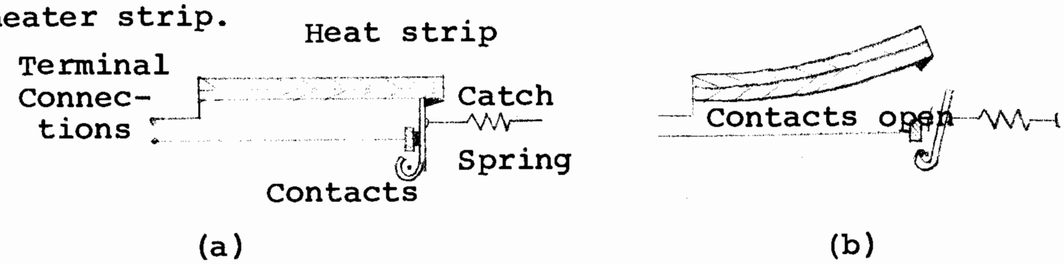


Fig. 32 Thermal type circuit breaker, (a) at normal current, (b) at over current.

2. Electromagnetic type. The electromagnetic breaker is an automatic switch that opens the circuit when the current passing through an electromagnet or solenoid reaches a predetermined value. From the illustration, as the armature moves toward the coil, it breaks the contact points and opens the circuit.

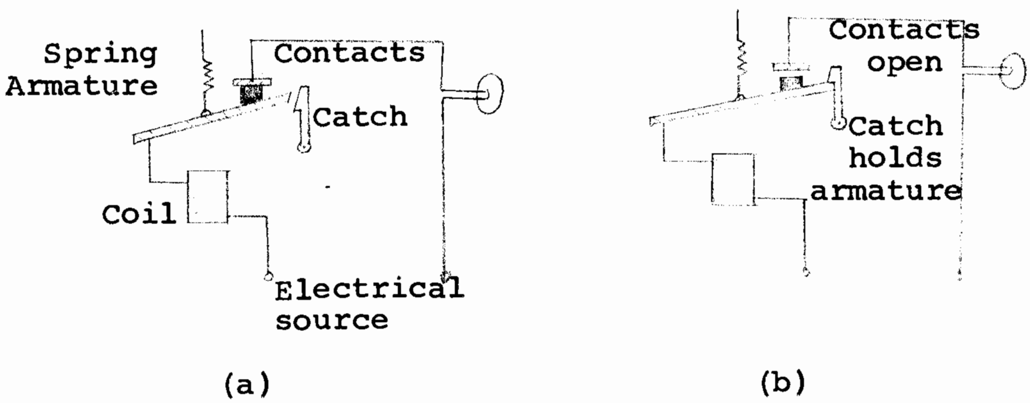


Fig. 33 Electromagnetic type circuit breaker, (a) at normal current, (b) at over current.

3. Thermal-magnetic type. Circuit breakers employing both thermal and magnetic action provide a cooperative action. The thermal action employs the bending of the expanding bi-metal strip to trip the breaker when a predetermined current-time rating is exceeded. The magnetic action uses an electro-magnet to operate instantly, breaking the circuit when the current setting is exceeded.

In setting circuit breakers for the protection of circuits it is justifiable to set the breaker so that it will trip on a current 30% greater than the allowable current for the conductor. The reason for this is that a circuit breaker is extremely sensitive and will, unless it is equipped with a time limit device, respond instantly and open its circuit if a current greater than that for which it is set flows through it. If a non-time-limit circuit breaker is set to trip on a current a few percent greater than the allowable current for the conductors of the circuit, it is likely that it would trip frequently on momentary overloads. This might result in considerable inconvenience. (Croft, 1929, p. 187).

CHAPTER VII

ELECTRIC LIGHT WIRING DESIGN

The method of installing electric light wiring must be such that life and fire hazard will be decreased to a minimum. Therefore, it is best to become familiar with the regulations covering the method of installing the wiring and necessary apparatus before starting any of the work. The National Electrical Code (NEC) rules, which are recommendations of the National Fire Protection Association, should be followed in this respect.

The type of wire to be used in electric light systems depends upon the conditions governing the installation and location. For example, in concealed work, raceways or moldings, damp locations, and on all systems exceeding 600V, rubber covered wires should be used. Weatherproof wire is used for outdoors, where moisture is certain. Slow-burning wire is used in hot, dry places, where ordinary insulations would deteriorate and where wires are bunched as on the back of large switchboards or in a wire tower, because the accumulation of rubber insulation would result in an objectionably large mass highly inflammable material. Lead-sheathed conductors or cables are used for underground work.

I. Conductor and Insulator

A. Conductor. This is a material that allows current to flow easily. All conductors have resistance, the greater the cross-sectional area of conductor, the lower its resistance, the longer the conductor is, the more resistance it has. The unit of the cross-sectional area of the conductor is called a circular-mil (commonly abbreviated cir mil or cm). A mil is equal to 0.001 inch and an area with a dimension of one mil on each side is called one square mil. Since most conductors are round, therefore, a unit is expressed in circular mil. One circular mil is equal to the square of the circle which has a diameter of one mil.

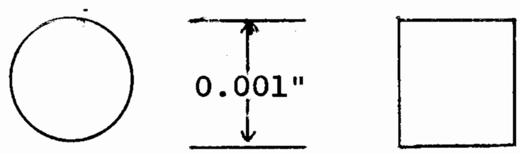


Fig. 34 Circular and square mil area

Instead of referring to the smaller size of conductors by their area in circular mils, sizes or numbers have been assigned them. The gauge commonly used is the American Wire Gauge (AWG) and is the same as the Brown and Sharpe Gauge (B & S).

The different diameters of copper wire are identified by gauge numbers. The higher the gauge number, the smaller the diameter and cross-sectional area of the wire. Therefore, the higher numbered gauges of wire have more resistance. Above number 0000 they are not designated by the numerical size, but simply by their cross-sectional area in circular-mil. Numbers 0, 00, 000, and 0000 are frequently designated also as number 1/0, 2/0, 3/0, and 4/0.

B. Insulator. Insulator is a material that opposes the flow of current. There are many different types of insulation, each is used for a specific purpose.

Each type of conductor insulation affords a given maximum safe-operating temperature, together with the "type letter" which is the identification accepted by the trade in referring to the particular grade of insulation, the maximum allowable operating temperature, and the wiring for which it is suitable. If a given type of conductor insulation is subjected for any considerable length of time to a temperature higher than its maximum operating temperature, the insulation will deteriorate rapidly. (Bredahl, 1929, p. 91).

Electric light wiring installation may be made with either (1) service cable, or (2) rigid or thin-wall conduit, which depends on local requirements. Service cable is the material most often used. Its advantages are low material and installation cost.

II. Electric Service

For economy, alternating current is transmitted long distances at high voltages and then changed to low voltages by step-down transformers at the point of service.

Small installations, such as one-family houses, usually are supplied with three-wire service. This consists of a neutral (transformer mid-point) and two power wires with currents differing 180° in phase.

From this service, the following types of interior branch circuits are available.

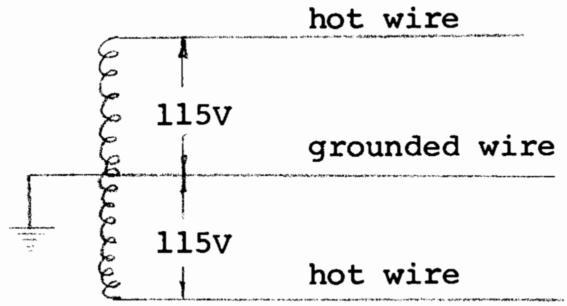


Fig. 35 Two-phase three-wire system.

Single-phase two-wire 230% - by tapping across the phase wires.

Single-phase two-wire 115V - by tapping across one phase wire and the neutral.

Single-phase three-wire 115/230V - by using both phase wires and the neutral.

For larger installations, the service most widely used is the 120/208V three-phase four-wire system. This has a neutral and three power wires carrying current differing 120^{o} in phase.

From this service the following types of interior branch circuits are available.

Single-phase two-wire 208V - by tapping across two phase wires.

Single-phase two-wire 120V - by tapping across one phase wire and the neutral.

Two-phase three-wire 120/208V - by using two phasewires and the neutral.

Three-phase three-wire 208V - by using three phase wires.

Three-phase four-wire 120/208V - by using three phase wires and the neutral.

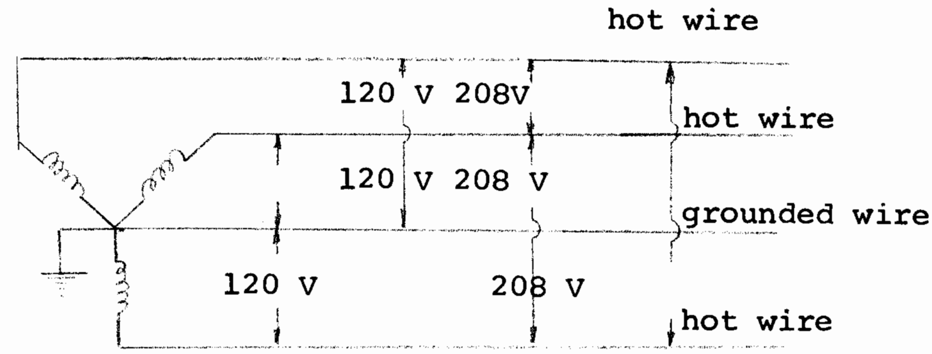


Fig. 36 Three-phase four-wire system.

III. Designing of Wire Size

In designing the size of wire, there are two important factors which must be considered. They are the current in the conductor and the voltage drop in a circuit.

A. Circuit and Conductor calculations. As described in Chapter II, in an AC electric circuit:

$$W = EI\cos\theta$$

Where, W = power in watts

E = voltage in volts

I = current in amperes

$\cos\theta$ = power factor.

Thus, Single-phase two-wire circuits: $I = \frac{W}{E_p \cos\theta}$

where, E_p = voltage between any two phase lags.

Single-phase three-wire (and balanced two-phase three-wire) circuits: $I = \frac{W}{2E_g \cos\theta}$

Where, E_g = voltage between a phase leg and neutral, or ground.

Three-phase three-wire (and balanced three-phase four-wire) circuits:

$$I = \frac{W}{3E_g\cos\theta}$$

or: $$I = \frac{W}{3E_p\cos\theta} \quad (\text{since } E_p = 3E_g)$$

In a three-phase four-wire system, there will be no current flows in the neutral when circuits are balanced. Thus when a three-phase four-wire feeder is brought to a panel from which single-phase circuits will be taken, the system should be designed so that under full load, the load on each phase leg will be nearly equal.

B. Voltage Drop Calculations.

1. D. C. or 100% pf. A. C. circuit voltage drop as described in Chapter II, $E = IR$

where, E = voltage in volts

I = current in amperes

R = resistance in ohms

since, $R \quad \frac{L}{A}$

thus, $R = 10.7\frac{L}{A}$

where, 10.7 = resistance in ohms to direct current of 1 mil-ft. of copper wire

L = one-way run in ft.

A = area in circular mil (c.m.)

Therefore, voltage drop $V_d = \frac{10.7IL}{c.m.}$ volts

where: V_d = voltage drop between any two phase wires, or between phase wire and neutral when only one phase wire is used in the circuit.

Single-phase two-wire (and balanced single-phase three-wire) circuits:

$$V_d = \frac{10.71(2L)}{c.m}$$

$$= \frac{21.41L}{c.m}$$

Balance two-phase three-wire, three-phase three-wire, and balanced three-phase four-wire circuits:

$$V_d = \frac{18.51L}{c.m}$$

Voltage drop used in design may range from 1 to 5% of the service voltage. Some codes set a maximum for voltage drop of 2.5% for combined light and power circuits from service entry to the building to point of final distribution at branch panels. When this voltage drop is apportioned to the various parts of the circuit, it is economical to assign the greater part, say 1.5 to 2%, to the smaller, more numerous feeders and only 0.5 to 1% to the heavy main feeds between the service and main distribution panels. In designing the wire size, first, select the minimum-size wire allowed by the code, and test it for voltage drop. If this drop is excessive, test a larger size, until one is found for which the voltage drop is within the desired limit. This trial-and-error process can be shortened by first assuming the desired voltage drop, and then computing the required wire areas. Then, the wire size can be selected. (Merritt, 1966, pp. 23-12 to 23-13).

<u>Example in calculation</u>: A 23-KW balanced lighting load is to be supplied from 3-wire 120/240 V mains. The length of the run between service switch and distribution panel is 250'. The voltage drop is not to exceed 2%. What size of conductor should be used?

$$I = \frac{W}{2E_g \cos\theta}$$

$$= \frac{23 \times 1{,}000}{2 \times 120 \times 1} = \frac{23{,}000}{240}$$

$$= 95.8 \text{ amp.}$$

Therefore, the kiloampere-feet = $\frac{95.8 \times 250}{1{,}000}$ = 22 Kamp.-ft.

Since the permitted percentage voltage drop is 2, the actual drop permitted is 0.02 x 240 = 4.8V.

From Appendix I.

To determine the wire size required, start at the top of the column marked 5V (which is nearest to 4.8). Follow down until the figure 22.3 is reached (which is nearest 22.0). This would indicate the use of 1/0 conductors. The actual drop would then be $\frac{22.0}{22.3} \times 5 = 4.93V$

2. <u>Reactance voltage drop</u>. Reactance in an A. C. circuit depends on conductor size, spacing between conductors, their arrangement, frequency of the supply, and the presence or absence of magnetic materials, e.g., steel conduit.

$$V_d = I\sqrt{R^2 + X^2}$$

Where: V_d = voltage drop in volts,

I = current in amperes,

R = resistance in ohms,

X = reactance in ohms.

In practice, tables and curves are resorted to for most calculations.

Example in calculation. With a load of 21KW at 80% power factor, on a 3-wire, 120/240V circuit, what wire size should be used to keep the voltage drop less than 3%? The total run is 175 ft.

3-wire, 120/240V

$$I = \frac{W}{2E_g \cos\theta}$$

$$I = \frac{21 \times 1{,}000}{2 \times 120 \times 0.8}$$

$$= 109 \text{ amp.}$$

Therefore, amp.-ft. = 109 x 175 = 19,000 amp.ft.

The permissible voltage drop is 3% of 240V.

= 0.03 x 240 = 7.2V

Since 7.2V drop will be permitted for 19,000 amp.-ft., the drop for 10,000 amp.-ft. should be limited to

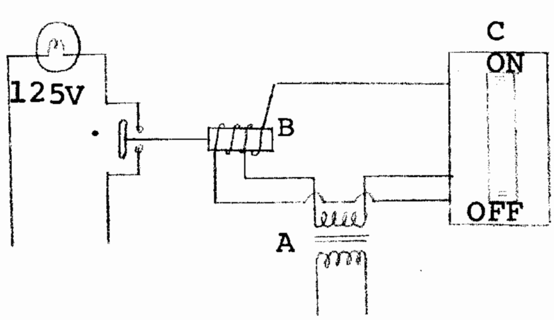
$$\frac{10{,}000}{19{,}000} \times 7.2 = 3.8V$$

Then, the size of the wire may be found above by using the curve given in Appendix J, by noting where the line through 80% power factor intersects the line through 3.8V (point a). This would indicate that the use of No. 2 conductors would be satisfactory from a voltage drop standpoint.

IV. Low Voltage Control Wiring

The method of placing switches in the 115V line to control electrical circuits is relatively simple. Three-way and four-way switches are necessary when control is desired from more than one location, and where master control is desired, the wiring becomes more complex. In order to obtain greater flexibility, versatility, and economy of installation the low-voltage control wiring system was developed.

The switching system operates on low voltage, is safer and permits the use of less costly conductors. Through the use of small relays, which are operated by low-voltage, manually operated switches, lighting circuits may be economically controlled from any number of desired locations. Another outstanding feature is the master switch control. One or more master switches may be installed for the control of a number of circuits.



A = transformer supply 24V current

B = relay controls 125 V current

C = push-button switch, control relay, thus light

Fig. 37 Simple low voltage system.

A. Relay Locations. The location of relays must be decided on in the planning stage. There are three methods to place relays.

1. Outlet-mounted relay method. Relay is placed in the outlet box at the fixture or outlet to be controlled.

2. Gang-mounted relay method. Relays are grouped in gangs and mounted in a centrally located gang box of, say, 6 or 12 units.

3. Zone-grouped relay method. It consists of grouping several relays in a gang box to take care of the relay requirements for a zone or local area.

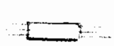
One relay is required for each circuit consisting of one or more outlets that are controlled from the same switch or group of switches. Where one switch, or group of switches, controls outlets on more than one branch circuit, then one relay must be used on each branch circuit. Also, where the power requirements are in excess of the relay rating, the outlets should be divided, using two or three relays to handle the divided load.

B. Transformer locations. The location of transformer should be as close to the relays as possible. In the outlet-mounted relay method, it is usually located in the attic, basement, or utility room and in a central location to the relays. In the gang-mounted method, it is most practical to locate the transformer at the gang box.

It is advisable to split the plan into convenient zones, each containing an approximately equal number of relays. Several transformer loop circuits permit isolation of the particular circuit in which the trouble exists, thus greatly diminishing the number of relays and switches to be checked.

V. Electrical Symbols

Wall	Ceiling	
—○	○	Outlet
—(E)	(E)	Electrical outlet - for use only when circle used alone might be confused with columns, plumbing symbols, etc.
—(J)	(J)	Junction box
—(L)	(L)	Lamp holder
—(L)PS	(L) PS	Lamp holder with pull switch
—(S)	(S)	Pull switch
(V)	—(V)	Outlet for vapor-discharge lamp
—(X)	(X)	Exit light outlet
⊖WP		Duplex convenience outlet
⊖ R		Convenience outlet other than duplex 1 = single, 3 = tripex, etc.
⊖S		Weatherproof convenience outlet
⊖ R		Range outlet
⊖S		Switch and convenience outlet
⊖[R]		Radio and convenience outlet
△		Special purpose outlet (designated in specifications)
•		Floor outlet
S		Single pole switch
S_2		Double pole switch

S_3	Three-way switch
S_4	Four-way switch
S_{CB}	Circuit breaker
S_{WCB}	Weatherproof circuit breaker
S_{WP}	Weatherproof switch
S_F	Fused switch
W_{WF}	Weatherproof fused switch
 a,b,c, etc.  a,b,c, etc. S a,b,c, etc.	Any standard symbol as given above with the addition of a lower-case subscript letter may be used to designate some special variation of standard equipment of particular interest in a specific set of architectural plans. When used they must be listed in the key of symbols on each drawing and if necessary further described in the specifications.
	Lighting panel
	Power panel
——	Branch circuit, concealed in ceiling or wall
— · —	Branch circuit, concealed in floor
- - -	Branch circuit, exposed
—➤➤	Home run to panel board. Indicate number of circuits by number of arrows. NOTE: Any circuit without further designation indicates a two-wire circuit For a greater number of wires indicate as follows: —///—(3 wires), —////—(4 wires), etc.
━━	Feeders. Note: Use heavy lines and designate by number corresponding to listing in feeder schedule.
	Underfloor duct and junction box. Triple system. Note: For double or single systems eliminate one or two

lines. This symbol is equally adaptable to auxiliary-system layouts.

(Merritt, 1966, pp. 23-9 to 23-10.)

CHAPTER VIII

ESTIMATING ELECTRIC WIRING

The methods of preparing wiring estimates are numerous and vary according to the estimator's experience and practice. The usual steps in preparing wiring estimates can be divided into four general steps:

1. The study of plans and specifications in order to become familiar with the details and contents. In studying, the estimator must take the note whether there are requirements concerning the job which is not familiar or whether any portion of the specification is contrary to the local electrical inspection ordinances. The system and manner of installing the wiring and the conditions about the premises must then be considered. Very often, channeling of concrete, or brick, or of stone and drilling of timbers must be accomplished. In some cases, only a certain number of men may work at one time, because other mechanics, such as carpenters, concrete workers, lathers, or plasterers, must begin their work previous to installation of the wiring system. The possible difficulties which may be met in installing feeders and mains, and in determining the length of runs to the farthese outlet, must also be considered. Circuits supplying heating devices, washing machines, etc. should be treated by themselves. Special type equipment, finishes, etc. must also be noted. Another problem

which the estimator will confront is the matter of fixtures, whether they are to be installed or furnished and installed.

2. Calculating the sizes of feeders and branches, and divide the outlets into groups or into circuits. This calculation is to insure an efficient and well-balanced wiring system, and will also simplify the compilation of quantities. The load on each branch, main or feeder must be planned so none will carry an excessive load. The location of the distribution panels must be considered and noted, because upon this will depend to a great extent the length of the runs.

3. Measuring for material and calculating the amount of labor required. The former may be done by counting the number of boxes, fittings, etc. and by measuring the length of the runs. Calculating the time necessary to perform a job is a task which requires considerable experience and a study of the ability of the workmen. When measuring the quantities, notice must be taken of the height of ceilings and of the scale to which the plans have been drawn. Each run should be figured separately and checked. The items should be listed and grouped under their proper headings and sizes, in order that they may be totaled. The time for labor should be listed separately, the unit system being preferable, and totaled likewise.

4. Pricing the material and the labor, and check the estimate with the plans, specifications, and wiring layout. Pricing the material and the labor can be easily accomplished

after requirements for both have been listed and totaled. The next step is to check the estimate whether everything shown in the plans, specifications, and wiring layout has been considered and included. The items listed on the separate sheets are then combined in the same sheet which give the complete estimate and selling price.

I. WIRING LENGTH ESTIMATE

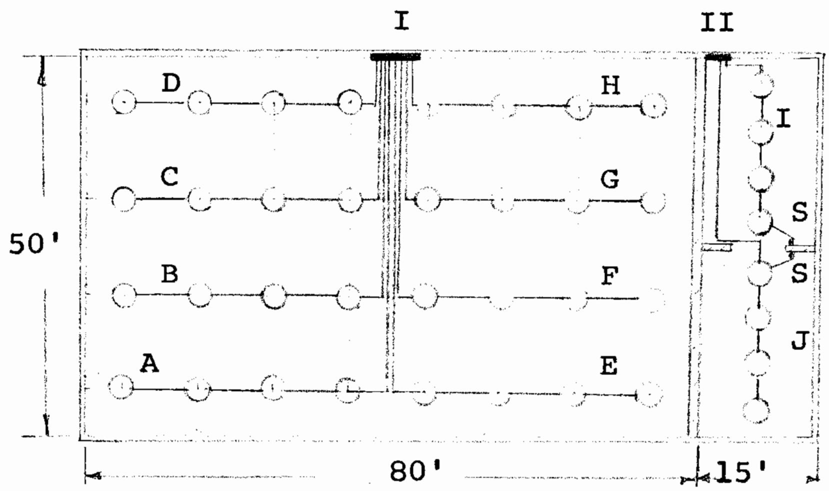


Fig. 38 Lighting System Layout.

<u>Starting at the main cabinet I:</u>

1. Figure the length of each run from beginning to end.

Circuit A,	approximate length	=	78	ft.
Circuit B,	" "	=	64	"
Circuit C,	" "	=	53	"
Circuit D,	" "	=	40	"
Circuit E,	" "	=	78	"
Circuit F,	" "	=	64	"
Circuit G,	" "	=	53	"
Circuit H,	" "	=	40	"
Therefore,	total of length	=	470	"

2. The vertical drops of each circuit down to the cabinet must be added. If the ceiling height is 15 ft., and the top of the cabinet is 5 ft. from each circuit; there are 8 circuits; therefore, total vertical drop = 8x10 = 80 ft.

3. The wire to be allowed inside of the cabinet for splices, slack, and connections should be about 2 ft. long for each run.

For 8 circuits, therefore, the total length: 8x2 = 16'.

4. Each outlet box requires slack of about one foot per run. For 32 outlets, therefore, the total length:

32 x 1 = 32 ft. Thus, the total length of wire required for the main cabinet:

470 + 80 + 16 + 32 = 598 feet.

<u>Starting at the smaller cabinet II</u>:

1 The length of each run:

Circuit I, approximate	length	=	25	ft.
Circuit J, "	"	=	50	"
Therefore, total length		=	75	"

2. Vertical drop of each circuit = 10 ft. For 2 circuits, total vertical crop = 2 x 10 = 20 ft.

3. The wire to be allowed inside of the cabinet for each run = 2 ft. For 2 circuits, total length = 2 x 2 = 4 ft.

4. Each outlet box requires 1 ft. per run. For 8 outlets, total length = 8 x 1 = 8 ft.

5. Vertical drop to the switch of each run is about 15 ft. For 2 circuits, total length = 2x15 = 30 ft. Thus, total length of wire required for the small cabinet:

= 75 + 20 + 4 + 8 + 30 = 137 ft.

Therefore, total length of wire required for both cabinets:

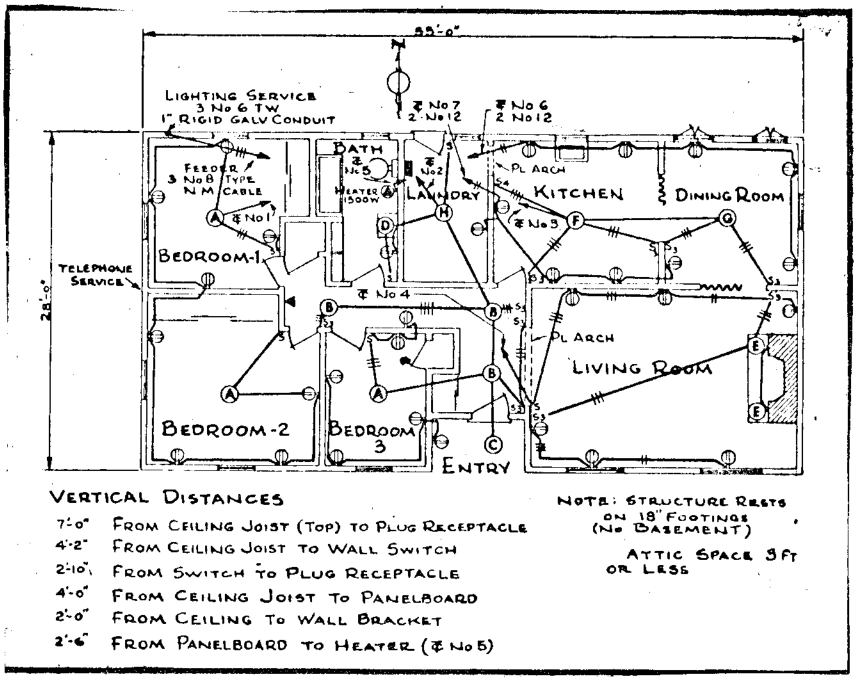
= 598 + 137 = 735 ft.

If the duplex wire will be used, the length of wire is 735 feet, but equal to 1,470 ft. if single conductor is used. The size of wire used can be considered by the method explained in Chapter VI, but one run of bigger size of duplex wire about 44 ft. long or 88 ft. of single conductor, will be required between the two cabinets, because this wire must carry the load of both two cabinets.

If the conduit is used, it may be figured as being the equal of the circuit runs (545 feet) plus the vertical drops to the cabinets and switches (100 ft.), plus sufficient length for bending and bringing it into the rear of the outlet boxes (70 ft.), making a grand total of 715 feet of the conduit. A piece of conduit, bigger than the one before abpit 4- ft. in length will be required for the wire providing between the two cabinets because the conduit is run on the same level and directly from one cabinet to another.

II. Sample of Total Wiring Estimate

The estimate shown below will not include pricing the material and the labor, since these two prices are variable and differ from place to place.



FIXTURE SCHEDULE

Circuit	Type A	B	C	D	E	F	G	H
1	2							
2	1	3	1	1				1
3						1	1	
4					2			

Fig. 39 Simple Plan from which Estimate is Prepared (Kennard, 1961, p. 234).

Branch Circuit Schedule

(This chart relates to Fig. 39)

Circuit	Location	Lighting Outlets		Switch Outlets			Receptacle Outlets		Spec.
		Ceiling	Bracket	SP	3-W	4-W	O	G	
1	Bedrm 1	1		1			4		
	Bedrm 2	1		1			4		
2	Bath		1	1			1		
	Laundry	1		1					
	Bedrm 3	1		1			4		
	Hall & Entry	4			4		1	1	
3	Kitchen	1			2	1			
	Dining room	1			2				
4	Living room		2	1	2		6		
5	Bath								1
6	Kitchen							2	
	Dining room							3	
7	Kitchen							3	
	Dining room							1	
	Laundry							1	

BRANCH CIRCUIT MATERIAL SCHEDULE

CIRCUIT	CABLE			BOXES				PLASTER RINGS						SWITCHES			PLUG RECEPTACLE		PLATES				WIRE NUTS	CONNECTORS	HANGERS	GRD STRAPS
	14-2	14-3	12-2	4" O	4" □	4 11/16"	SR	4" R	4" SQ	4" SS	4" 2G	4 11/16" R	4 11/16" S	SP	3-W	4-W	ST	GR	SS	2-G	PR	SP				
1	129'-0"	10'-8"		2			10	2						2			8		2		8		4		2	
2	152'-0"	35'-2"		4	3	1	12	4	2		1	1		3	4		5	2	5	1	6	1	14	2	7	2
3	53'-4"	44'-8"			1	1	5		1			1			4	1			5				4	2	2	1
4	78'-8"	76'-10"		1	3	1	5	1	1	2			1	1	2		6		1	1	6		4	2	2	
5	4'-6"																									
6			54'-0"				5											5			5					
7			54'-0"				5											5			5					
SUB-TOTAL	417'-6"	167'-6"	108'-0"																							
ADD 10% TO CABLE	42'-0"	17'-0"	11'-0"																							
TOTAL	459'-0"	184'-0"	119'-0"	7	7	3	42	7	4	2	1	2	1	6	10	1	19	12	13	2	30	1	26	6	13	3

ROUND FIGURES (arrows pointing to the TOTAL cable figures)

(This chart relates to Fig. 39).

(Kennard, 1961, p. 237).

CHAPTER IX

CONCLUSION

Lighting design is a combination of applied art and applied science. There are the large number of interrelated factors in lighting for which no single design is the correct one, and for this reason it is not entirely desirable to solve a lighting problem with a step-by-step technique. However, since this technique is the only help of approach to the uninitiated who lacks the experience necessary to view an entire solution, this approach is adopted.

The most simple goal of lighting is to create an efficient and pleasing interior lighting. Lighting levels should be adequate for efficient seeing, yet absolute uniformity is not required. On the contrary, moderate variations within acceptable brightness ratios in a given field of view are desirable to avoid monotony and to create perspective effects, and lighting should have proper quality.

With these goals, a lighting design procedure can be written to help the decision and solve the problem.

1. Analyze the lighting problem: this can be done by considering occupancy tasks, reflectances, brightnesses, lighting levels, and quality of light.

2. Select the lighting system: select type of fix-

tures and their candlepower distribution curve, consider effects of daylight, economics, and electric loads.

3. Calculate the lighting requirements: use the applicable calculation method as described in Chapter IV.

4. Design the supplementary lighting: if the supplemental lighting is desired in a particular area.

5. Review the resultant design: check for quality, quantity, aesthetic effect and originality.

This order of steps is not necessarily the same in each lighting design; however, it helps cope with problems which will be confronted by the designer.

For further research, the following topics are suggested in order to give more information and details to cope with problems in electrical lighting design.

1. Natural-light source. The question of what amount of the natural light illumination should be considered in lighting design may be raised. The proportion of our natural light coming from the sun and from the sky vary greatly. Its components will be different in different parts of the world, at different times of the year, at different times of the day, and under different atmospheric conditions. Because of the above variations, the research on "natural light source" that gives the best way to arrive at an acceptable value of average natural light illumination will be very useful and helpful in considering electrical lighting design.

2. Photometry and Photometers. All elementary photo-

metry is based on the assumption of a point source of will apply. This subject should be investigated. Besides, much attention is being given to the measurements of illumination in homes, offices, commercial houses, and the industries to insure adequate illumination for the particular tasks performed therein. Also for providing a check on a new installation, comparing different lighting systems, and securing information necessary to predetermine the details of a lighting installation, illumination measurements of surveys by photometers are necessary.

3. Light color. There remains the question of what and how color will be used. Color is a highly complicated subject, and there is wide variation in the response of people to a certain color. Colors in relation to lighting should be researched, together with the means and methods whereby light may be used to increase the appeal of merchandise, enhance architectural characteristics, emphasize an actor, dramatize a display, bring out the inherent beauty of colors, illuminate a waterfall, and for a variety of other purposes.

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APPENDIX A

ILLUMINATION LEVELS

(McGuinness, 1967, pp. 382-387)

APPENDIX B

COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS

(McGuinness, 1967, pp. 105-116)

APPENDIX C

ROOM INDEX

(McGuinness, 1967, pp. 402-403)