

**UNITED STATES COAST GUARD**

**AIDS TO NAVIGATION  
MANUAL**

**JANUARY 1953**



**CG-222**

**UNITED STATES  
GOVERNMENT PRINTING OFFICE  
WASHINGTON : 1953**



# Electric Lamps

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### 14-1 INTRODUCTION

#### 14-1-1 Diversity of Types

A. There are thousands of electric-lighted aids to navigation maintained by the Coast Guard. These aids are of numerous types depending on many factors such as voltage supplied, whether battery or commercial power is used, candlepower required, etc. Consequently it is apparent that if the most efficient lamp that could be obtained were to be used in each individual aid, the number of different types of lamps would be very great. In order to reduce the number of different types to a practical working minimum it is Coast Guard practice to often use a lamp which, although fairly efficient in a particular apparatus, is not necessarily the most efficient. This practice applies especially to types of apparatus of which there are only a limited number in service.

B. Only incandescent lamps are discussed in this chapter inasmuch as fluorescent, gaseous discharge or any other types of electric light sources have not yet been approved for use in aids-to-navigation work.

#### 14-1-5 Policy Regarding Special Lamps

A. It is the policy in the Coast Guard to refrain from the use of special lamps except where the use of a special lamp produces some outstanding advantage. A slight increase in efficiency is not of itself ordinarily considered justification for the use of a special lamp. By *special* in this sense is meant a lamp which is manufactured to a Coast Guard

specification and is used nowhere else except in an aid to navigation. Lamps such as railway signal lamps, locomotive headlight lamps, projection lamps, etc., are not considered to be special and are frequently used. These lamps are a standard product of industry, and are readily available at all times and at moderate cost.

#### 14-1-10 Reduction in Number of Types

A. As a result of the constant application of the policy expressed in part 14-1-5, the number of different lamps used by the Coast Guard in aids to navigation has dropped from literally hundreds to a total of a few dozen at the time of this writing. Tables I and II list the lamps most commonly used in aids to navigation service. The meanings of the various abbreviations in these tables are as follows:

Med.....	Medium Screw.
Mog.....	Mogul Screw.
Mog. Bip.....	Mogul Bipost.
S. C. Pf.....	Single contact, prefocus.
S. C. B. C.....	Single contact, bayonet candelabra.
B. D.....	Base Down.
B. D. to Hor..	Base down to horizontal.
Any-1.....	Any except within 45° of vertically base up.
Any-2.....	Any, but lumen maintenance best when burned vertically base up.
Any-3.....	Any within 60° of vertically base up or base down, but lumen maintenance best when burned vertically base up.

Other lamps, not listed in Tables I and II are occasionally used. However, the frequency of their use is too small to warrant inclusion in the table.



TABLE I.—30- to 120-volt lamps for aids-to-navigation use <sup>1</sup>

Item	Volts	Watts	Lumens	Bulb		Filament			Base		Life (hours)	LCL (inches)	
				Shape	Finish	Type	Width (cm.)	Height (cm.)	Brightness cp/cm <sup>2</sup>	Type			Burning position
1	30	1,000	25,500	T-20	Cl.	C-13	1.3	1.39	1,125	Mog. Bip.	B. D.	500	4.
2	32	36	340	A-19	Cl. or I. F.	C-5	.7	.8	65	Med.	Any.	1,000	2 3/16.
3	32	60	820	A-21	Cl. or I. F.	C-5	.6	.43	275	Med.	B. D. to Hor.	500	3.
4	32	100	1,560	A-21	Cl. or I. F.	C-5	.6	.49	490	Med.	Any-1	500	3.
5	32	250	4,475	P-25	Cl. or I. F.	C-5A	.8	.6	825	Med.	Any-1	500	3.
6	32	500	9,100	G-40	Cl. or I. F.	C-5	.8	1.0	1,255	Mog.	B. D. to Hor.	800	4 3/4.
7	120	56	525	P-25	Cl. or I. F.	C-5	1.0	1.0	55	Med.	B. D. to Hor.	1,000	2 1/16.
8	120	94	845	P-25	Cl. or I. F.	C-5	1.3	1.0	60	Med.	B. D. to Hor.	1,000	2 1/16, 2 3/4. <sup>2</sup>
9	120	100	1,105	A-21	Cl. or I. F.	C-5	.9	.7	160	Med.	B. D. to Hor.	800	3.
10	120	150	1,935	P-25	Cl. or I. F.	C-5	.7	.7	400	Med.	B. D. to Hor.	500	2 1/16, 2 3/4, 3. <sup>2</sup>
11	120	250	3,705	G-30	Cl. or I. F.	C-7A	2.4	.8	90	Med.	Any.	1,000	3.
12	120	250	3,750	P-25	Cl. or I. F.	C-5	1.0	.8	430	Med.	B. D. to Hor.	800	3.
13	120	250	3,750	G-30	Cl. or I. F.	C-5	1.0	.8	430	Mog.	B. D. to Hor.	800	3 3/8.
14	120	250	3,745	P-25	Cl. or I. F.	C-5	1.0	.8	430	Med.	B. D. to Hor.	500	3.
15	120	250	3,750	T-14	Cl.	C-5	1.0	.8	430	Med.	B. D.	800	3.
16	120	250	2,200	T-14	Cl.	4C-8	.6	2.6	190	Med.	B. D.	1,000	3.
17	120	300	5,760	PS-35	Cl. or I. F.	C-7A	2.5	1.0	125	Mog.	Any-2	1,000	7.
18	120	500	8,850	G-40	Cl. or I. F.	C-5	1.1	.97	795	Mog.	B. D. to Hor.	800	4 1/4.
19	120	500	9,900	PS-40	Cl. or I. F.	C-7A	3.2	.8	150	Mog.	Any-2	1,000	7.
20	120	500	8,420	T-20	Cl.	4C-8	.8	2.5	535	Mog.	B. D.	1,000	4 3/4.
21	120	500	7,035	T-20	Cl.	2C-5	1.7	1.4	240	Mog.	B. D.	1,000	4 3/4.
22	120	500	9,000	T-20	Cl.	C-13B	1.95	.98	375	Mog.	B. D.	800	4 3/4.
23	120	500	8,950	T-24	Cl.	C-13B	1.95	.98	375	Mog. Bip.	B. D.	800	4.
24	120	750	15,450	PS-52	Cl. or I. F.	C-7A	3.3	1.4	185	Mog.	Any-2	1,000	9 1/2.
25	120	1,000	21,400	PS-52	Cl. or I. F.	C-7A	3.3	1.4	260	Mog.	Any-2	1,000	9 1/2.
26	120	1,000	17,500	T-20	Cl.	4C-8	.56	2.6	1,635	Mog.	B. D.	1,000	4 3/4.
27	120	1,000	20,795	T-20	Cl.	CC-8	.4	4.0	1,035	Mog.	B. D.	1,000	4 3/4.
28	120	1,000	16,600	T-20	Cl.	2C-5	1.6	1.55	590	Mog.	B. D.	1,000	4 3/4.
29	120	1,000	20,500	T-20	Cl.	C-13	1.72	1.76	540	Mog. Bip.	B. D.	500	4.
30	120	1,000	21,100	T-20	Cl.	C-13	1.72	1.76	555	Mog.	B. D.	500	4 3/4.
31	120	1,500	32,550	PS-52	Cl. or I. F.	C-7A	3.0	3.4	300	Mog.	Any-3	1,000	9 1/2.

<sup>1</sup> Data furnished by Westinghouse Electric Corp.

<sup>2</sup> When ordering this lamp, LCL must be specified.

Corrected to 15 December 1954.

TABLE II.—3.5- to 12-volt lamps for aids-to-navigation use <sup>1</sup>

Item	Volts	Amps.	Watts	MSCP	Bulb	Filament		Base	Life (hours)	LCL (inches)
						Type	Height (cm.)			
1	3.5	1.0		2.5	S-8	C-8		S. C. Pf.	500	1 3/8
2	6.2	.25		1.0	S-8	C-8	0.31	S. C. Pf.	500	1 3/8
3	6.2	.46		2.0	S-8	C-8	.27	S. C. Pf.	500	1 3/8
4	6.2	.70		3.5	S-8	C-8	.43	S. C. Pf.	500	1 3/8
5	6.2	.92		5.0	S-8	C-8	.47	S. C. Pf.	500	1 3/8
6	6.2	1.40		8.5	S-8	C-8	.44	S. C. Pf.	500	1 3/8
7	6.2	1.84		11.0	S-8	C-8	.48	S. C. Pf.	500	1 3/8
8	6.2	2.80		19.0	S-11	C-8	.47	S. C. Pf.	500	1 3/8
9	12	.55		6.0	S-8	C-8	.70	S. C. Pf.	500	1 3/8
10	12	.77		9.0	S-8	C-8	.74	S. C. Pf.	500	1 3/8
11	12	1.15		17.0	S-8	C-8	.80	S. C. Pf.	500	1 3/8
12	12	1.35		21.0	S-8	C-8	.825	S. C. Pf.	500	1 3/8
13	12	2.03		33.0	S-11	C-8	.75	S. C. Pf.	500	1 3/8
14	12	3.05		49.0	S-11	C-8	.88	S. C. Pf.	500	1 3/8
15	3.5	.3		.5	S-8	C-2R		S. C. B. C.	1,000	1 3/4
16	4		3	2.0	S-11	C-2R		S. C. B. C.	1,000	1 3/4
17	6		10	9.0	S-11	C-2R		S. C. B. C.	1,000	1 3/4
18	8	.25		1.5	S-8	C-2R		S. C. B. C.	1,000	1 3/4
19	8		5	4.0	S-11	C-2R		S. C. B. C.	1,000	1 3/4
20	8		10	9.5	S-11	C-2R		S. C. B. C.	1,000	1 3/4
21	8		18	20.0	S-11	C-2R		S. C. B. C.	1,000	1 3/4
22	10	.25		2.0	S-8	C-2R		S. C. B. C.	1,000	1 3/4
23	10		5	4.0	S-11	C-2R		S. C. B. C.	1,000	1 3/4
24	10		10	10.0	S-11	C-2R		S. C. B. C.	1,000	1 3/4
25	10		18	20.0	S-11	C-2R		S. C. B. C.	1,000	1 3/4
26	10		25	28.5	S-11	C-2R		S. C. B. C.	1,000	1 3/4
27	12	.25		2.25	S-8	C-2R		S. C. B. C.	1,000	1 3/4

<sup>1</sup> Data furnished by General Electric Co.

NOTES.—(1) All lamps will operate in any position. (2) Filaments shown as C-2R may be either C-2R or C-2V.

Corrected to 15 December 1954.



## 14-2 LAMP CHARACTERISTICS

### 14-2-1 Differences Between Lamps

A. There are many ways in which lamps differ, the principal of which are:

- (a) Wattage (or amperage).
- (b) Voltage.
- (c) Bulb shape.
- (d) Type of filament.
- (e) Size of base.
- (f) Type of base.
- (g) Finish.
- (h) Rated life.
- (i) Color.
- (j) Efficiency.
- (k) Light center length.

To completely describe a lamp, all of (a), (b), (c), (d), (e), (f), (g), and (h), and sometimes (k) should be given, thus:

"1000-watt, 115-volt, PS-52 bulb, C-7A filament, mogul base, inside frosted, 1,000-hour life."

"1.4 ampere, 6.2-volt, S-8 bulb, C-8 filament, candelabra, prefocus base, clear, 500-hour life."

The meaning of the symbols for the base and filament are explained in subsequent paragraphs.

### 14-2-5 Wattage

A. The size of a lamp is usually indicated by its wattage. The Coast Guard uses lamps from as low as one watt in some small, unattended aids to as high as 2,000 watts in large lighthouses lenses. The majority however are in the lower wattage range.

B. Frequently lamps are rated in amperes rather than in watts, especially in the low voltage series of aids to navigation lamps commonly known as marine signal lamps. In such cases, since the voltage is always known, the wattage is easily determined from the formula,

$$P=EI$$

where P=power in watts  
E=voltage  
I=Current in amperes

An incandescent filament lamp constitutes an almost pure resistance load, consequently the formula applies to either direct or alternating current.

### 14-2-10 Voltage

A. The voltages that are more commonly used on aids to navigation are as follows:

B. 3.5 volts.—Used quite extensively on minor lights in the Intracoastal Waterway and in the Mississippi River and tributaries area where the optic consists of a 90 mm fresnel lens. This voltage also has limited application in certain railway signal apparatus which are used as range lanterns. The lamps are customarily operated from either five cells of caustic-soda, copper-oxide primary cells or from a T-2600 and a T-1600 air cell in series.

C. 4 volts.—Used in a large number of low intensity minor lights which are intended to be operated

from two lead acid storage cells. Many railway signal type range lights also use this voltage.

D. 6 volts.—This is the voltage of one size of lamp (10 watts) used in railway signal type range lanterns.

E. 6.2 volts.—This is a very commonly used voltage. It has wide spread use on minor lights. The exactness of the rating, i. e., *six point two*, was originally selected with the idea in mind that three lead acid cells would be used and that 6.2 volts represented the average voltage of three cells in series. It is used on one buoy which is of such small size that the weight of a 12-volt battery would be undesirable.

F. 8 volts.—Frequently used on railway signal type range lanterns.

G. 10 volts.—Frequently used on railway signal type range lanterns.

H. 12 volts.—Used on buoys and minor lights. When a C-8 filament lamp of this voltage is used in a conventional buoy lantern the vertical divergence of the resulting beam is adequate for satisfactory buoy performance. Except for the 3½ FE buoy using 6.2 volts, buoyage has been standardized on this voltage.

I. 14 volts.—A number of 14-volt installations have been made in the past. However, the regular use of this voltage on new installations is no longer approved since a 14-volt lamp gives almost identical performance as the more frequently used 12-volt lamp of corresponding wattage. Instructions have been issued to all districts using this lamp to convert to 12 volts. It is possible that in the near future 14-volt lamps will no longer be made by the lamp manufacturing companies.

J. 32 volts.—This is used at both minor and major lights. It is used at minor lights when the wattages are too high for the lower voltages and at major lights when a more concentrated filament is desired than would be available were a 120-volt lamp used.

K. 120 volts.—This is a standard commercial voltage as well as a typical voltage generated by locally installed Coast Guard power plant. In addition to 120 volts most lamps are usually available in 115 and 125 volts also. The performance of the 115-volt lamp or a 125-volt lamp is very similar to the performance of the 120-volt lamp. Only very slight differences in the filament dimensions, i. e., wire sizes and lengths, exist and in computing candlepowers or beam spreads these slight differences can be ignored. The technical data on 120-volt lamps can be used without appreciable error for either the 115-volt or the 125-volt lamps. All engineering studies of 115, 120, or 125 volt installations can be made on the basis of the same lamp performance data.

L. *Care in Ordering*.—When ordering lamps in the 115 to 125 volt range particular care should be exercised to select the exact voltage. Although a 115-volt lamp for example is very similar to a 125-volt lamp's being operated at 115 volts and the 125-volt lamp at 125 volts, or at least that the two are operated on proportional degrees of either undervolting or overvolting. There will be a considerable difference in performance between a 115-volt lamp and a 125-volt lamp if both are operating from the same voltage supply. At 115 volts, the 115-volt



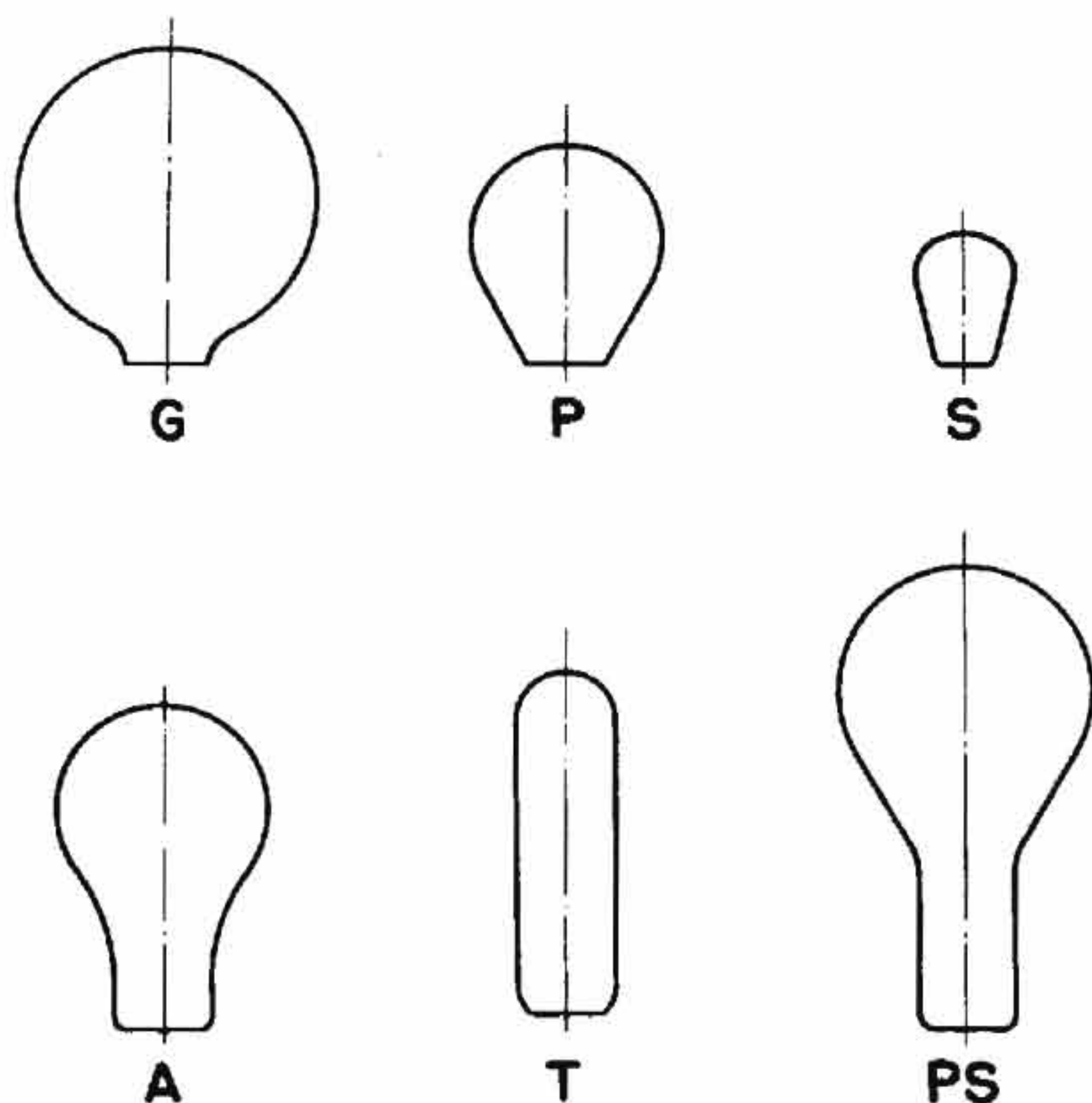


FIGURE 14-1.—Various bulb shapes.

lamp will perform as rated, while the 125-volt lamp will, as a result of its being undervoltaged, give considerably less light, last longer, and perform differently in many other respects.

The voltage at the lamp socket, and with the lamp in operation, should be checked frequently. It is on this voltage that the choice of lamps should be made. It can be expected that the line voltage will vary. While no hard and fast rule can be given to permit selecting the voltage for all possible patterns of voltage variations some guides can be given.

If the voltage is stabilized at a given value for long periods of the time the lamp should be selected for that voltage. If the voltage varies more or less uniformly, and between reasonable limits, the average of the limits will be selected. For very wide fluctuations in voltage the advisability of a voltage regulator should be investigated.

#### 14-2-15 Bulb Shape

A. The word *bulb* refers to the glassware portion of a lamp. Bulbs are identified by a letter or letters, and a number; typical examples are T-20 and PS-52. The letter is a designation which identifies the shape of the bulb while the number gives its approximate size in eighths of an inch measured through the largest diameter. Thus, a T-20 bulb is tubular in shape and about twenty eighths or  $2\frac{1}{2}$ " in diameter while a PS-52 bulb is pear shaped with a straight neck and about fifty-two eighths or  $6\frac{1}{2}$ " in diameter. Figure 14-1 shows the outline of the bulbs more commonly used in aids to navigation work.

B. The shape or size of a clear bulb has no effect on the optical performance of a lamp in a lens or other type of illuminating apparatus. Therefore, in selecting a clear lamp for use in an aid to navigation, the selection is made on the basis of the lamp's other properties. The only limitations on

the use of any type of clear bulb in so far as its physical size is concerned are the practical factors of whether or not the lamp will fit into the optic, permit the lampchanger to swing inside a lens, etc.

C. The shape of the bulb does however make an appreciable difference in the performance of a lamp when the bulb is frosted. This is due to the fact that frosting changes the size of the apparent light source from the dimensions of the bare filament to something larger. The amount and character of this change depends on the bulb shape.

#### 14-2-20 Filaments

A. Lamp manufacturers designate filament shape by a combination of letters and numbers; for example, C-13 or CC-8. The prefixed letter describes the form of the wire, i. e.

S. a straight wire (not coiled).

C. a wire wound into helical coil.

CC. a coiled coil. A helical coil is itself wound into a larger helix.

Numbers are used to arbitrarily designate the shape into which the wire is bent. Fig. 14-2 shows a number of types of filaments used in aids to navigation lamps.

B. Occasionally a letter is added after the number. This has a special meaning usually applicable only to the particular filament in question, the meaning not following any general rule. For example the C-7A filament is a modification of the C-7 filament, the A being added because the supporting arrangement differs from that of the C-7.

C. In some filament designations a numeral precedes the letter, for example 2C-5. This designates that the filament is similar to a C-5 filament except that two such filaments are electrically in parallel. Likewise a 4C-8 means four C-8 filaments in parallel.

D. In the case of some "special" lamps an unusual filament shape may be designated by the use of a descriptive word, for example "C-7A Saw-tooth."

E. The more common of the filaments used by the Coast Guard in aids to navigation work are as follows:

(1) *C-2 filament*.—This filament (Fig. 14-2) is used in an obsolete type of apparatus known as the "type D" range lantern manufactured by the General Railway Signal Co. It is used in a special, re-based, 3-pin lamp designed specifically for this lantern. Its use is not authorized in other than this lantern.

(2) *C-2R and C-2V filaments*.—Both of these filaments, (Fig. 14-2) are extensively used in reflector type, range light apparatus. The filament lies in a horizontal plane; thus the vertical divergence of the beam is a minimum. The longest dimension is positioned perpendicular to the optical axis, thus the entire filament is as nearly as possible in focus and the principal effect of the parts that are out of focus is to increase the horizontal divergence which is useful. Lamps with either of these filaments produce highly concentrated pencil beams. The C-2R filament is rounded while the C-2V is Vee shaped.

(3) *C-5 filament*.—This filament (Fig. 14-2) is very frequently used in 32-volt and 120-volt lamps.



It is used in drum lenses as a substitute for the C-8 filament lamp for the principal reason that if the C-8 filament were made in high voltages it would be very long and would give excessive divergence. The C-5 filament lamp is used also in a large number of assembled lenses of the smaller orders where the ratio of the size of the filament to the size of the optic is not too small to permit "filling" the lens. The width of a C-5 filament as reported by the lamp manufacturers and as listed in Table I, is the dimension X in fig. 5. The ratio  $Y \div X$  for C-5 filaments averages about  $\frac{5}{6}$ .

(4) The 2C-5 variation of this filament is illustrated in Fig. 14-2.

(5) There is a modification of the C-5 filament, known as the C-5A, the difference being that in the C-5 type two filament supports are used between coil sections, whereas in the C-5A type only one support used between coil sections.

(6) C-6 filament.—This filament (Fig. 14-2) has only infrequent use. It is used in certain range light apparatus designed in the former 3rd Lighthouse District, and known either as the *Third District range lantern* or the *diverged beam range lantern*. Its use in other than this piece of equipment is not authorized for aids to navigation use.

(7) C-7 filament.—This type of filament is used in medium size assembled lenses. It is large enough in plan to insure "filling" a lens which might not be adequately filled by the smaller C-5 filament of the same wattage and voltage. In flash panels it gives more horizontal than vertical divergence—a desirable feature. It has been used in two other variations known C-7A and C-7A Saw-tooth. Of the three, C-7A (Fig. 14-2) is the type currently approved for use.

(8) C-8 filament.—This filament (Fig. 14-2) was designed specifically for use in drum type fresnel lenses. It is used in practically no other application.

(9) The design of the C-8 filament meets the requirements of a drum lens most admirable. In the first place, the filament lies entirely in the vertical axis of the lens. Thus, although almost every point on the filament is theoretically out of focus, the resulting effect is one of uniformity around the complete horizon. The practical effect of the out-of-focus condition is therefore to produce uniform vertical divergence of the emitted fan beam. Some vertical divergence is desirable, especially on buoys. Furthermore, within the limits of the available ratios of filament height and lens diameters, the amount of the divergence is easily controlled.

(10) Another advantage to be gained from the use of the C-8 filament in a drum lens is the fact that the lens utilizes a very high percentage of the emitted light. Unlike the case of many other filaments, the candlepower distribution of the light from the C-8 filament is such that the highest intensities are projected in directions that will be intercepted by the lens. The light that is emitted in sectors above and below the lens is of low intensity. In other words, the brightest portions of the emitted light are utilized while only the weaker portions are wasted. This is illustrated by Fig. 14-3 which shows the vertical candlepower distribution curve of a typical C-8 filament lamp superimposed on a vertical

section thru a 200-mm. drum lens. Although the lens intercepts only about 70% of the area of the complete sphere surrounding the lamp, about 81% of the emitted light is utilized. The cross hatched portion of Fig. 14-3 represents the 19% of the emitted light which is wasted.

(11) All C-8 filament marine signal lamps are made with a single, spiral shaped support. This particular shaped support reduces the loss of luminous output of the lamp to a minimum when seen from any angle. Furthermore the loss is reasonably uniform around the horizon and consequently the horizontal candlepower distribution is likewise uniform.

(12) C-13 filament.—This filament (Fig. 14-2) is used in large pieces of equipment designed to produce pencil beams. It is a flat grid type of filament and is installed with the plane of the grid perpendicular to the axis of the beam. As a result of this arrangement a maximum utilization of the emitted light is obtained. Thus vertical divergence is a minimum. A variation of the C-13 filament includes the C-13B (Fig. 14-2), the variation consisting essentially of different height and width proportions.

(13) CC-8 filament.—This "special" filament (Fig. 14-2) was designed for lamps to be installed in a 375-mm. or 500-mm. lightship lens. The design was a result of an attempt to adhere to the shape of the C-8 filament, i. e., a narrow vertical source, to utilize a 120-volt supply, and to get an appreciable vertical divergence. The lamp is used in only a few applications and extension of its use is not encouraged.

(14) 4C-8 filament.—This is another "special" filament (Fig. 14-2). It is used on 120-volt supply at lightships where large divergence of the beam is desired and at some lighthouses where photometric tests have shown it to be suitable for "filling" an old style piece of apparatus. Like the CC-8 filament, extension of its use is not encouraged.

#### 14-2-25 Size of Base

A. The size of a lamp base is designated by a word, usually from the following; the word at the top of the list represents the smallest size and the word at the bottom the largest:

Miniature  
Candelabra  
Intermediate  
Medium  
Mogul

Of the above, the candelabra, medium and mogul sizes are regularly used for aids to navigation work. Fig. 14-4, which is drawn approximately to scale, shows these three sizes.

#### 14-2-30 Base Types

A. The four types of bases that have been used on lamps for aids to navigation use are:

Screw  
Bayonet  
Prefocus  
Bipost

Figs. 14-4, 14-5, and 14-6 show these types of bases. It is the practice in the lamp industry to omit the



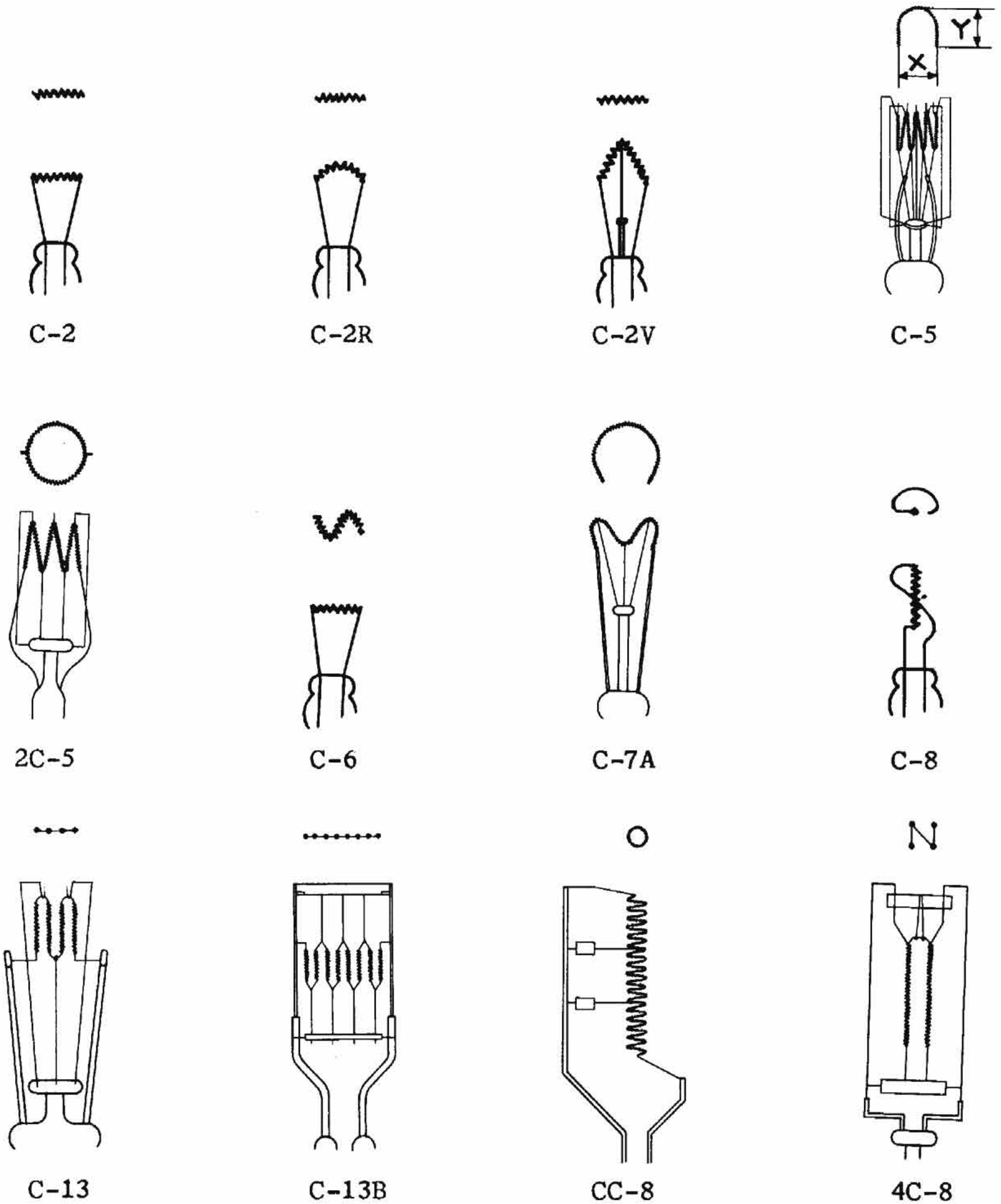


FIGURE 14-2.—Various Filaments.

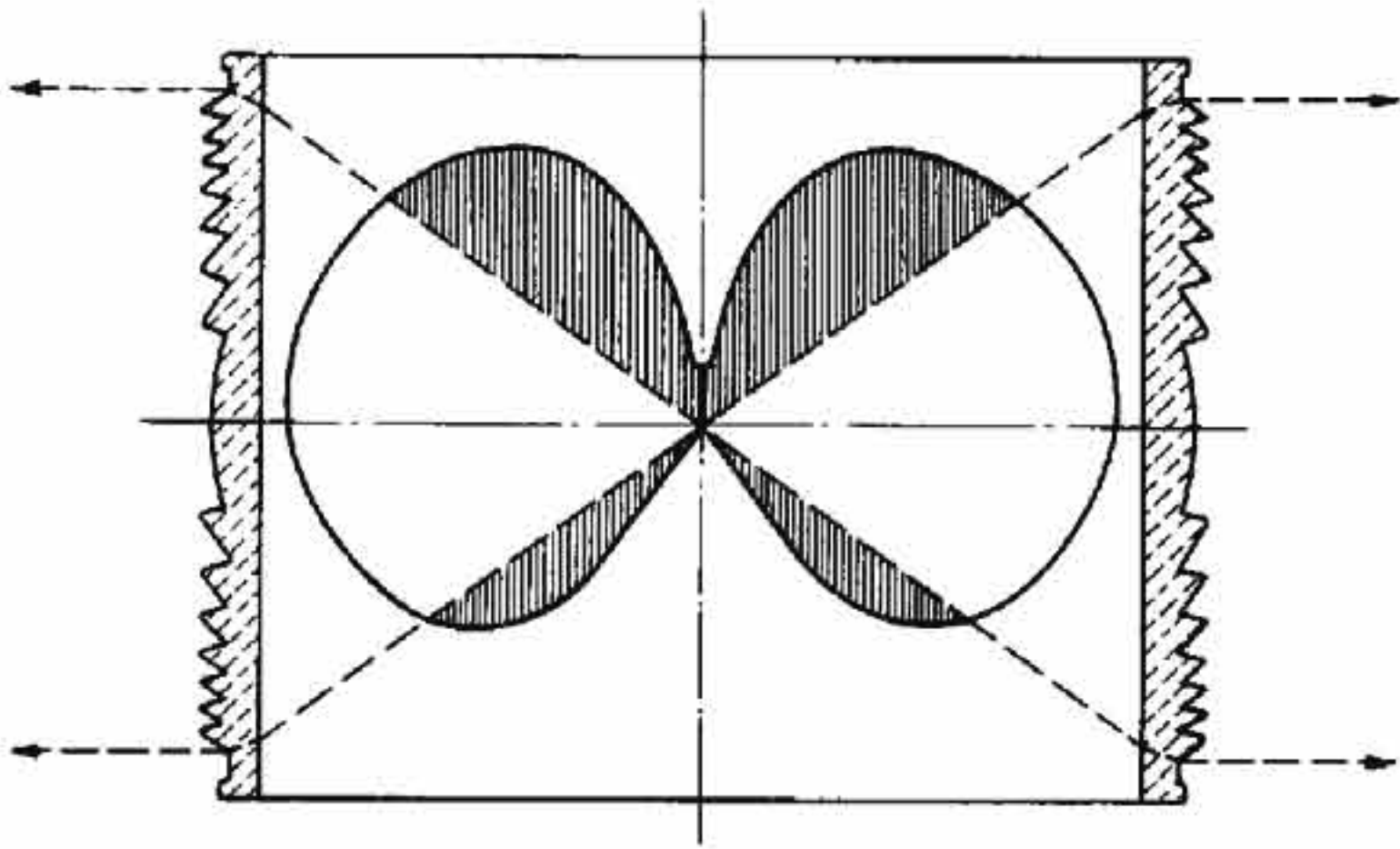


FIGURE 14-3.—Light distribution from a C-8 filament lamp in a drum lens.

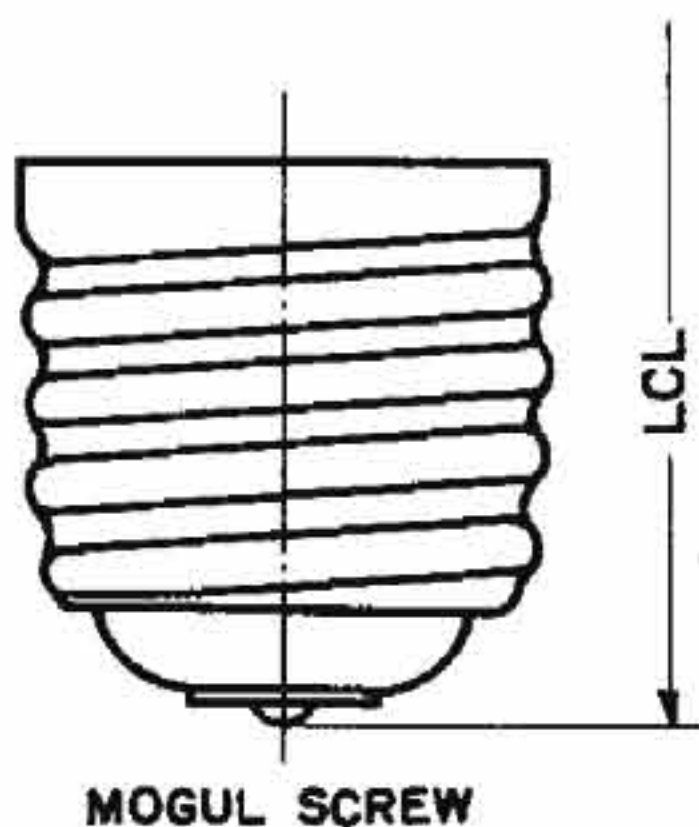
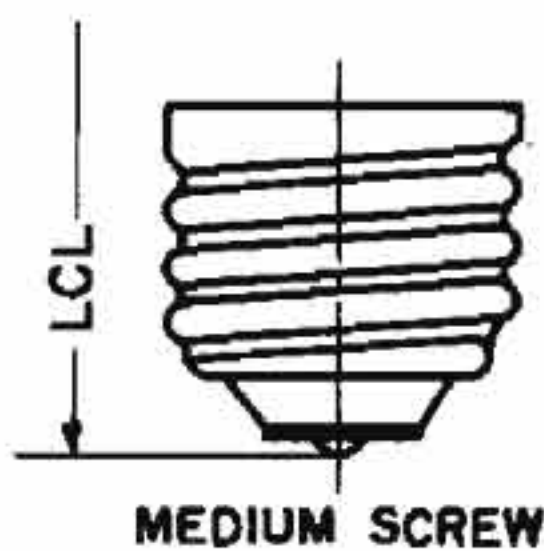
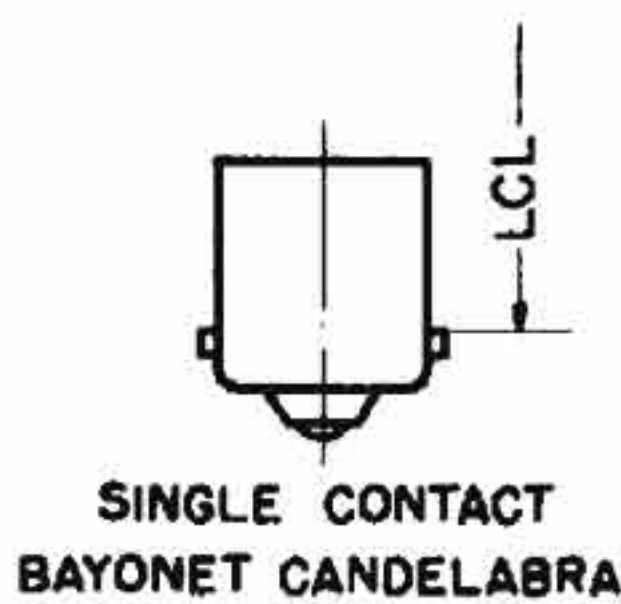


FIGURE 14-4.—Sizes of lamp bases (approx. full size).

word *screw* in describing a lamp with a screw base. Thus unless some specific mention were made to the words bayonet, prefocus, or bipost the lamp would be assumed to have a screw base. For example, the first of the two lamps described in paragraph 14-2-1 (A) is a screw base lamp.

B. *Prefocus base lamps* are used whenever precise focusing is of great importance. Such cases are found in small apparatus such as the 200-mm. lantern where a lampchanger is usually used and a slight error in the position of the light source as a new lamp swings into position can mean an appreciable change in the character of the beam. A prefocus base type of lamp is shown in Fig. 14-5.

D. *Bipost base lamps* are used where a definite orientation of the filament is required. The flat grid filament type of lamp such as shown in Fig. 14-2 which is used in apparatus designed to project a pencil beam is a good example of the use of this type base. Fig. 14-6 shows a bipost type of lamp base. This type base is available in either medium or mogul size.

E. *Bayonet base lamps* are used primarily for their ability to resist vibrations which could cause a screw base lamp to loosen. For standardization purposes many bayonet base lamps are installed where a screw base lamp could be used were it not for the fact that the corresponding bayonet base lamp is more readily available because of other commercial applications. The C-2R filament, S-11 bulb, bayonet base lamp used in certain types of range light apparatus is a good example of such use. Fig. 14-4 illustrates a bayonet type lamp base.

F. *Screw base lamps* are used where no need for one of the preceding three types exist. They are cheaper primarily because industry uses them in greater numbers than the others.

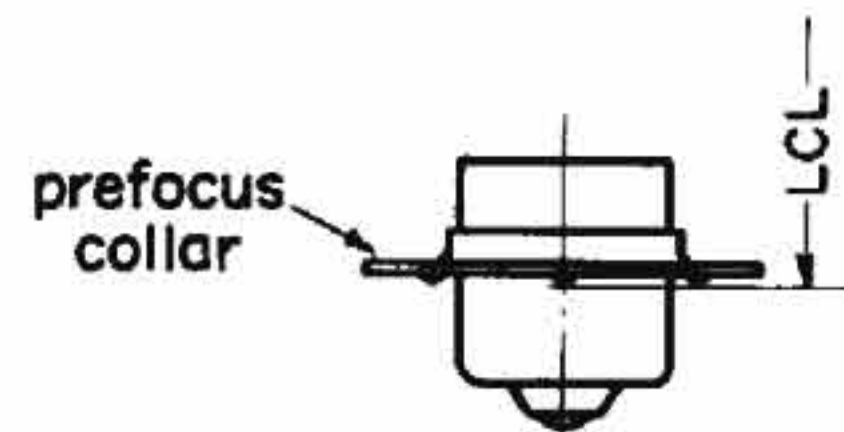


FIGURE 14-5.—Candelabra prefocus base (approx. full size).

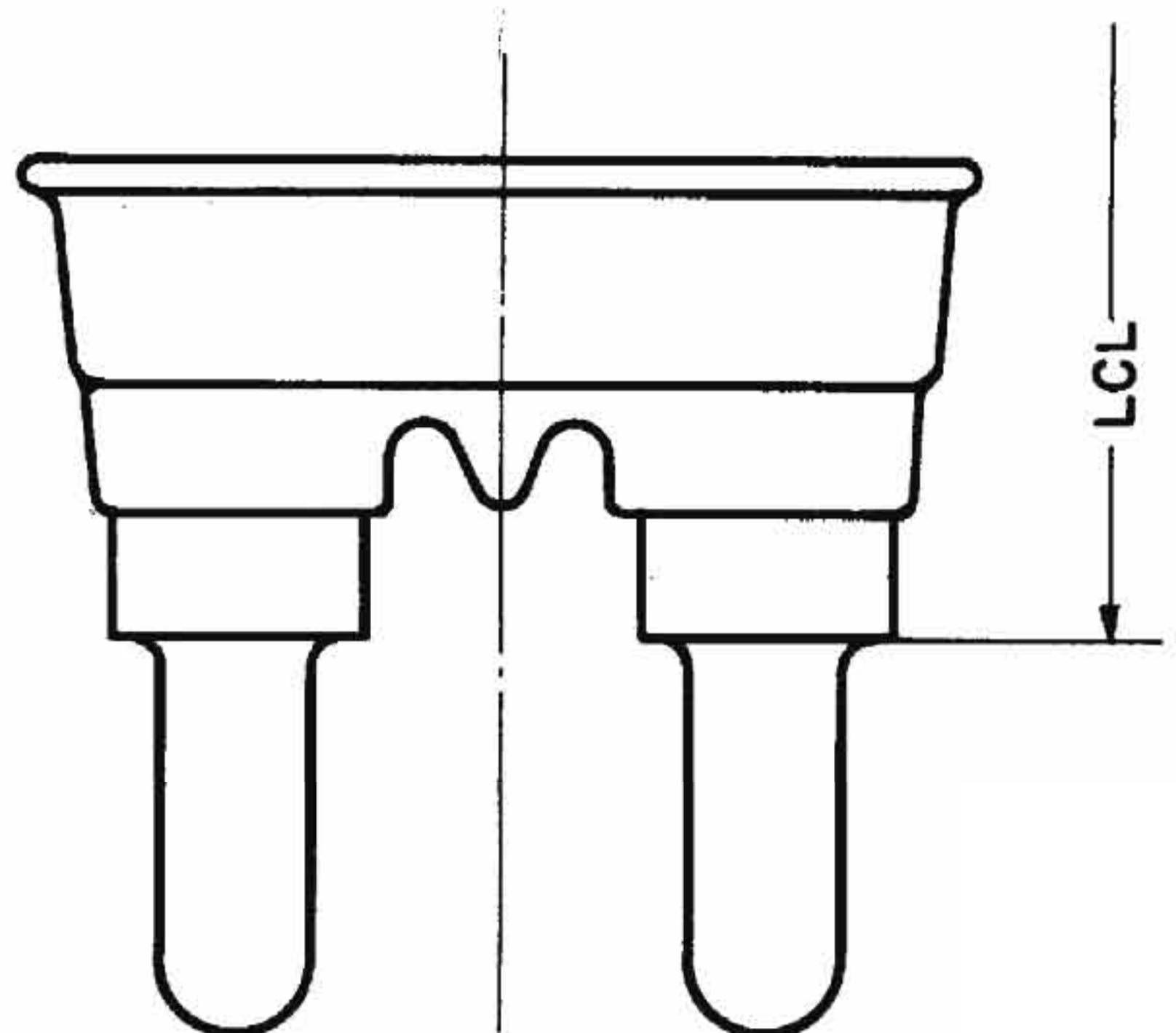


FIGURE 14-6.—Mogul bipost base.



## 14-2-35 Finish

A. *Finish* is the term used to describe the surface treatment the manufacturer gives to a bulb. The finish may be any of (1) *clear*, (2) *inside frosted*, or (3) *outside frosted*. Of these three types, the number of clear lamps used in navigational aids is by far in excess of the total of the other two combined.

B. The effect of frosting a lamp bulb is to change its appearance from an intensely bright and concentrated source to one that is larger in size but less intense. Outside frosting makes the entire surface of the lamp glow more or less uniformly as viewed from any angle. Inside frosting has the effect of increasing the dimensions of the apparent source of some two to four times the dimensions of the area outlined by the naked filament.

C. Since frosting a lamp bulb always decreases its brightness, the advantage of using a clear lamp in order to get a high candlepower beam is obvious. A second advantage of the clear lamp over the frosted lamp lies in its slightly higher luminous efficiency. A very small amount of light is lost by absorption when inside frosting is resorted to, while a somewhat larger amount is lost if outside frosted. The relative efficiencies of the same lamp with different finishes are about as follows:

Clear .....	100%
Inside frosting.....	98%
Outside frosted.....	96%

D. *Inside frosted lamps* are very frequently used where the filament in a clear bulb would be too small to "fill" a large lens. This is particularly true in the case of the old type, large order lenses which were designed originally for oil lamps—either IOV or wick type—in which the various prisms of the middle, upper and lower sections were all designed for different focal points. The brightness of the oil flame sources varied considerably over their own surfaces and the location of the *hot spot* as seen from one direction differed from the location when viewed from another direction. Consequently the designers of these old style lenses positioned each individual prism in the lens in such a manner that its focal ray originated from the direction of the brightest portion of the flame.

E. The change from a clear bulb to an inside frosted bulb affects a lamp's performance in two important respects:

(1) The dimensions of the apparent source, both height and width, are increased over the dimensions of the bare filament. Thus the divergence of the beam emitted from the apparatus is likewise increased. This applies to both the vertical and the horizontal divergence.

(2) The brightness of the lamp decreases and, as a consequence, the candlepower of the beam is very much reduced.

F. Very little authoritative data are available on the quantitative effect that frosting has on a filament's apparent dimensions and brightness. Some approximate values are however available and are listed in Table III.

TABLE III.—Apparent increase in filament dimensions and decrease in brightness caused by inside frosting

Description of lamp				Ratios of filament dimensions inside frosted to clear lamp		
Volts	Watts	Fil.	Bulb	Width	Height	Brightness
32	60	C-5	A-21	1.5	1.5	0.444
32	100	C-5	A-21	1.5	1.5	.444
120	100	C-5	A-21	1.5	1.5	.444
120	56	C-5	P-25	2.0	1.5	.333
120	94	C-5	P-25	2.0	1.5	.333
120	150	C-5	P-25	2.0	1.5	.333
120	250	C-7A	G-30	2.0	1.5	.333
120	250	C-5	G-30	2.5	2.5	.160
32	250	C-5A	P-25	2.5	2.5	.160
120	250	C-5	P-25	2.5	2.5	.160
120	300	C-7A	PS-35	2.5	2.5	.160
120	500	C-5	G-40	2.5	2.5	.160
120	500	C-7A	PS-40	2.5	2.5	.160
120	750	C-7A	PS-52	2.5	2.5	.160
120	1,000	C-7A	PS-52	2.5	2.5	.160
120	1,500	C-7A	PS-52	2.5	2.5	.160
32	500	C-5	G-40	3.0	3.0	.111

G. *Problem*.—A 250-watt, 120-volt, C-7A filament, G-30, clear lamp, has a filament height of 0.8 centimeter, width of 2.4 centimeters and brightness of 90 candles per square centimeter. What are the height, width and brightness of the source if the lamp is inside frosted?

H. *Solution*.—(a) From Table III, the height factor is 1.5; the height of the source when inside frosted is therefore:

$$1.5 \times 0.8 = 1.2 \text{ centimeters ANS.}$$

$$(b) \text{ Width} = 2.0 \times 2.4 = 4.8 \text{ centimeters ANS.}$$

$$(c) \text{ Brightness} = .333 \times 90 = 30.0 \text{ candles per cm}^2 \text{ ANS.}$$

I. *Outside frosted lamps* are rarely used. However, since outside frosting causes the entire outer surface of the bulb to act as the light source such lamps may have occasional use where very large light sources are required, as in one of the very largest lenses, in order to insure "filling" it, and also in flash panels where it is desired to increase the length of flash.

J. *Problem*.—In order to increase the length of flash from a revolving four panel fresnel lens, an outside frosted 115-volt, 500 watt, C-5 filament G-40 lamp is used. What will be (1) the change in the width of the source, and (2) the brightness, as a result of outside frosting?

K. *Solution*.—(1) The clear lamp has a filament width of 1.1 centimeters and a height of 0.97 centimeters. Outside frosting will increase the light source width to the full width of the bulb, i. e. about 40+8 or 5 inches. The increase in width is therefore

$$\frac{5 \times 2.54}{1.1} = \text{about } 11.5 \text{ ANS. Thus the flash length}$$

using the outside frosted lamp will be about 11.5 times as long as the flash length using the clear lamp.

(2) The brightness will decrease in proportion to the increase in the projected area of the source. As an approximation, the filament in the clear lamp is about  $1.1 \times 0.97$  or  $1.07 \text{ cm}^2$  projected area. The bulb is  $\frac{\pi}{4} (2.54 \times 5)^2$  or  $127 \text{ sq. cm.}$  projected area.



The brightness will be thus reduced from 795 to:

$$795 \times \frac{1.07}{127} = 6.7 \text{ candles per cm}^2 \text{ ANS.}$$

L. Filaments in frosted lamps are not ordinarily visible. Consequently it is somewhat difficult to identify the filament in one of these lamps. However, if it is necessary to determine the type filament of an inside frosted lamp at any time the following procedure may be used:

(1) Select a piece of cardboard larger in size than the entire bulb.

(2) Pierce a small hole in the center of the cardboard, about  $\frac{1}{8}$ " in diameter for the larger lamps and proportionately smaller for lamps of lesser size.

(3) Place the cardboard so that the hole is close to another bright light.

(4) Place the frosted lamp in front of the cardboard and in line with the light beam emitted from the small hole in the cardboard. When properly done the outline of the filament will become clearly visible.

#### 14-2-40 Rated Life

A. The rated life of a lamp is defined as the average number of hours that a large number of that particular type of lamp will burn at rated voltage before failure.

B. Incandescent lamps are designed for a certain rated life at a given voltage. However, in spite of rigid care taken in manufacture and test, it is not possible to control the life of an individual lamp within narrow limits. This would be true even were the lamp to be burned at precisely its design voltage and were it to be free from vibration during its operation, or from mechanical injury due to shock during handling, shipping, etc. Consequently, if a lamp is rated at 500 hours, it would be an extremely

dangerous practice to arrange a servicing schedule on the basis of an assumption that 500 hours will always be obtained. The lamp may only last 400 hours. On the other hand it is almost equally likely to last 600 hours. The 500-hour life will be obtained only as the *average* of very many lamps.

C. Fig. 14-7 illustrates a typical *lamp mortality curve* for 115 to 125 volt lamps. Approximately, although not exactly, half of the lamps burn out before reaching their normal life, and about half exceed normal life. The majority fail within 25 percent plus or minus of rating.

D. When a lampchanger is used, the various lamps burn successively and the mortality curve for the combination of lamps is appreciably different as a result of this successive burning. The effect of burning two or more lamps in succession, rather than simultaneously, is to improve the shape of the mortality curve. It more nearly approaches the ideal shape which is represented by the lines a, b, c, d in Fig. 14-8. The curves, which are based on low voltage lamps, shows how the use of a four-lamp lampchanger reduces the probability of the average of four lamps burning out at less than rated life as compared with the probability of any one lamp burning out at less than rated life. Theoretically, with an infinite number of lamps in a lampchanger the ideal curve a, b, c, d would be reached. From a practical viewpoint as many as 17 lamps in one changer has been successfully used in the Wallace & Tiernan device known popularly as the "daisy-chain."

E. The use of a lampchanger thus can be seen to accomplish two things:

(1) It increases the total rated hours of operation before failure.

(2) It increases the probability that the number of rated hours will be obtained.

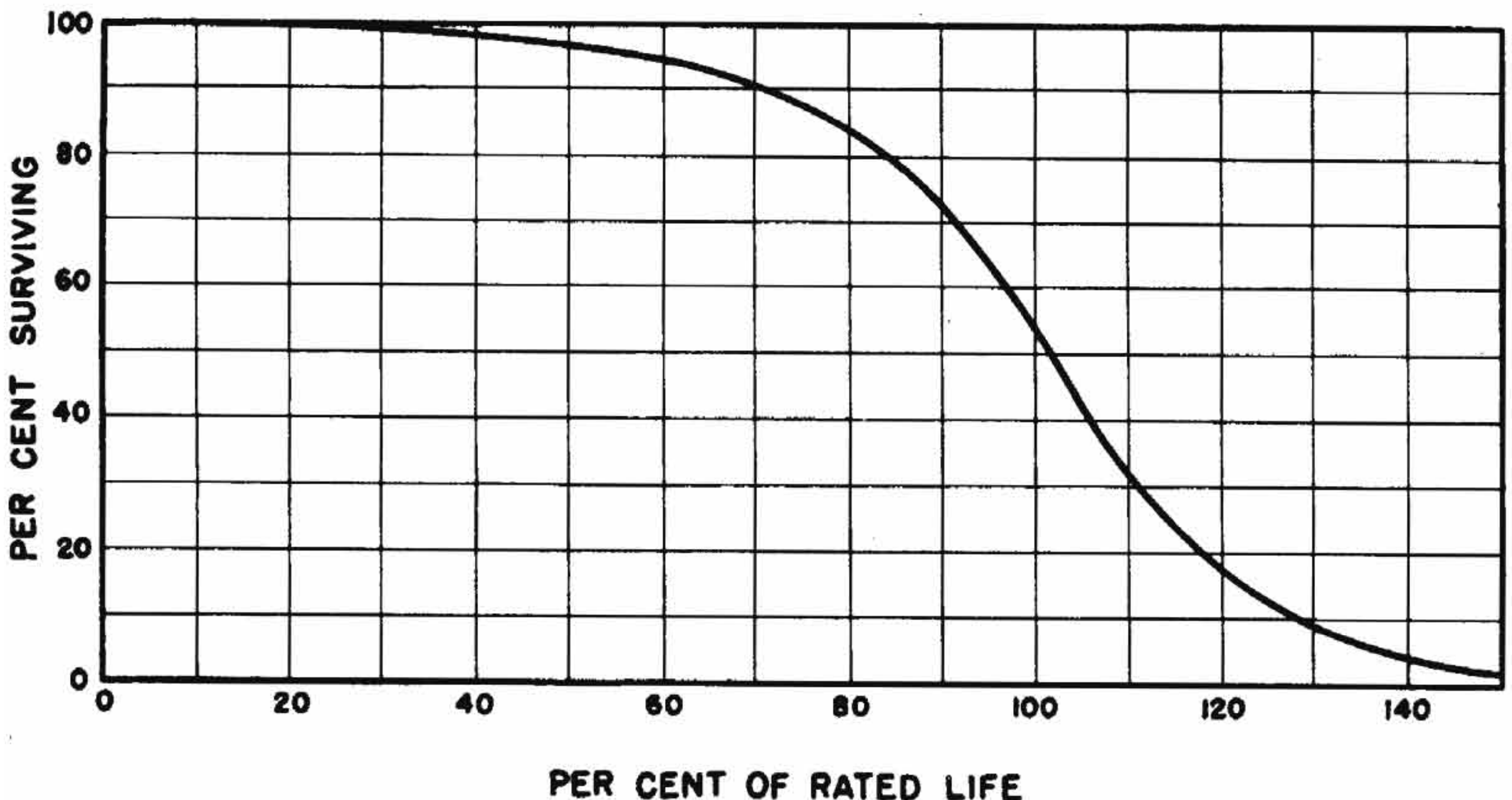


FIGURE 14-7.—Typical mortality rate of 115 to 125 volt lamps.



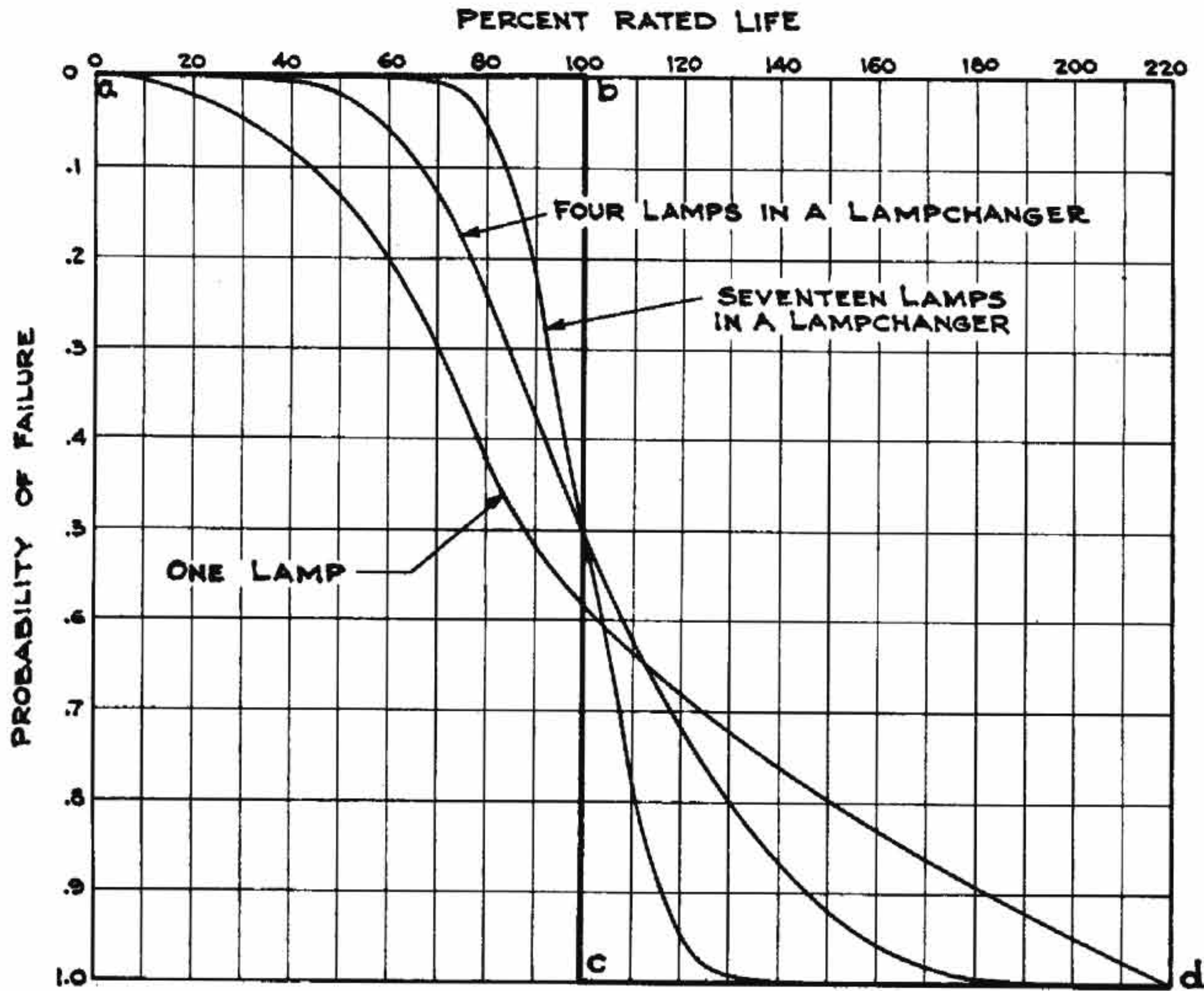


FIGURE 14-8.—Mortality rate of low voltage lamps.

F. Figs. 14-7 and 14-8 are applicable regardless of whether or not the lamps are burned at rated voltage provided all lamps are burned at the same voltage. For example, the curve of Fig. 14-7 shows that if a batch of 1,000-hour life lamps are burned at rated voltage, 90% will survive to 70% of rated life, i.e. to 700 hours. If the same batch of lamps were to burn at say 10% undervoltage, the average life would be 4,000 hours rather than 1,000 hours. The curve still applies; 90% will survive to 70% life which now is 2,800 hours.

G. Rated life is an important item to consider in studying a lamp's performance. As will be shown later, when a given lamp is operated at higher than rated voltage, considerably more than its normal light output is obtained. However, the life is reduced correspondingly. Thus in comparing two lamps of the same voltage and wattage, care must be taken to see that the life ratings are the same, or at least that this factor is properly evaluated.

H. It is evident from the lamp mortality curves of Figs. 14-7 and 14-8 that occasional lamp failures must be expected even within a few hours after the lamps are placed in service. It is only the performance of the average which can be predicted with a fair degree of accuracy over an appreciable period of time. Very little as to the cause of failures can be determined from inspection of a few lamps that have failed except in such obvious cases as a loose base, a broken lead wire, a defect in the bulb causing leakage of air into the bulb, etc. If it is suspected

that a shipment of lamps is performing unsatisfactorily, samples of both burned and unburned lamps from the shipment should be returned to the manufacturer for tests and check. Generally, however, the best information for arriving at accurate conclusions on lamp performance is a record of lamp failures in service. If it is found that the actual life of an appreciable quantity of lamps, differs percentagewise from the mortality curves, the manufacturer should be informed and given all facts relating to operating conditions.

**14-2-45 Efficiency**

A. A lamp's efficiency is usually expressed in terms of lumens per watt. The lumens per watt for a tungsten incandescent filament lamp depends upon the temperature to which the filament is heated. In general, the greater the wattage or the lower the voltage, the higher will be the lumens per watt since the higher wattage or lower voltage lamps have heavier filaments which can be heated to higher temperatures without increasing the probability of burning out.

B. Occasionally the efficiency of a lamp is expressed in terms of mean spherical candlepower per watt. The relationship between mean spherical candlepower and lumens is given by the formula,

$$L = 4\pi I$$

In which *L* is the number of lumens and *I* is the mean spherical candlepower. Lamp efficiencies range from about 10 lumens per watt in small size



lamps to about 25 lumens per watt in the larger sizes. Precise values can be computed from the data of Tables I and II.

C. *Problem.*—A 1,000-watt, 120-volt, 2C-5 filament, T-20 lamp has a mean spherical candlepower output of 1320. What is the luminous efficient?

D. *Solution:*

$$\begin{aligned} L &= 4\pi I \\ &= 4\pi 1320 \\ &= 16,600 \text{ lumens} \\ &= 16.6 \text{ lumens per watt. ANS.} \end{aligned}$$

#### 14-2-50 Light Center Length

A. Light center length usually referred to as LCL, is the distance from the center of the filament to the point shown below the base used:

- |                     |  |
|---------------------|--|
| All screw Bases     | —The bottom of the base contact.                               |
| Mogul Bipost        | —The shoulder of the post.                                     |
| Bayonet Candleabra  | —The top of the base pins.                                     |
| Prefocus Candelabra | —The plane of the locating bosses of the pre-focussing collar. |

Figs. 14-4, 14-5 and 14-6 show the locations of these points.

B. Light center length of a lamp is extremely important in any application where precision focusing of the filament is involved. In the case of many small optics where even a slight mislocation of the filament can cause a considerable reduction in beam candlepower, special rebased lamps are used to insure a degree of precision over and beyond that obtained with usual manufacturing tolerances.

C. Light center length of a lamp is an especially important feature in installations where a lamp changer is used. Unless the light center lengths of the lamp were consistently uniform, every time a lampchanger was filled with new lamps it would be necessary to adjust the base receptacle for each lamp to insure that all lamps would swing into focus as burn outs occurred.

D. When a change is made from one type of lamp to another in any optic care should be taken to see that the LCL's are the same. If they differ, then an investigation of the lamp holding apparatus should be made to determine whether or not the limits of adjustment, if any, are sufficient to permit focusing the new lamp.

E. As an example of the effect of neglecting the above, suppose the Officer-in-Charge of a light station is directed to change over from a 250-watt, 115-volt, G-30, C-5 filament, mogul base lamp to a 500-watt lamp of the same type. The bulb shapes are the same; the bases are identical; and the physical sizes are somewhat comparable, the 500-watt lamp being but slightly larger. An uninformed person could easily make the mistake of substituting the 500-watt lamp for the 250-watt lamp without making any refocusing adjustments. Yet the light center lengths of the two lamps are  $3\frac{3}{8}$ " for the 250-watt size and  $4\frac{1}{4}$ " for the 500-watt size. The difference,  $\frac{7}{8}$ ", will make an appreciable difference in the performance of the lens. Raising the light

source  $\frac{7}{8}$ " in a 375-mm. lens will depress the beam  $6\frac{1}{2}^\circ$ . The result of depressing most beams  $6\frac{1}{2}^\circ$  would be to direct the light towards the water very close to the lighthouse and reducing the beam intensity on the horizon to only a few percent of the maximum beam intensity.

#### 14-2-55 Color

A. Clear lamps, which give a white light, are the only ones authorized for regular aids to navigation use in the Coast Guard. Where a red or green beam is required color filters or colored lenses are employed. Colored lamps should never be purchased, or used, except in a rare emergency.

#### 14-2-60 Burning Position

A. Many lamps are designed to be burned in only one position, some lamps can be burned over a range of positions, while other lamps can be burned in any position. For example, a lamp with a C-13 filament or a C-13B filament has the filament supporting arrangement so designed that the lamp must be burned base down. Were it to be burned base upward reduced life would result. A number of C-5 filament lamps can be burned base down or rotated to  $45^\circ$  from the vertical base up position. Others like C-6 or C-9 can usually be operated in any position.

B. There are many lighthouses at which the mounting of the electric lamp in the main lens is a matter of suspension from overhead. If these, as well as in similar cases, care should be taken to select a lamp that will burn properly in the position indicated. Fig. 14-2 illustrates a lamp filament the C-6 which is so supported that it can be burned in a base up position as well as any other position.

C. Tables I and II give details of the manufacturer's recommended burning positions for lamps used in aids to navigation.

#### 14-2-65 Brightness

A. Brightness of a light source, often called luminance, is the intensity per unit of projected area. Lamps used for aids to navigation service, including the lamps in Table I, usually have the brightness of these filaments expressed in the unit *candles per square centimeter*, frequently spoken of as *candlepower per square centimeter*. This unit is also known as the stilb. (The name stilb has been adopted by the International Commission on Illumination, and is commonly used in European publications.)

Table I includes a tabulation of brightnesses. In general the brightnesses in the table were calculated on the basis of the following assumptions:

- The projected area is the mean of the areas of the envelopes as projected on the horizontal and the vertical planes, i. e.:

$$A = \frac{A_v + A_H}{2}$$

- The candlepower is the mean spherical candlepower, i. e.:

$$CP = \frac{\text{Lumens}}{4\pi}$$



In the case of the C-5 filament, the dimension which is listed in the table as the width, is the dimension *X* of figure 14-2. Dimension *Y* is about  $\frac{5}{6}$  of *X*. In calculating  $A_H$  and  $A_V$  for this filament the average of *X* and *Y*, i. e.  $\frac{1}{2}$  of *X* was taken as the diameter of a circle which represented the equivalent light source. For example, the brightness of item 12 of the table was calculated as follows:

$$W = 1.0 = X$$

$$Y = \frac{5}{6} = X \frac{5}{6} \times 1.0 = 0.833 \text{ cm.}$$

$$\text{Average of } X \text{ and } Y = \frac{1.0 + 0.833}{2} = .917 \text{ cm.}$$

$$A_H = \frac{\pi}{4} (.917)^2 = 0.66 \text{ sq. cm.}$$

$$A_V = .917 \times .80 = 0.734 \text{ sq. cm.}$$

$$A = \frac{A_H + A_V}{2} = \frac{0.66 + 0.734}{2} = 0.697 \text{ sq. cm.}$$

$$CP = \frac{3750}{4\pi} = 298$$

$$\text{Brightness} = \frac{298}{.697} = 430 \text{ Candlepower sq. cm. (approx.)}$$

A few filaments have had their brightnesses computed using only the projection on the vertical plane. These include the various C-13 types, and the CC-8.

### 14-3 LAMP PERFORMANCE

#### 14-3-1 Essential Information

A. The most essential information that should be known in regard to the performance of a lamp that is to be used on an aid to navigation is data relative to the luminous output, the life, the energy consumption, and the color characteristics. If a lamp is operated at rated voltage and at a steady (non-flashing) rate, this information is obtained from the manufacturer's ratings and published

data; for Coast Guard aids to navigation use such ratings and data are usually accepted as facts and used without any test or other verification. Manufacturers' data on the more commonly used aids to navigation lamps are listed in Tables I and II. In using these data it should be appreciated that lamps manufactured in small lots, as are the majority of lamps used in aids to navigation, can vary in performance as follows: candlepower plus or minus 20%; amperes plus or minus 10%; efficiency in lumens per watt plus or minus 15%.

B. When operated at a voltage other than its design voltage or when operated flashing instead of fixed, a lamp's performance is in many respects considerably different than when burned steady and at rated voltage. The effects and changes in voltage or operation on a flashing characteristic have on various phases of lamp performance are described in the following paragraphs.

#### 14-3-5 Effect of Voltage Change in General

A. A change in voltage has a very pronounced effect on the operating characteristics of a lamp. All lamps are sensitive to even slight voltage changes. With an increase of voltage the light output is increased, the life is reduced, the wattage and the amperage are increased, while a larger proportion of blue or green light and a small proportion of red light are emitted. On lowering the voltage the reverse is true.

This effect is illustrated by Fig. 14-9 which is applicable to any gas filled 115-volt incandescent lamp and which can also be used with but negligible error for the smaller, low voltage marine signal lamps used in aids to navigation equipment.

B. Because of the frequent use made of the performance curves of Fig. 14-9, data from them has been tabulated in Table IV. This table is to be used for all calculations regarding aids to navigation lighting problems. In using the table the following rules are to be strictly adhered to:

TABLE IV.—Change in performance of incandescent lamps due to a change in voltage supply

% Volts	% C. P.	% Life	% Amps	% Watts	% Ohms	% Volts	% C. P.	% Life	% Amps	% Watts	% Ohms
71	28	8,800	83	59	85	96	88	170	98	94	98
72	30	7,400	84	60	86	97	91	150	98	95	99
73	32	6,200	84	62	87	98	94	130	99	97	99
74	33	5,100	85	63	87	99	97	110	99	98	100
75	35	4,300	86	64	88	100	100	100	100	100	100
76	37	3,600	86	66	88	101	103	88	101	102	100
77	39	3,100	87	67	89	102	106	77	101	103	101
78	41	2,600	87	68	89	103	110	68	102	105	101
79	43	2,200	88	70	90	104	114	60	102	106	102
80	45	1,900	89	71	90	105	118	53	103	108	102
81	48	1,600	89	72	91	106	122	47	103	109	103
82	50	1,300	90	74	91	107	125	41	104	111	103
83	52	1,100	90	75	92	108	129	36	104	113	104
84	54	980	91	76	92	109	133	32	105	114	104
85	57	840	92	78	93	110	137	29	105	116	104
86	59	720	92	79	93	111	142	25	106	117	105
87	62	620	93	81	94	112	146	23	106	119	105
88	64	530	93	82	94	113	151	20	107	121	106
89	67	460	94	84	95	114	155	18	107	122	106
90	70	400	94	85	95	115	159	16	108	124	107
91	73	340	95	86	96	116	163	14	108	126	107
92	75	300	96	88	96	117	167	13	109	127	107
93	78	260	96	89	97	118	172	11	109	129	108
94	81	220	97	91	97	119	177	10	110	131	108
95	84	200	97	92	98	120	182	9	110	132	109



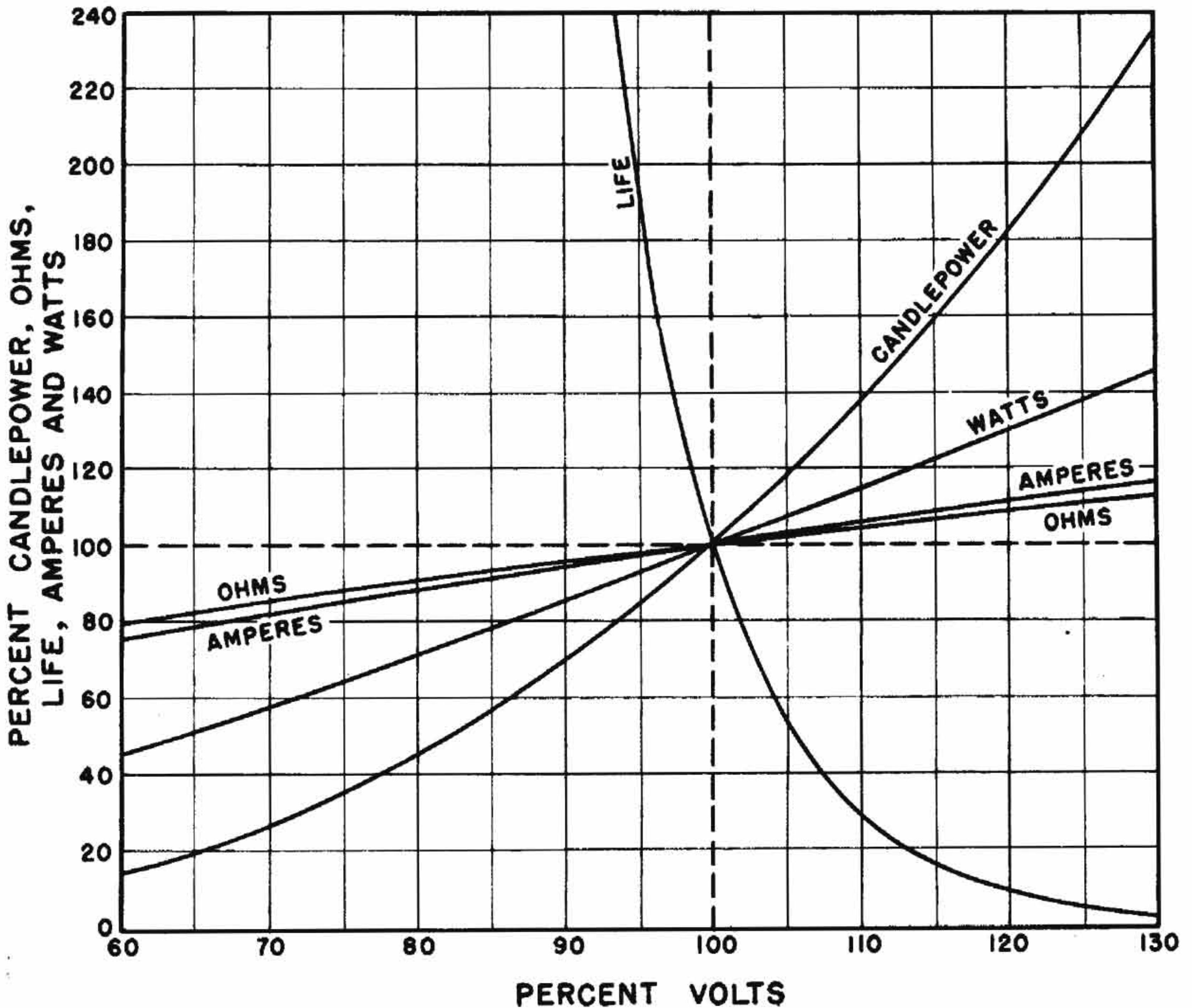


FIGURE 14-9.—Effect of voltage change on lamp performance.

- (a) The values in the table are listed as integers and are not to be extended, by interpolation or otherwise, to decimal figures.
- (b) Where it is found that a lamp is operating at a percentage of voltage which is not a whole number, use the nearest whole number in applying the table; for example,  $83\frac{1}{3}\%$  voltage would be called 83% and the percentage of candlepower would be taken as 52.
- (c) Where the fraction is an exact half, drop the half; for example,  $87\frac{1}{2}\%$  voltage would be called 87% and the percentage candlepower read as 62, the % amps. as 93, etc.
- (d) No allowance for voltage drop between power source and lamp base is made in

calculations of candlepower for publication in the Light List.

- (e) The voltage of batteries is taken from the listing below:

Type of Cell	Volts
Lead Acid.....	2.05
Nickle-Iron.....	1.2
T-2600 air cell.....	2.4
T-1600 air cell.....	1.2
3-S-J-1 Carbonaire.....	3.6
2-S-J-1 Carbonaire.....	2.4
Dry Cell.....	1.2
Copper oxide primary cell.....	0.65

C. Problem.—A 500-watt, 120 volt, C-13B Filament, T-20, 800-hour life lamp has an output of 715 mean spherical candlepower. What will be the (a) mean spherical candlepower, (b) current consumption, (c) power consumption, (d) life, and (e), ohms resistance at 110 volts?



D. Solution:

$$\% \text{ volts} = \frac{110}{120} \times 100 = 91.7\%$$

At 92% volts the table lists 75% CP, 96% amps, 88% watts, 300% life and 96 ohms.

(a) CP, at 110 volts = .75 × 715 = 536 MSCP ANS.

(b) Current at 120 volts =  $\frac{500}{120} = 4.17$  amperes.

Current at 110 volts = .96 × 4.17 = 4.0 amps. ANS.

(c) Power consumption at 110 volts = .88 × 500 = 440 watts. ANS.

(d) Life at 110 volts = 3.00 × 800 = 2,400 hours. ANS.

(e) Ohms at 120 volts =  $120^2 \div 500 = 28.8$ .  
Ohms at 110 volts = .96 × 28.8 = 27.65. ANS.

14-3-10 Effect of Voltage on Candlepower

A. Probably the most important of the operating characteristics of a lamp as far as aids to navigation use is concerned in the lumen output. This, of course, is a major factor in determining the candlepower of the optic's beam. A voltage change very critically affect a lamp's luminous output. The curve of Fig. 14-9 shows that a 1% change in voltage produces a change of about 3½% in candlepower. This curve is based on the formula

$$i = v \cdot 3.38$$

in which *i* is the change in candlepower or lumens and *v* is the change in voltage, both being expressed as a ratio of the values at operating voltage and rated voltage. Unless special provisions are made to insure that the voltage at D. C. light stations is maintained within close tolerances, great variations from published candlepowers of lights can occur. Consider, for example, an improperly operated station at which the engine generators are secured for the night and the main light is operated from the battery bank without additional charging until morning. If the battery bank begins discharging at 115 volts (2.13 volts/cell) and discharges to 97.2 volts (1.8 volts/cell) by morning, the candlepower of the main light is reduced to 55% of the rated candlepower. It is clearly apparent that lamps must be operated at rated voltage in order to produce published candlepower.

B. Normally all candlepower calculations of aids to navigation which are made for Light List purposes are based on the data of Table IV.

C. In applying Table IV to actual problems, it is always assumed that the candlepower of the combined apparatus, i. e., lamp plus lens or mirror, changes in proportion to the candlepower of the lamp.

D. Certain combinations of battery cells result in voltages so closely approximating the rated voltages of various lamps that the small difference between battery voltage and rated lamp voltage is disregarded for reasons of simplicity, convenience and uniformity in maintaining the Light Lists and other records of candlepower. It is assumed in all such cases that the lamp is being operated at rated voltage. For example, a type SA General Railway Signal Company range lantern with an 8° spreadlite roundel using a 10-volt, 25-watt C-2R filament lamp

projects a beam of 14,250 candlepower. If five Willard low discharge cells were conected in series to provide the power source for this lantern, the voltage would be 5 × 2.05 or 10.25 volts. Theoretically, line drop being ignored, the lamp would be slightly overvoltaged and the intensity would be somewhat greater than 14,250 candlepower. Nevertheless, with this combination of equipment the candlepower is assumed to be the candlepower at 10.0 volts for preparing the Light List or Notice to Mariners.

E. The more common combination of battery cells which are arbitrarily assumed to furnish rated voltage to certain lamps are as follows:

3.5-volt lamp-----	{ 1 T-2600 plus 1 T-1600 air cell. 5 Copper oxide cells. 3 Nickle iron cells.
4.0-volt lamp-----	{ 1 3-S-J-1 Carbonaire cell. 2 Lead acid cells. 6 Copper oxide cells.
6.0-volt lamp and 6.2-volt lamp-----	{ 2 T-2600 plus 1 T-1600 air cells. 3 Lead acid cells. 9 Copper oxide cells. 5 Nickle iron cells.
8.0-volt lamp-----	{ 1 3-S-J-1 plus 1 2-S-J-1 Carbonaires. 4 Lead acid cells. 12 Copper oxide cells.
10-volt lamp-----	{ 5 Lead acid cells. 15 Copper oxide cells. 6 Lead acid cells.
12-volt lamp-----	{ 5 T-2600 air cells. 18 Copper oxide cells. 10 Nickle iron cells.
32-volt lamp-----	{ 5 2-S-J-1 Carbonaires. 16 Lead acid cells. 48 Copper oxide cells. 27 Nickle iron cells.

F. Problem.—A latern using a 32-volt, 60-watt, C-5 filament lamp gives a candlepower of 2000 when operated at rated voltage. What is the candlepower when used with 44 copper oxide primary cells in series?

G. Solution:

$$\text{Voltage} = 44 \times .65 = 28.6 \text{ volts.}$$

$$\% \text{ voltage} = 28.6 \div 32 = 89.4\%$$

From the Table at 89% voltage, the % candlepower is seen to be 67.

$$\text{Candlepower at 28.6 volts} = .67 \times 2000 = 1340. \text{ ANS.}$$

14-3-15 Effect of Voltage on Lamp Life

A. A change in the voltage on a lamp affects the lamp's life to a greater extent than it affects any other factor of lamp performance. Overvoltaging a lamp has the effect of rapidly shortening its life. Correspondingly an even moderate amount of undervoltaging will increase its life considerably. The curve of Fig. 14-9 shows that a one percent change in voltage results in a change in life of about 13%. This curve is based on the formula

$$L = v - 13.1$$

in which *L* is the change in life and *v* is the change



in voltage, both being expressed as a ratio of the values at operating voltage and rated voltage. The negative value of the exponent shows that the life decreases as the voltage increases, and vice versa.

B. Table IV is to be used in all calculations involving change in life due to voltage changes.

C. *Problem.*—An 800-hour life, 115-volt lamp is operated at 125 volts. What is the probable life?

D. *Solution:*

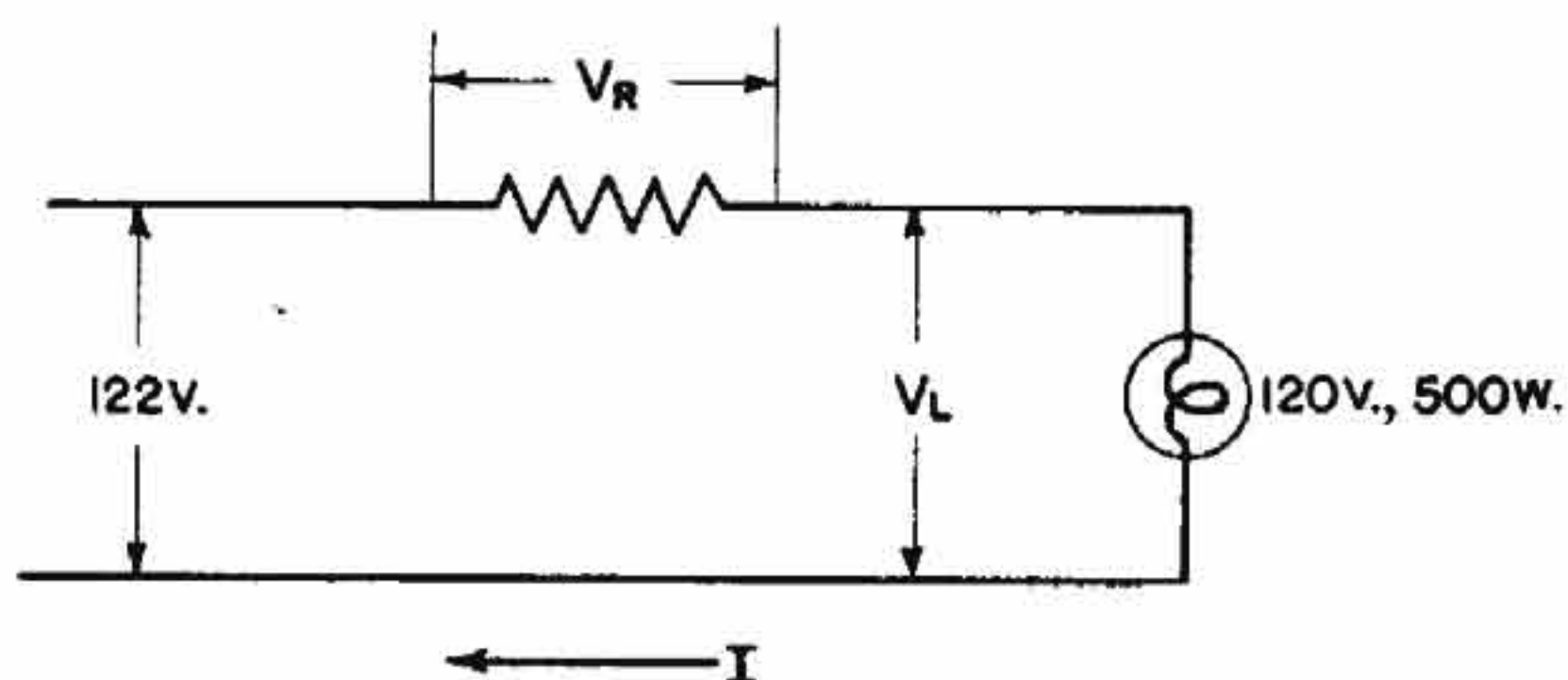
$$\% \text{ volts} = 125 \div 115 = 108.7\%$$

From the table at 109% volts, % life = 32.0

$$\text{Life at 125 volts} = .32 \times 800 = 256 \text{ hours. ANS.}$$

E. *Problem.*—A commercial line averages 122 volts. It is desired to install a 500-watt, 120-volt, 1,000-hour life lamp undervoltaged to give 4,000 hours life. What resistance should be inserted in series with the lamp to accomplish this?

F. *Solution:*



I, at rated voltage of 120 volts, is  $500 \div 120 = 4.17$  amps.

% Life for 4,000-hour operation = 400%.

To obtain 400% life, voltage = 90% from Table IV =  $.90 \times 120 = 108$  volts.

At 90% voltage, current = 94% from the Table IV =  $.94 \times 4.17 = 3.92$  amps.

$$V_R = 122 - 108 = 14 \text{ volts.}$$

$$R = 14 \div 3.92 = 3.57 \text{ ohms. ANS.}$$

G. A resistor inserted in series with the lamp will be suitable only for that particular lamp. If the lamp size is changed then the resistor must be also changed otherwise the second lamp will be operated at a different degree of undervoltage than was the first. This is due to the fact that the voltage drop thru the resistor depends on the lamp current which changes with lamp rating. Another example will illustrate this point more clearly.

H. *Problem.*—In the preceding problem, suppose that because of wartime dimout requirements a 60-watt, 1,000-hour, 120-volt lamp is inserted in the lantern, and the 3.57 ohm resistor is not changed. What would be the lamp life?

I. *Solution:*

At rated voltage the current taken by the 60-watt lamp would be  $60 \div 120$  or 0.5 amps.

At this current the voltage drop through the resistor would be  $0.5 \times 3.57$  or 1.79 volts.

The lamp voltage is thus  $122 - 1.79$  or 120.2 volts.

This can be considered 100% voltage. As a result the life of the lamp will be only 1,000 hours, instead of 4,000 hours as originally intended.

### 14-3-20 Effect of Voltage on Power Consumption

A. An increase in voltage results in an appreciable increase in the power input to a lamp. Since  $\text{Watts} = \text{volts} \times \text{amps.}$ , it can be seen that the variation in power is greater than a direct proportionality of the voltage. The curve of Fig. 14-9 shows that a 1% increase in voltage will cause an increase of about 1½% in power required. The curve is based on the formula:

$$w = v^{1.5}$$

in which  $w$  is the change in watts, and  $v$  is the change in voltage, both being expressed as a ratio of the values at operating voltage and at rated voltage.

B. Table IV can be used for all computations involving changes in power input due to voltage changes.

C. *Problem.*—An unattended light operated from commercial power uses a 100-watt lamp and gives 4,500 candlepower at rated voltage of 120 volts. In order to increase lamp life and thus reduce servicing, the voltage is reduced to 105 volts and a 150-watt lamp is installed. What is the consumption in watts?

D. *Solution:*

At 105 volts, the % volts =  $105 \div 120$  or 87½%.

From Table IV, % watts at 87% volts = 81%.

Power consumption at 105 volts =  $150 \times .81$  or 121.5 watts. ANS.

### 14-3-25 Effect of Voltage on Filament Resistance

A. If the voltage on a lamp is increased, the current increases. As the current increases the filament in turn gets hotter. At the same time, since it is a property of tungsten that its resistivity increases with temperature, the resistance of the lamp filament increases. This increase in resistance thus makes the lamp partially self-regulating to voltage change since the increase in resistance tends to minimize the increases in candlepower, amperes and watts and to minimize also the decrease in life.

B. Fig. 14-9 shows that a change in resistance of about ½% is caused by a 1% change in voltage. The curve in Fig. 14-9 is based on the formula:

$$r = v^{0.425}$$

in which  $r$  is the change in resistance and  $v$  is the change in voltage, both being expressed as a ratio of the values at operating voltage and rated voltage.

C. Table IV can be used for all calculations involving change in filament resistance due to voltage changes.

### 14-3-30 Effect of Voltage on Current Consumption

A. Undervoltaging a lamp, while resorted to primarily for the purpose of increasing lamp life, has the effect of reducing current consumption. This in some respects compensates for the fact that as a result of the undervoltaging a higher wattage lamp must be used in order to obtain a specified candlepower. The curve of Fig. 14-9 shows that decreasing



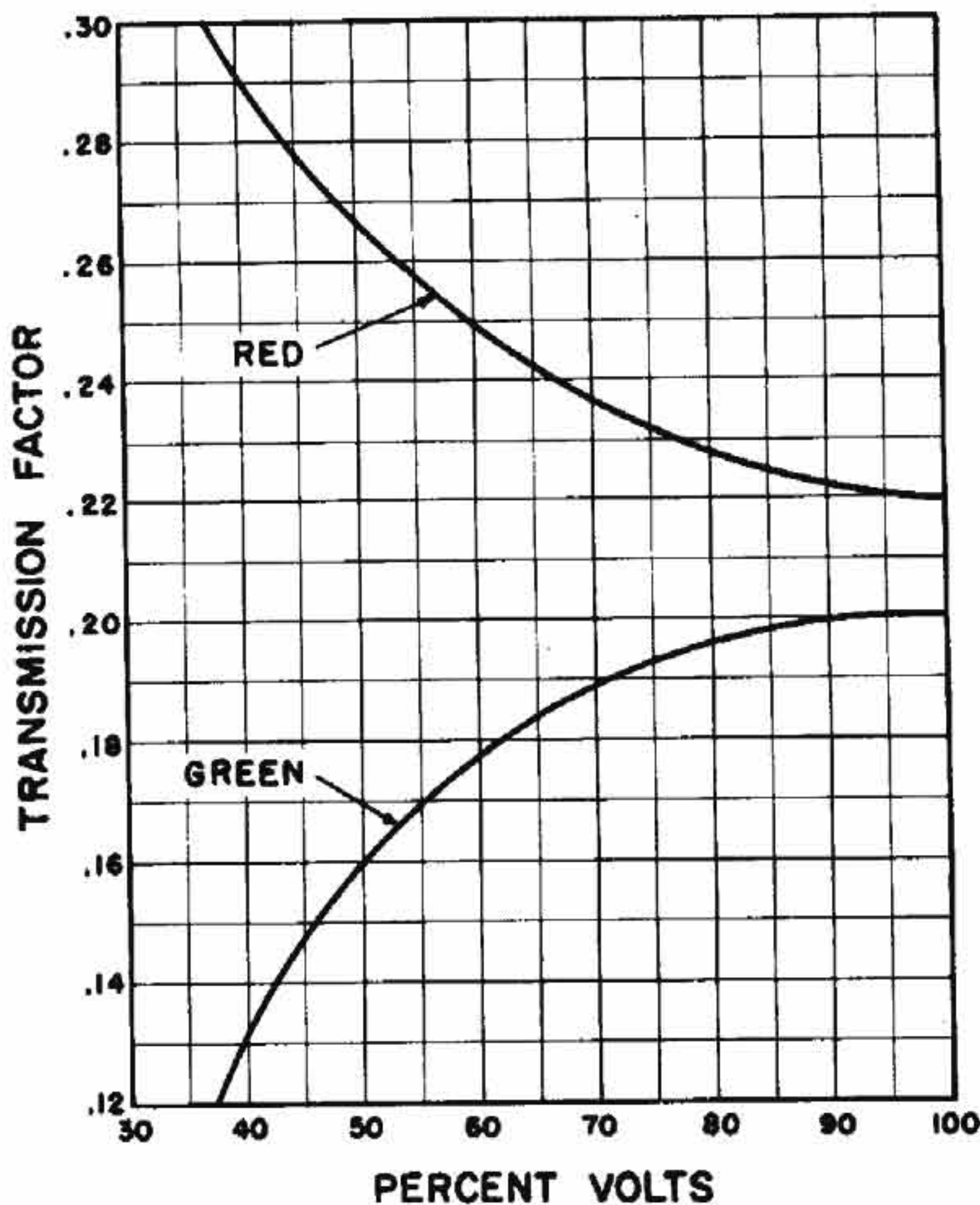


FIGURE 14-10.—Effect of voltage change on transmission factors for color shades.

the volage by 1% results in a decrease in current of about 1/2%. This curve is based on the formula:

$$a = v^{0.241}$$

in which *a* is the change in current and *v* is the change in voltage, both being expressed as a ratio of the values at operating and rated voltage.

B. The data of Table IV is to be used in all calculations of this nature.

C. *Problem.*—A lamp consumes 2.36 amperes at 120 volts. What will be the current consumption when operated at 140 volts?

D. *Solution:*

$$\% \text{ voltage} = 140 \div 120 = 116.67\%$$

From the table at 117% volts, the % amps is 109.

$$\text{Current at 140 volts} = 1.09 \times 2.36 = 2.57 \text{ amperes.}$$

ANS.

### 14-3-35 Effect of Voltage on Color

A. The transmission factor of standard color shades, colored lenses and other pieces of colored glassware used for aids to navigation purposes is fixed by Military Specification MIL-C-25050 (ASG). Conventional values, when incandescent filament electric lamps are used as the light sources, are 0.20 for green and 0.22 for red. These values are obtained when the light source temperature is 2842° K. For purposes of simplicity and uniformity in compiling and publishing Light List data, it is assumed that all electric lamps used in aids to navigation work operate at this temperature if at rated voltage. Consequently there is no correction ever

made to these values to compensate for the fact that the designed temperatures might be other than 2842° K.

B. When a lamp is operated at a voltage lower than that for which it was designed the temperature of the filament drops. Since the light spectrum from the filament depends on its temperature it is apparent that the transmission factor of the glassware will change somewhat also. As the filament temperature drops, a bigger proportion of the emitted light will be found in the red end of the spectrum and a lesser proportion in the green. This has a slight effect on the transmission factor of the glassware in raising the factor for red glass and lowering it for green glass. Fig. 14-10 shows this effect. Table V, which also expresses this effect, is based on Fig. 14-10 and should be used for all calculations involving this feature.

TABLE V.—Change in transmission factor due to change in voltage

Percent Voltage	Transmission factor		Percent Voltage	Transmission factor	
	Red	Green		Red	Green
61	0.25	0.18	81	0.23	0.20
62	.25	.18	82	.23	.20
63	.24	.18	83	.22	.20
64	.24	.18	84	.22	.20
65	.24	.18	85	.22	.20
66	.24	.19	86	.22	.20
67	.24	.19	87	.22	.20
68	.24	.19	88	.22	.20
69	.24	.19	89	.22	.20
70	.24	.19	90	.22	.20
71	.24	.19	91	.22	.20
72	.23	.19	92	.22	.20
73	.23	.19	93	.22	.20
74	.23	.19	94	.22	.20
75	.23	.19	95	.22	.20
76	.23	.19	96	.22	.20
77	.23	.20	97	.22	.20
78	.23	.20	98	.22	.20
79	.23	.20	99	.22	.20
80	.23	.20	100	.22	.20

C. When a lamp is operated overvoltage the transmission factor is assumed to be that of 100% voltage. From the shape of the curves of fig. 14-10 it can be appreciated that overvoltage a lamp results in only a small change in the transmission factor—at least within the limits of overvoltage normally encountered in aids to navigation work. Were voltage changes of 60% or 80% to be encountered, as in photoflood work, then the effect might not be negligible.

D. *Problem.*—A semi-floating battery system of 54 lead acid cells has become discharged to 1.9 volts per cell. If the main light uses a red color shade and a 125-volt lamp, (1) what will be the change in the shade's transmission factor, and (2) how will this change effect the candlepower?

E. *Solution:*

At 1.9 volts per cell the voltage will be  $54 \times 1.9$  or 102.5 volts. This will be  $102.5 \div 125$  or 82% voltage.

(1) At 82% voltage the transmission factor will be 0.23.



(2) The candlepower of the bare lamp will be greatly reduced because of low voltage. However a slightly greater proportion of the light consists of usable red rays. Instead of a factor of 22%, the rated voltage value, 23% will be passed through the screen. The candlepower will thus be a little greater than it would have been had the transmission factor remained constant.

**14-3-40 Effect of Flashing a Lamp**

A. The most common method by which a flashing characteristic is obtained from an electrically operated aid to navigation is by flashing the lamp. The act of flashing causes the performance of the lamp and consequently the performance of the assembled optic to differ from their steady burning performances in many ways. The differences are described in the following paragraphs.

**14-3-45 Surge Effect**

A. A lamp draws a higher current when it is flashing than when it is burning steady. This is due to the fact that the resistance of a cold filament is much less than the resistance of the same filament when it is hot. It follows therefore that there is a so-called inrush period when a lamp is turned on. During the inrush period, which is very short, a heavy current is momentarily drawn. As the filament heats up, which it does very quickly, the resistance increases and this heavy current rapidly tapers off. When the filament finally reaches its steady operating temperature the current has likewise reached a steady value. Obviously the average current will be higher than the steady current and a little reflection will show that the shorter the total flash length, the higher will be this average. Measurements have been taken of this effect, the results being shown in Fig. 14-11. In the figure the ordinate, SURGE FACTOR, is defined as the ratio of the average current during the flashing period to the steady burning current.

B. Since the matter of accurately estimating the life of batteries at isolated lights is very important, and since the effect described above is of appreciable magnitude, it is necessary to take current surges into account when making such estimates. Table VI, which is based on Fig. 14-11 should be used for this purpose.

C. Where a lamp is operated at other than rated voltage, the surge factor can be applied to the reduced amperage of the lamp (a result of the reduced voltage) with no appreciable error.

D. *Problem.*—A 12-volt, 2.03-ampere lamp is operated on a flashing characteristic of 0.4 seconds light, 3.6 seconds eclipse. What is the average current consumption?

E. *Solution.*—From Table VI the surge factor is seen to be 1.29 when a 2.03-ampere lamp is flashed for 0.4 seconds. The average current during the flashing period is therefore  $1.29 \times 2.03$  or 2.62 amperes. For the complete period, including the eclipse, the average current will be  $1/10 \times 2.62$  or 0.262 amperes. **ANS.**

TABLE VI.—Surge factors for low voltage lamps

Lamp size, amperes	Surge factor at various flash lengths				
	0.2 sec.	0.3 sec.	0.4 sec.	0.5 sec.	1.0 sec.
0.25	1.13	1.09	1.07	1.05	1.03
0.30	1.15	1.10	1.08	1.06	1.03
0.46	1.19	1.14	1.11	1.09	1.05
0.50	1.20	1.15	1.12	1.09	1.05
0.55	1.21	1.16	1.13	1.10	1.05
0.625	1.23	1.17	1.14	1.11	1.06
0.70	1.25	1.18	1.15	1.12	1.06
0.75	1.26	1.19	1.15	1.12	1.06
0.77	1.26	1.19	1.16	1.13	1.06
0.92	1.29	1.22	1.18	1.14	1.07
1.00	1.31	1.23	1.18	1.15	1.07
1.15	1.33	1.25	1.20	1.16	1.08
1.25	1.35	1.27	1.21	1.17	1.08
1.35	1.36	1.28	1.22	1.18	1.09
1.40	1.37	1.29	1.23	1.18	1.09
1.67	1.41	1.32	1.25	1.21	1.09
1.80	1.43	1.33	1.27	1.22	1.10
1.84	1.43	1.34	1.27	1.22	1.10
2.03	1.46	1.36	1.29	1.23	1.10
2.25	1.48	1.39	1.30	1.24	1.11
2.50		1.41	1.32	1.26	1.11
2.80		1.44	1.34	1.27	1.12
3.05		1.47	1.36	1.28	1.12

**14-3-50 Incandescence and Nigrescence Time**

A. When the electric circuit to an incandescent lamp filament is closed, current is immediately drawn from the power source. However, the filament has a small thermal capacity and an appreciable time interval is required not only for the filament to heat to its maximum temperature but also to produce maximum luminous output. In

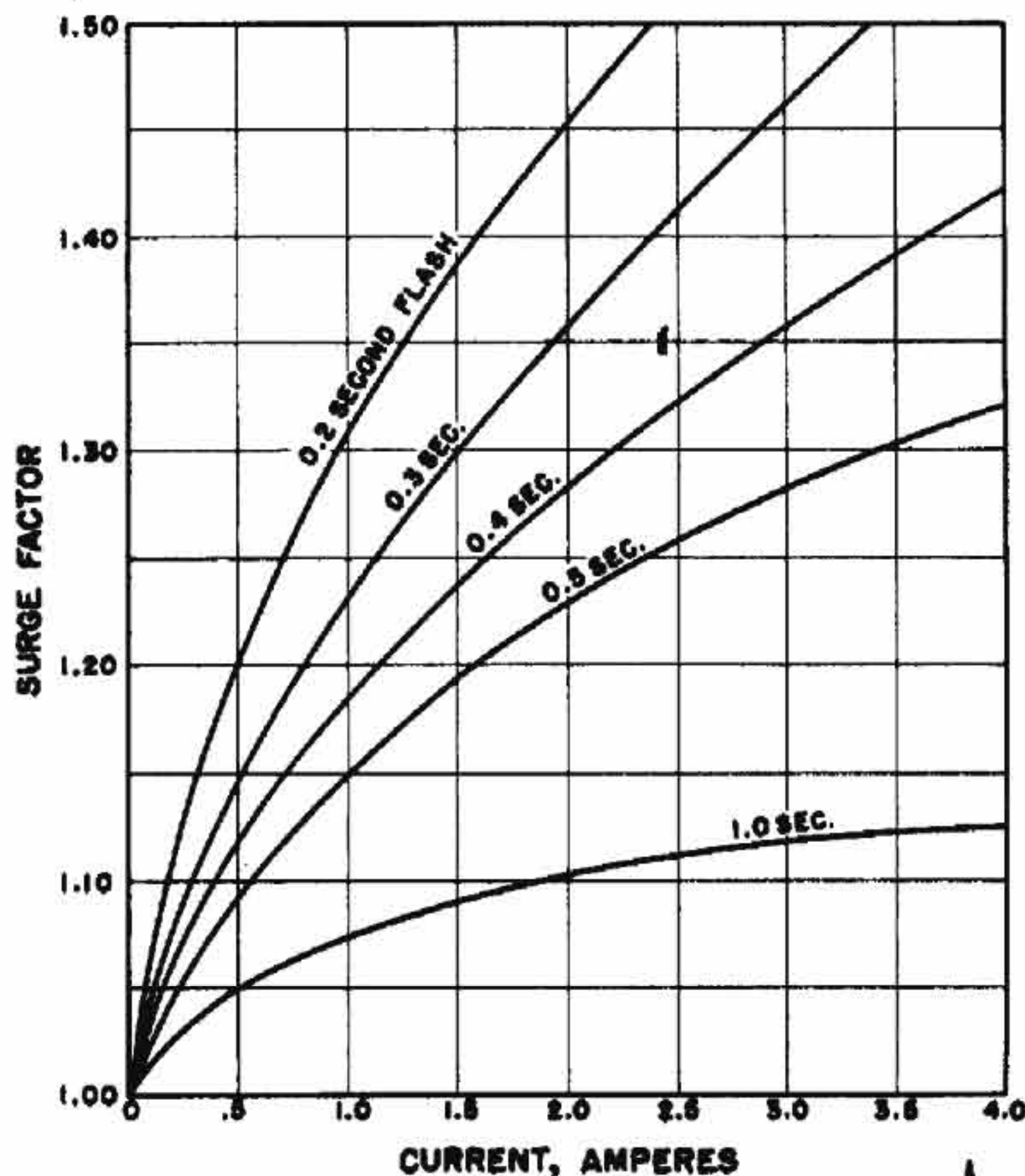


FIGURE 14-11.—Current consumption of flashing lamps.



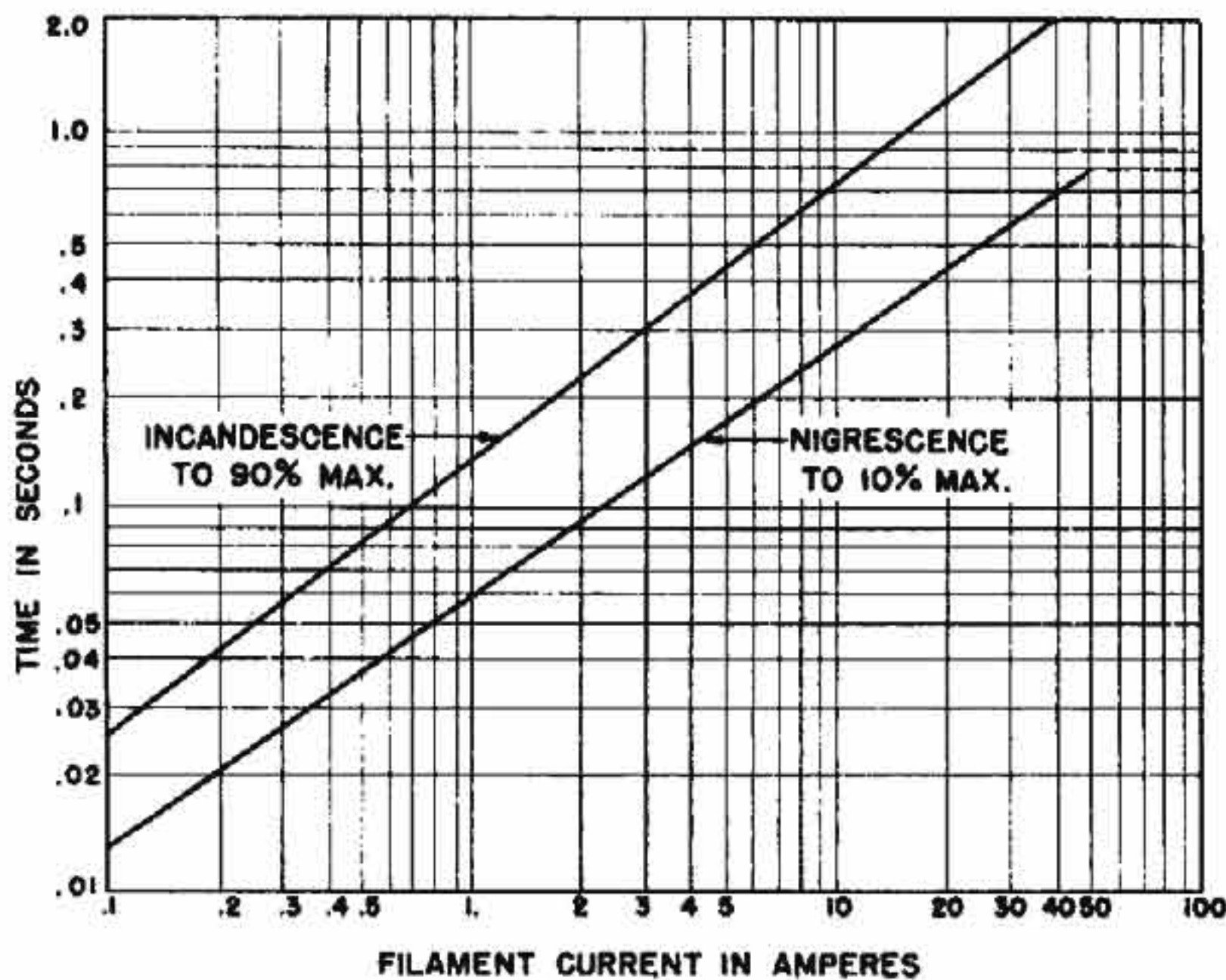


FIGURE 14-12.—Heating and cooling time of gas-filled lamps.

other words it takes a certain amount of time, after the switch is closed, for the lamp to reach full brilliance. This interval of time is known as the incandescence period.

B. The reverse of the above is true when the electric circuit is broken. Although the power source no longer is supplying current to the lamp, the filament, since it cannot cool off instantaneously, continues to emit light for a short period of time. This extent of time is known as the nigrescence period.

C. The incandescence period is of much greater duration than the nigrescence period.

D. The factor which most influences the length of the incandescence or nigrescence period is the amperage of the lamp. Other factors such as voltage, rated life and operating temperature, shape of filament, etc., enter to a smaller degree. However for all practical purposes the effect of these latter factors can be ignored and the determination of incandescence and nigrescence time can be made solely on the basis of the ampere rating of the lamp.

E. Fig. 14-12 which is applicable to all aids to navigation lamps of the incandescent filament type can be used for estimating the incandescence and nigrescence times. The curves shown in Fig. 14-12 agree closely to the formula: where  $t$  is the time in

$$\begin{aligned} \text{Incandescence, } t &= 1 A^{.723} \\ & \quad \quad \quad \frac{7.5}{16.7} \\ \text{Nigrescence, } t &= 1 A^{.613} \end{aligned}$$

seconds and  $A$  is the rated current of the lamp in amperes.

F. When a flasher mechanism is adjusted, or cams are cut, or other similar work done which has for its purpose setting the mechanism to give a certain definite flash interval, such work is almost invariably carried out solely on the basis of the geometry of the cam or some other kinematic property of the mechanism. Allowances are seldom made for the effects that nigrescence or incandescence have on the flash period. Strictly speaking the assumed flash period of the lamp should be obtained by deducting the time lag resulting from incandescence and adding the time lag resulting from nigrescence. Where large currents are involved the error in not taking this into account can be considerable. As can be seen from the curves of Fig. 14-12 even at 3 or 4 amperes the time factors involved are significant. In Fig. 14-12 the curve for incandescence has for its ordinate the time that it takes for the filament to heat to the point where the luminous output is 90% of its steady burning value while the nigrescence curve is based on reduction of luminous output to a 10% value.

G. *Problem.*—A flasher has its cam cut to give a flash of 2 seconds. If a 1,000-watt, 30-volt lamp is used, what will be the length of time between the moment when the filament first lights up to 90% of maximum brightness and the moment when it cools off to 10% brightness?

H. *Solution:*

The Current is  $1000 \div 30 = 33.3$  amperes.

Fig. 14-12, at 33.3 amperes, gives the time of incandescence as 1.7 seconds and the time of nigrescence as 0.6 seconds.

The flash length will therefore be  $2.0 + 0.6 - 1.7$  or only 0.9 seconds. *ANS.*

I. The curves of Fig 14-12 are not intended to be used as a basis for correcting the characteristics of lights as now advertised in the Light Lists. They are intended primarily for engineering purposes in the design and selection of apparatus for new lights. While it is unquestionably true that there are many existing aids which are not exhibiting their advertised characteristics because of the effects of nigrescence and incandescence, the disadvantages of attempting widespread remedial procedures outweigh the benefits to be derived. To correct the "mistakes" of the past would involve either correcting the Light List to agree with the actual flash length or, as a wholesale procedure, attempting to change the flashing apparatus at all lights where the flash length is slightly shorter than is advertised.

J. Where a high current (5 amperes or more) is involved, improved performance will be obtained if a suitable resistance or choke is inserted in the nigrescing circuit so that a current of not less than 5% of the normal maximum current for which the lamp is designed passes through the filament at all times during the eclipse period.