CHAPTER 23

Lighted Aids to Navigation—Theory, Design, and Application

The material contained in this chapter is under revision. However, due to the length of time that will be required, most of the data contained in this interim chapter has been reprinted from chapter 31, "Lighted Aids to Navigation," Engineering Instructions, without factual change.

CONTENTS

ILLUSTRATIONS

23–1 HISTORY, EARLY DEVELOPMENT, AND USES OF LIGHT AS APPLIED TO NAVIGATION

23–1–1 Forms of Illuminant—

A. *Fire.*—Until the first application of electricity to lighting late in the nineteenth century, all artificial light was produced by fire.

The earliest form of illuminant used as a guide was a burning pyre of wood, and, later, coal set in a brazier or grate, erected on top of a tower. Because of the huge flame area, sufficient light was evolved to be seen at a distance of several miles. The useful candlepower to the mariner was limited by the low intensity per unit area of the flame and its total projected area. Until the end of the eighteenth century—even into the nineteenth—these primitive illuminants continued to be almost the only ones in use.

B. *Oil lamp.*—Oil wick lamps were used in the lighthouses of Liverpool as early as 1763, when Argand, the German physicist, perfected his cylindrical wick lamp, which provided a central current of air through the burner, thus allowing more perfect combustion of the gas issuing from the wick. Fresnel produced burners having two, three, and four concentric wicks.

(1) *Multiple wick burner.*—It was not until 1868 that a burner was devised which successfully consumed hydrocarbon oils. A multiple wick burner, invented by Captain Doty, it was quickly adopted by lighthouse authorities. The "Doty" burner, and other patterns involving the same principle, remained practically the only oil burners in lighthouse use until the last few years of the nineteenth century.

(2) *High-pressure type.*—Mineral oil, heated under high-pressure air to a vapor, was first used in 1898. This process resulted in a sixfold increase in candlepower over oil wick lamps. From time to time, sperm oil, olive oil, lard oil, and coconut oil have been used for lighthouse purposes in various parts of the world.

C. *Gas burner.*—Gas burners were introduced in 1837. The invention of the Welsbach mantle placed at the disposal of lighthouse authorities the means of producing a light of high intensity combined with great focal compactness.

(1) *Oil gas.*—In 1870 the Pintsch oil gas burner first came into use. It was used for both buoys and beacons. High-pressure containers (9 to 10 atmospheres) were used to recharge large storage tanks connected to the lights.

(2) *Acetylene,* generated from calcium carbide, was first shown to be a possibility by Thomas M. Wilson in 1892. The lights, which were open flame burners, were first used in Sweden in 1904, and assumed widespread use in 1906. The gas was placed in cylinders (accumulators) under pressures of from 10 to 15 atmospheres. The brightness of this flame was about equal to that of the mantle oil vapor burners. (See par. 23–6–1 (A).) The high illuminating power and the brightness of the flame of acetylene make it a very suitable illuminant for lighthouses and beacons, providing certain difficulties attending its use can be overcome.

23–1–5 Lenses—

A. The first really brilliant light for lighthouse purposes, and the next great step forward in illuminating apparatus, came with the work of the French engineer Fresnel. His discoveries resulted in the design and construction of a glass optic or lens which reflected or refracted a major portion of all the light emitted from the light source. These aggregations of beautiful cut-glass prisms collected and concentrated a very high percentage of the light emitted by the lamp and directed it out along useful horizontal beams. The beam emitted became primarily a function of intensity per unit area, horizontal width of the light source, and the projected vertical height of the lens.

23–1–10 Incandescent Oil Vapor—

A. The introduction of kerosene or coal oil was another important step resulting in more brilliant lights, and from kerosene the incandescent oil vapor (I. O. V.) light was developed. This lamp, placed within a carefully designed lens of great size, produced the most powerful light known up to the time of the general introduction of electricity, which, in lighthouse work, was undertaken about 1916.

23–1–15 Electric Lamp—

A. The first arc lamp, known as the Wright arc, was patented in England in 1845. This arc light, used only in the larger English lighthouses, was the first experiment with electricity as an aid to navigation. The first attempt to electrify buoy lights through cables in New York Harbor was made in 1888, but proved unsuccessful.

B. Nineteen twenty-eight marked the beginning of widespread use of electricity at both attended and unattended stations, as well as on buoys. By this date, electricity had been proven to be an economical and a reliable source of power, and made available a light source having a greater intensity per unit area.

23–1–20 Modern Lighthouses—

A. Electricity is the illuminant now used in most of the larger lighthouses. Electric incandescent lamps placed inside the larger sizes of lenses can produce beams of several million candlepower.

B. The flashing characteristics which distinguish many of the lighthouses are produced by revolving the entire lens. Electric flashers provide the characteristics in the drum lenses.

23–1–25 Lightships—

A. The first modern lightship was established on the Thames in England in 1732. It had two small lanterns which were carried at the extremities of a yard. The light, which burned oil with small flat wicks, was dim at its best. The lanterns were so defective that the flame was frequently blown out in stormy weather, and the violent pitch and roll of the vessel often snapped the lanterns bodily from their lashings.

B. In the United States, lightships were first authorized by Congress early in the year 1819, and in succeeding years they fully demonstrated their worth as efficient aids to navigation. These sturdy vessels, which remain anchored at the same spot, often for a year at a time, are really floating lighthouses. Their tall masts serve as towers for the light, and their signaling equipment is very similar to that found at shore stations.

23–2 FUNDAMENTALS OF ILLUMINATION AS APPLIED TO NAVIGATION

23–2–1 General—

A. A number of preliminary considerations on the visibility of lights and on the range of lighthouses will be discussed in the following paragraphs. Though based in part on theoretical hypotheses possibly open to question, they are matters of prime interest to the officer charged with the engineering incident to the installation of lighted aids to navigation.

23–2–5 Factors Affecting Visible Range—

A. The determination of the range of a light, which is so important to a navigator, depends not only on the power (or luminous intensity) of its optical apparatus but also on various laws which govern the propagation of luminous waves through the atmosphere, and the extent to which the human eye, at sea and with or without glasses, is susceptible to the fugitive sensation of that amount of light which exists at the extreme limits of the range.

B. Two principal methods are used for determining the range or the visibility of maritime lights as a function of their luminous intensity:

(1) An exclusively empirical method recommended by Ribiere which deduces from the observations made at various distances, the percentages of visibility corresponding thereto, and then interpolates graphically the percentages corresponding to other distances.

(2) A method based on a formula developed by Allard and published by Renard in 1864 which gives the relation between candlepower and optical range.

C. With regard to the employment of the first method, it is rare that a light is so surrounded by observing stations at various distances that the curve of visibility may be drawn with certainty.

23–2–10 Luminous Range Based on Many Factors—

A. The ranges obtained by the use of a formula would have, in practice, a certain uniformity of character which is very desirable, but in view of the numerous criticisms which have been made against the exclusive use of a strict formula, it is advisable to modify it by introducing into the calculations the results of a long series of precise and methodical observations.

23–2–15 Atmospheric Transparency—

A. The hypothesis that the transparency of the atmosphere is the same, and remains constant throughout the distance over which the luminous wave travels from the apparatus to the eye of the observer, is popularly assumed to be true.

B. *Causes of variation.*—However, the transparency of the atmosphere varies essentially with atmospheric conditions and at the same place on the surface of the earth, with the season, and even during the day with the hour, the temperature, the amount of moisture in the air, and the direction of the wind. It increases with height above ground; at an equal height it is generally greater over sea than over land. It varies with the azimuth at which the observation is made, and depends on the general amount of light in the atmosphere due to lunar effects. When it is a question of distances which extend over several miles, it is probable that the transparency of the atmosphere does not remain the same over the whole of the space traversed by the light ray. This is true especially when the light passes over land, sandy shores, highly heated dunes, forests, low coasts or marsh, and also when it follows the general direction of the coast, passing alternately over portions of sea and land or crossing mouths of estuaries or rivers. The causes of variations in range are so numerous that two lights of equal candlepower situated near each other on the same coast sometimes have very different ranges.

C. *Measurement of transparency.*—The direct measurement of atmospheric transparency on the seashore appears to be impossible in practice. Further, when it is a question of luminous ranges, only average values obtained from a great number of observations can be considered. The results must be applied to each particular case with very great caution, even to a case on the same portion of the coast where the results of experiments were gathered.

D. *Standard unit.*—The candlepowers to be taken into account, both in formulas for visibility and in comparative light lists, might be advantageously expressed by means of a standard unit (i. e., the International Candle defined at the International Convention of July 1, 1909) as they normally appear in practice and at a distance from an observer coming from the open sea, and not by the result of photometric measurement in the laboratory.

0.60 for yellow

23–2–20 Brightness—

A. An optical panel of surface (A), when placed before a luminous source around the focus of which a certain brightness (B) is emitted over a proper apparent surface (a), has the effect, for an observer at a certain distance, of increasing the surface of the source to the dimensions of the panel. The latter thus becomes for the observer a new source of the same brightness but of the apparent dimensions of A, much greater than a. Theoretically, the apparent maximum intensity would be expressed by the product AB, but in reality there only remains available outside the lantern (owing to losses due to the optical system, to dispersion, to refraction or reflection, or to the absorption of the lenses) a maximum useful intensity, KAB, the constant K representing the coefficient of utilization of the whole optical system. This coefficient, of which the practical value may be determined experimentally by photometric measurement, varies between rather wide limits (20 percent to 85 percent) for the various types and shapes of refractors and reflectors, as well as with the nature of the glass and of the various colors of screens employed. The seaman perceives the full effect of a light only when he is at such a distance that his eye can embrace the whole optical panel, and from there on until he is in the neighborhood of the geographical horizon of the light (where the beam has been concentrated by an appropriate displacement in height of the source in its optical system corresponding to the angle of apparent depression.)

B. *Effect of rotation or passing across beam from range light.*—Further, in the case of rotary flashing lights, the rotation of the apparatus brings all directions and, consequently, all the intensities of the beam in succession toward the eye of the observer. This happens also when the observer moves across the beam from the range light.

C. For certain group-flashing apparatus the curves of intensity may even present an asymmetry in respect to the central axis in different azimuths covered by the angle of divergence of the beam (fig. 23–1). At the limits of the range, certain exterior parts of the beam may not reach the observer, and the duration of the flashes and the extent of the lighted sector may be found to be affected. Thus it might not suffice to define the power of a light by a single figure corresponding, for instance, to the maximum intensity measured along the direction of the axis. The flashes of a light can only be defined exactly by the individual curve corresponding to the various intensities of its beam.

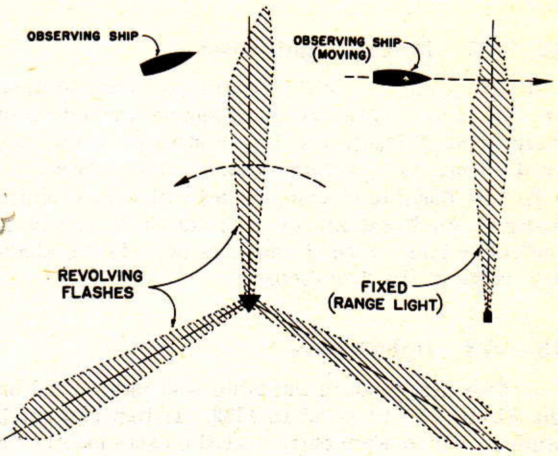

FIGURE 23–1.—Variable intensity of beams.

D. *Irregularities of flash duration.*—At sea, the duration of visibility of a flash may be found to be increased or diminished according to the peculiarities of the curve representing the intensities, such as the presence of a more or less extensive maximum or of a special asymmetry. These irregularities have caused great value to be placed on the curves which give the percentages of visibility directly from observation at different distances on a certain coast; all the particulars of the optical system of the light and of the local transparency are thus included in the results of the observation. Thus the relative intensity of lights is expressed by some governments in terms of visibility in sea-miles. (See par. 23–3–1(D).)

E. *Range expressed in candlepower.*—It is not possible, however, to give all of the characteristic curves for all lights in the United States Coast Guard light lists. In default of being able to obtain the curves of percentage of visibility for all lights, it is at least advantageous to indicate luminous power as a help in the classification of the lights. It must however be selected in a practically uniform manner. The maximum intensity corresponds occasionally only to a narrow and irregular zone of the beam, but there exists in all curves a fairly wide part of high intensity on both sides of the central axis, and on each edge of the beam a point at which the intensity commences to fall somewhat sharply. Limits can be taken, therefore, between which it is possible to agree that the power would always be greater than a selected value. An arbitrary value of 15 percent of the maximum intensity has been selected since this value corresponds to a candlepower which is generally visible at two-thirds of the maximum luminous range. It is applicable to the candlepower distribution from existing large Coast Guard optical systems. (See fig. 23–2). The relation between such a value and the corresponding portion of the extreme range of visibility is of great importance. A relationship must be arrived at which permits of a statement in the light lists of length of flash which will be generally recognizable whether the light be passed near to or observed at the extreme range, or in different states of the intervening path of light.

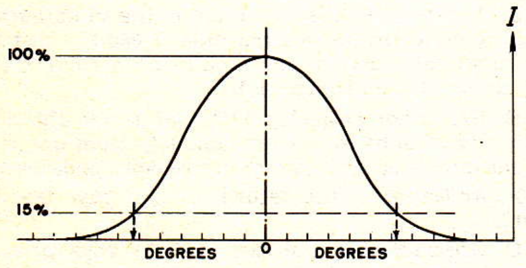

FIGURE 23–2.—Typical candlepower distribution.

23–2–25 Duration of Flashes From Rotating Lenses—

A. The adoption of such values has permitted the deduction of amplitudes (and duration of flashes) which are effectively comparable and practically uniform for the calculation of the ranges in the vicinity of their limits, i. e., at the most important point for the navigator. For this purpose, however, a guide was found in the fact that the duration of the flash is based on the speed or period of rotation of the optical system and on the divergence of the beam. The maximum divergence of the beam corresponds to the horizontal angle at which the useful portion of the source is seen from the center of the lens, and the divergence of the central part of maximum intensity of the beam corresponds to the smaller angle, within which the active part of the source is seen from the farthest edge of the panel of the system.

B. *Other factors.*—In practice it may have been advisable to take into account under conditions of regular service, the reduction of light caused by deterioration of the burner, the mantle, or the blackening of the incandescent lamps, etc., and perhaps also a reduction caused by occultations by the uprights and crossbars of the lantern, although these factors have not been considered in derivation of candlepower for United States Coast Guard lights.

23–2–30 Persistence of Vision

A. The candlepower of a given optical system should not be considered as a fixed element independent of the method of utilization of the system. Thus, with flashing lights, whether generated by revolving panels or in fixed lenses, if the duration is very short, the practical candlepower that the eye of the seaman actually perceives is entirely different from that which would be measured by a photometer if the system and the beam were not moving. The law enunciated by Blondel and Rey in 1911 as to the perception by the eye of short flashes at the limits of their ranges allows this practical candlepower (the power of a steady and fixed light which is equivalent in range to revolving light giving flashes) to be deduced from luminous photometric power measured when the beams remain immobile. (From an operational and engineering standpoint, the combinations of lens, light source, and rotational speed are selected by the United States Coast Guard to avoid abnormally short flashes for marine aids.)

B. *Minimum light necessary to create impression.*—Physiological considerations have shown that for visual stimulation of an observer to begin, it is necessary that the eye receive a certain luminous intensity corresponding to a threshold of lighting (λ) of the retina.

(1) This limit of lighting, which corresponds to the point where the stimulation of the human retina begins, varies with the visual sensitivity of different observers and with different conditions of observation. If the lighting does not pass beyond this limit (λ) the visual organs would not be excited and would remain inactive. It is necessary, therefore, that the luminous source should emit light of greater intensity in order that the physiological sensation be produced under the influence of its growing intensity. In order that the brain should react to such sensation, this necessary greater intensity must be maintained during a certain period (a) capable of giving the constant minimum quantity of lighting (λ) which will produce the minimum of sensation.

(2) The quantity of light emitted by the source to the observer during a period (t) of a uniform flash of constant intensity will be expressed by the product Et in which E represents the amount of light produced at the distance at which the eye is situated.

(3) The quantity of light which is transmitted by the optic nerve in order to affect the brain would thus be represented by $(E-\lambda)t$. Consequently the following equation, which satisfies the above considerations, constitutes the analytical expression of the law enunciated by Blondel and Rey:

$$(E-\lambda)t => a\lambda. \qquad (1)$$

(4) *The constant (a) has been found to lie between the extreme limits 0.15 and 0.35 and is, on an average for different observers, equal to 0.21 of a second.* (The minimum stimulation has been determined by test to be .67 sea-mile candle confirmed by convention.) Referring to Figure 23–3, if λ=.67 and a=.21 then a light to be seen must have an intensity E and a duration t which are equal to or greater than .67 sea-mile candle and .21 second.

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(5) The validity of the Blondel-Rey law has been checked by experiment over duration limits of from 1/1000 of a second to more than 1 second. It is interesting to note that the human eye can, under special conditions, perceive extremely short durations.

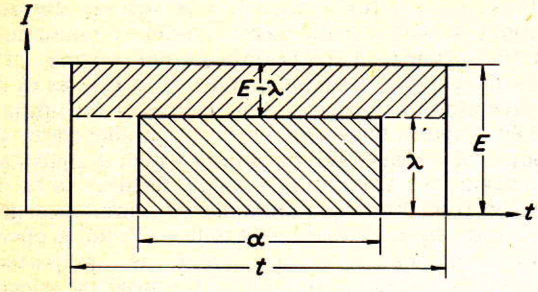

FIGURE 23–3.—Graphical representation of Blondel-Rey expression $(E-\lambda)t=>\alpha\lambda$.

C. *Effect of movement of eye on location of light.*—In practical navigation the conditions are very different from those of the laboratory. When a search is made in the middle of the night for a light which is suspected to exist within a certain arc of the horizon, the eye is kept constantly in motion and the line of sight moves forward at a certain speed by a series of short pauses. Let each short pause have the value δ. If the light for which a search is being made can only be perceived at the limit of range, at the end of a duration greater than δ, it will never be sighted because the eye will have ceased to be fixed on the point in question immediately after the pause (δ). On the other hand, if it were possible to fix the sight on the location of the same light for a period exceeding δ (though at first no light would be perceived), it would be discovered after the elapse of the period (δ). It is obvious, therefore, that it is quite useless to use flashes of a greater duration than δ because for a longer duration it still would be necessary to calculate their photometric power or intensity as though this duration were reduced to the time during which it can act effectively on the searching eye, viz, to δ.

D. *Maximum flash necessary for perception at maximum range.*—It is difficult to determine δ practically, i. e., the period during which a searching eye remains fixed on a definite point at night. It is already known from the curve of ranges of a white flash, according to its effective duration, *that little range is gained when the duration is increased beyond 0.50 second.*

23–3 UNDERSTANDING THE PHYSICAL LAWS

23–3–1 Definitions—

A. *The inverse square law of the propagation of light* states that light decreases in candlepower inversely as the square of the distance. Illumination, *E*, at any distance, *d*, from a source equals:

$$E=\frac{I}{d^2} \quad \text{where } d=\text{feet and } I=\text{candlepower at the source.} \qquad (2)$$

This is based on the premise that light is emitted from a point source. (See pars. 23–3–10 (A) and 23–3–15 (A).) (The foregoing is theoretical and is true only in a perfectly clear medium. Practically, light decreases with distance more rapidly than indicated.)

B. *Candle* is the unit of luminous intensity. (The unit used is the International Candle as defined by the International Commission of Illumination.)

C. *Candlepower* (c. p.) is the luminous intensity expressed in candles.

D. *Sea-mile candle* (s. m. c.) is the illumination falling on a surface one sea-mile (6,080 ft.) distant from a light source of one candle and normal to the direction of the incident light.

E. *Refraction* is the bending from a straight path of a ray of light in passing obliquely from one medium into another in which its velocity is different.

F. *Reflection* is the return of light rays from a surface.

G. *Absorption* is the loss of light rays passing through a body. (The absorbed light is the difference between the incident light and the sum of the transmitted and the reflected light.)

23–3–5 Standard of Threshold of Visibility—

A. The acceptable value of illumination for perception after dark, and with the eyes of the observer adapted to darkness, is 0.67 sea-mile candle. For moonlight, this must be multiplied by 10; for daylight, by approximately 350 to 1,000.

23–3–10 Range—

A. The distance at which a light is visible depends upon five major factors, separated under luminous and geographical range:

(1) Intensity (the candlepower of the light[1]).
(2) Atmospheric conditions.
(3) Height of the light.
(4) Height of the observer's eye.
(5) Amount of illumination required for threshhold sensitization of the eye (*E*).

[1] Range, when of considerable length, is also affected to a slight degree by the color of the light, depending upon the atmospheric conditions. For all practical purposes, the curves in Figure 23–4 may be used without regard to color. (See Paragraph 23–5–35 (A).)

23–3–15 Luminous Range—

A. If lights transmitted their rays through a vacuum, the relative ranges would be proportional to the square roots of their intensities, and it would be sufficient to know the distance at which a light of a given power could be seen by a person endowed with ordinary vision to determine the range of a light of different intensity. On the other hand, the atmosphere always contains more or less suspended particles which have the effect, in connection with the distance, of weakening the luminous rays. This action varies between very wide limits. There are some dense fogs that the rays of our most powerful lights can penetrate only a short distance. The ranges, therefore, depend upon the state of the atmosphere and are actually much less than those which would be deduced from the law just referred to. It is evident, besides, that ranges also depend upon the acuteness of the observer's vision. Elements so variable and so difficult to estimate accurately do not enable us to obtain great exactness in the measurements of the ranges nor to place much confidence in them; yet it is desirable, even from a practical point of view, to study the question and subject it to calculation.

B. *Calculation of luminous range.*—The luminous range of a light on any given occasion depends on the intensity of the light, the atmospheric transmission, and the illumination required at the eye of the observer. These factors, except a constant for the atmospheric transmission, have been mentioned previously. Using formula 2:

$$E=\frac{I}{d^2} \text{ and rearranging} \qquad (2)$$

$$I=Ed^2 \qquad (3)$$

If a transmission constant T per unit of distance is introduced, then formula 3 becomes

$$\boxed{IT^d=Ed^2} \qquad (4)$$

C. *International visibility code.*—In practice, it is convenient to measure T as the atmospheric transmission factor per sea-mile and to measure d in sea-miles. The accepted value of E for threshold visibility after dark is 0.67 sea-mile candle, and for the purpose of this formula the luminous range of a light is defined as that distance at which the light produces an illumination of 0.67 sea-mile candle. The International Visibility Code (see table) also gives corresponding values of the transmission constant T. Formula 4 may be restated as

$$\boxed{I=\frac{Ed^2}{T^d}} \qquad (5)$$

and represents Allard's law. If E is considered to be a variable, E_v the law is recognized as accurate.

D. *Transmissivity affects range.*—Beyond certain limits there is no great advantage in an increase of intensity. Figure 23–4 shows this strikingly. For instance at 25 miles, whether 10,000 candlepower or 1,000,000 candlepower is visible, depends only on the *degree* of very clear weather. Conversely, when there is dense fog, an increase from 10 candlepower to 1,000,000 candlepower will increase the range only a few hundred feet.

INTERNATIONAL VISIBILITY CODE

Code No.	Weather	Daylight visual range		Transmission constant T	
		Statute miles	Sea miles	Per statute mile	Per sea mile
0	Dense fog	0 to 0.031	0 to 0.027	------------	------------
1	Thick fog	.031 to .124	.027 to .108	------------	------------
2	Moderate fog	.124 to .31	.108 to .27	------------	------------
3	Light fog	.31 to .62	.27 to .54	------------	------------
4	Thin fog	.62 to 1.2	.54 to 1.1	0.0019 to 0.044	0.0007 to 0.027
5	Haze	1.2 to 2.5	1.1 to 2.2	.044 to .21	.027 to .16
6	Light haze	2.5 to 6.2	2.2 to 5.4	.21 to .53	.16 to .48
7	Clear	6.2 to 12.	5.4 to 11.	.53 to .73	.48 to .70
8	Very clear	12. to 31.	11. to 27.	.73 to .88	.70 to .87
9	Exceptionally clear	Over 31.	Over 27.	Over .88	Over .87

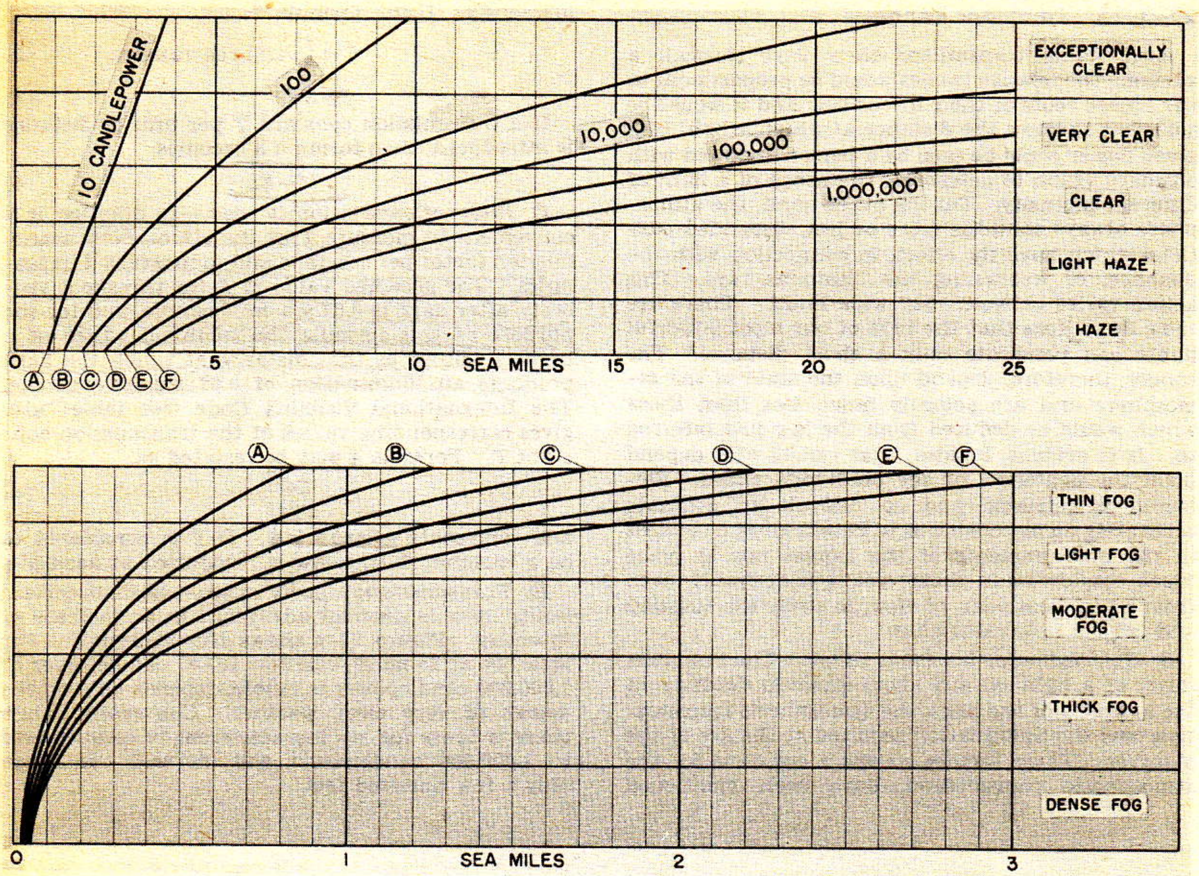

FIGURE 23–4.—Luminous range for different atmospheric conditions.

23–3–20 Geographical Range—

A. *Definition.*—The geographical range of a light is the distance at which it can be seen over the horizon, and is dependent upon the height of the light and the height of the eye of the observer.

B. *Calculation.*—Theoretically, the range is limited to the length of the tangent line drawn from the light to the horizon, as represented by *BC* in figure 23–5. This distance (*D*) can be calculated from the formula:

$$D=1.06\sqrt{H} \qquad (6)$$

where

D=the range in nautical miles for an observer whose eye is at sea level.

H=the elevation of the light above sea level, in feet.

C. *Effect of refraction.*—The luminous rays which traverse the atmosphere pass through strata of air, the density of which diminishes in proportion to their elevation. The rays undergo continuous refractions and consequently describe curves when their directions are not normal to the surface of the earth. These curves are concave toward the earth and refraction has the effect of increasing the ranges. (See fig. 23–4.) The amount by which the range is increased depends on factors of temperature, pressure, and humidity. However, for average conditions it has been found that the actual geographic range can be estimated very closely by a slight modification of the theoretical formula as follows:

$$D=1.15\sqrt{H} \qquad (7)$$

where *D* and *H* are used as in formula (6).

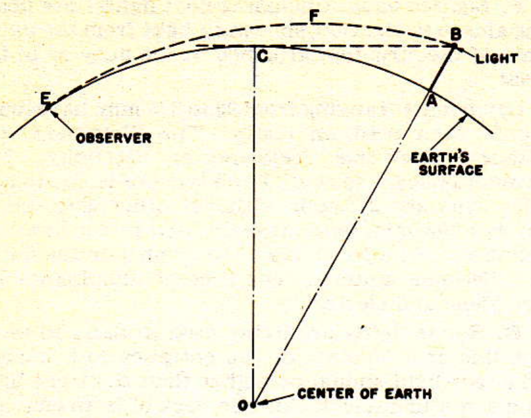

FIGURE 23–5.—Effect of refraction on geographic range.

D. *Range table.*—It is from formula No. 7 that the official United States Coast Guard Range Table, shown below, is calculated. This table shows the distances to the horizon in sea-miles for various elevations. The geographical range is obtained by adding together the two distances given in this table appropriate to the two heights above sea level of the light source and of the eye of the observer.

NOTE.—The United States Coast Guard Light Lists show range based on the observer being 15 feet above sea level.

Distance of visibility for objects of various elevations above sea level

Height (feet)	Distance (nautical miles)	Height (feet)	Distance (nautical miles)
5	2. 5	110	12. 0
10	3. 6	120	12. 6
15	4. 4	130	13. 1
20	5. 1	140	13. 6
25	5. 7	150	14. 1
30	6. 3	200	16. 2
35	6. 8	250	18. 2
40	7. 2	300	19. 9
45	7. 7	350	21. 5
50	8. 1	400	22. 9
55	8. 5	450	24. 3
60	8. 9	500	25. 6
65	9. 2	550	26. 8
70	9. 6	600	28. 0
75	9. 9	650	29. 1
80	10. 3	700	30. 3
85	10. 6	800	32. 4
90	10. 9	900	34. 4
95	11. 2	1, 000	36. 2
100	11. 5		

E. How far will a light 200 feet high be visible to an observer whose eye is elevated 15 feet above the water?

Answer:	*Nautical miles*
15 feet elevation; distance visible	4. 4
200 feet elevation; distance visible	16. 2
	20. 6

F. Under certain atmospheric conditions, and especially with more powerful lights, the glare of the light may be visible considerably beyond the calculated range.

23–3–25 Types of Light Beams—

A. *A fan beam* is one in which the light is concentrated in and about a single plane. The angular spread in the plane of concentration may cover either 360° or a smaller angle. (This beam is the most widely used.)

B. *A pencil beam* is one in which the light is concentrated symmetrically about a single direction. (The rays of light from revolving systems and range lights are of this category.)

C. *A converged beam* is a form of fan beam in which the angular spread of a fan beam is decreased by diverting a part of the light laterally to increase the intensity of the remaining beam over its full arc or over a limited arc. (This type of beam is used in a few large fresnel lenses.)

D. *A diverged beam* is a form of fan beam in which the divergence of a pencil beam is increased in a plane containing the axis of the beam (usually either horizontally or vertically) so that the angular spread of the fanned beam is greater than that of the original beam. (This type of beam is used in many range lights and in the latest revolving apparatus.)

E. *A diverted beam* is one whose axis is changed from the original direction in which it issued from the projection apparatus by means of diverting prisms placed in its path which do not change the beam divergence. (This is frequently done to *only a portion* of a pencil beam to provide asymmetrical lateral spread.)

23–4 NAVIGATIONAL REQUIREMENTS OF LIGHTS

(Water-Borne—Air-Borne)

23–4–1 Optical Standpoint

A. From the optical point of view, the requirements which a light must fulfill to be considered satisfactory are as stated in the following paragraphs.

B. It should be visible to the full extent of the range required of it. (This implies that the luminous range, which is governed by the type and assembly of the light source and projector, should be at least as great under specified weather conditions as the geographical range, which is limited by the curvature of the earth.) (See par. 23–5–35 (A).)

C. The signals sent out should present a distinctive appearance to an observer. (This implies that the color and the characteristic of the light signal should be distinctive, enabling the observer to pick up and identify the aid from among other competitive lights.)

D. The characteristic employed should be such that a sequence of flashes or occultations has sufficient duration, or the flash recurs frequently enough so that it is easily possible for a mariner to take bearings on the light.

E. The apparatus used to send out the signals should be as efficient and as reliable as possible. While not of direct importance optically, this last condition has had a profound influence on the choice of light sources and optical apparatus for use in lighthouses.

23–4–5 Geographical Standpoint

A. From a geographical standpoint, to satisfy the requirements of navigation, several types of lights have been established as described in the following paragraphs.

B. *Primary seacoast lights* (sometimes called landfall lights) are those which the mariner first sights when approaching land.

The apparatus installed in these lights was designed to attain maximum geographical ranges with the light sources available at the time of installation. The apparatus installed in them during the nineteenth, and first few years of the twentieth century has been of the larger "orders." (See par. 23–5–5 (B).) Revolving weatherproof types of apparatus will gradually supersede these units for the reasons given below. The light source consisted first of the multiple wick lamp, gradually superseded by the incandescent oil vapor (I. O. V.) lamp, and lately by the incandescent electric lamp.

C. *Lightships* are attended vessels having all necessary lights and fog signals, and which show a light from the top of one of their masts.

300-, 375-, and 500-mm. cylindrical drum lenses are used in the lanterns at the masthead on United States lightships. The light source today is exclusively the incandescent electric lamp, ranging from 250 to 1,000 watts in size. Several filament designs are used. (See par. 23–7–1 (E).)

D. *Secondary lights* are lights shown at the entrances to harbors and inlets along the coast.

Here again, as in the primary lights, the assembled type lenses were installed throughout the years. Within the period during which electrification received its greatest impetus, the optic has frequently been changed to a smaller drum lens. These changes are occasioned by the condition of the older optic, worn condition of the revolving equipment (chariot, float, and drive), and/or a trend toward unattended operation of the aid. When revolving apparatus is replaced by a drum lens, the flashing characteristic, if retained, is generated by an electric flasher.

E. *Minor lights* are lights of low candlepower which are usually used in harbors, rivers, channels, and isolated locations. They are unwatched lights, necessary or convenient to leave unattended for considerable periods on account of their inaccessibility; i. e., lights on small rocks in the sea, in out-of-the-way places on land, on breakwaters washed by the sea, or on structures having submarine foundations.

The optic is, in all cases, a drum lens. It may be a partial or full 360° unit. The larger sizes may be protected by storm panes; the smaller units usually are not so protected.

F. *Lighted buoys* (including float lights) are floating aids to navigation, showing a light from the upper part of the structure attached to the buoy or to the float.

Drum lenses ranging from 90 to 375 mm. have heretofore been used on buoys. The illuminant was either Pintsch gas, acetylene, or electricity. The present policy is to confine the types of lenses to 90-, 150-, 200-, and 375-mm., although other sizes (notably the 300-mm. lens) are still used in considerable numbers. The policy is also to emphasize the use of the 200-mm. lantern. The present illuminants are acetylene and electricity.

G. *Range lights* are lights used in pairs to mark the line of a channel or the entrance to a harbor. The rear light should be higher than the front light and a considerable distance in back of it, to enable a navigator to use the range by keeping the lights vertically in line as he progresses into a channel. The problem of correctly spacing range lights and of properly determining the optimum focal plane heights is relatively simple. The primary considerations are:

(1) The distance of the range out to the limit of usefulness. This fixes the minimum difference in focal plane height required to prevent the lights from blending together and appearing as a single light.

(2) The width of the channel. This determines the distance required between the lights in order to provide sufficient sensitivity to "open up" within the channel limits.

H. *Calculation of range lights.*—Fig. 23–6 illustrates a typical application of range lights to mark a dredged channel. In designing such a range it is necessary to calculate the distance R and the heights h and H. These are determined from the following formulas:

$$\Delta = 3438 \frac{(H-h)}{D+R} \qquad (8)$$

and $K = \dfrac{WR}{D(H-h)}$ where (9)

Δ=the vertical angle of separation of the lights, in minutes of arc, subtended from a point at a distance D from the front light.

K=the coefficient of lateral sensitivity as explained in the table below.

NOTE.—W, R, D, H, and h used in fig. 23–6 are measurements expressed in feet.

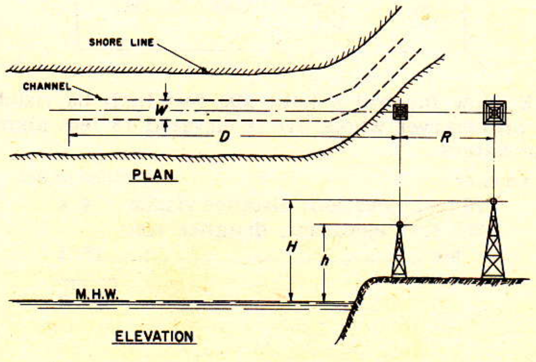

FIGURE 23–6.—Range lights.

(1) *Value of* Δ.—Experience has shown that if Δ is equal to, or greater than, 4.5 minutes of arc, a person with average eyesight will see the range as two separate and distinct light sources. Consequently, in applying formula 8 to the design of any range, Δ should not be allowed to go below this minimum.

(2) *Values of K.*—Values of the coefficient K, established by laboratory tests and analyses of actual ranges, are as follows:

Values of K	Description of sensitivity	Interpretation
Under 0.6	Not acceptable	Range must be improved or will be unworkable.
0.6 to 1.0	Poor	Increase the sensitivity if physically possible, even if considerable cost is involved.
1.0 to 1.5	Fair	Increase the sensitivity if doing so involves only moderate cost.
1.5 to 2.5	Good	Increase the sensitivity only if very little cost is involved.
2.5 to 3.5	Very good	In no case expend more funds to increase sensitivity.
3.5 to 4.5	Excellent	Upper limit beyond which sensitivity shall not be increased, since making any range more sensitive might create an impression that other ranges are not sensitive enough; also might cause navigator to fear using those portions of the channel near the edge.

(3) *Example.*—A range is to be built for a channel 350 feet wide and 15,000 feet long. Investigation of the most desirable site for a front light shows that the focal plane elevation of the front light must be not less than 28 feet because of shrubbery. Purely as a guess, a first value of R is assumed, say 1,000 feet. Then from formula 8 the factor $(H\text{-}h)$ necessary to give a minimum value of 4.5 to Δ is calculated to be:

$$H\text{-}h=\frac{\Delta\ (D+R)}{3438} \qquad (10)$$

$$=\frac{4.5\ (15000+1000)}{3438}$$

$$=21 \text{ feet; hence } H=49 \text{ feet.}$$

Knowing $H\text{-}h$, K is now calculated from formula 9:

$$K=\frac{WR}{D(H\text{-}h)} \qquad (11)$$

$$=\frac{350\times 1000}{15000\times 21}$$

$$=1.11$$

The table (par. H (2) above) shows that this value of K is acceptable. An effort should be made, however, to increase K by increasing R. Examination of the charts and investigation of local conditions show a satisfactory site for the rear light to be 1,735 feet back. A reapplication of formula 9 shows the required elevation of the rear light to be 50 feet. Solving again for K from formula 9:

$$K=\frac{350\times 1735}{15000\ (50\text{–}28)}=1.84.$$

This value is satisfactory and can be accepted if further attempts to increase the value of K involve the expenditure of funds in excess of what is considered justified because of the importance of the particular range.

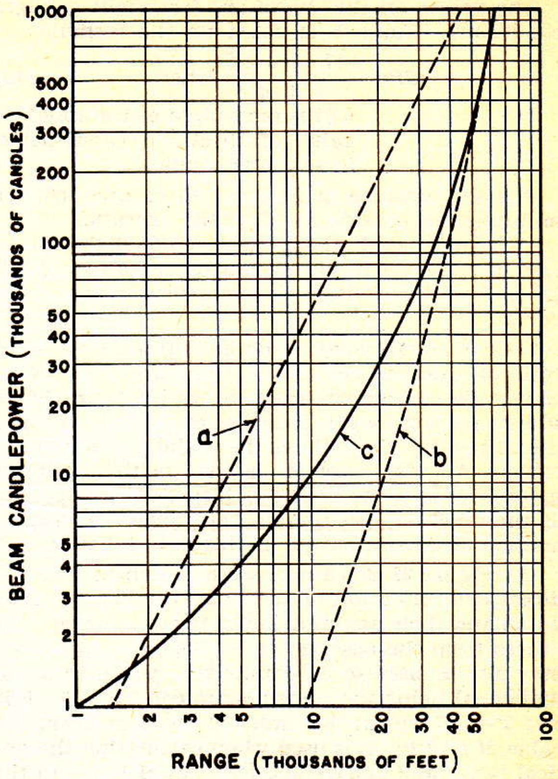

FIGURE 23–7.—Daylight visibility of range lights.

(4) *Formula (9) has other uses than in the design of a single range.*—For example, in a series of ranges marking successive reaches of a channel with a number of turns, it is desirable to have the ranges on all reaches operate with about the same degree of sensitivity. This is very easily accomplished by using the same value of K for all ranges. In examining a given range that is suspected of being faulty, it is necessary only to substitute directly in formula (9) and solve for K. Its value will immediately tell whether or not it is the proportioning of the principal dimensions of the range that is wrong.

(5) *Lighting apparatus.*—If intended only as a range light, the optic may be an assembled bull's-eye of any order, with or without mirror or reflecting prisms, all mounted in a large lantern, or it may consist of a weatherproof metal case, housing any combination of a bull's-eye lens, doublet [1] lens, and/or mirror. The mirror may assume any of several forms. (See Chapter 21.)

(6) *Daylight visibility.*—Range lights are now quite commonly operated on a 24-hour basis. Figure 23–7 will serve as a basis for estimating the candlepower required for ranges. Curve *a* is based on railway practice and on the empirical formula:

$$\text{Range}=\sqrt{2000\times CP} \qquad (12)$$

[1] A transparent medium consisting of concentric dioptric elements which partially bend the rays of light from a source. Its purpose is to recover rays from a greater solid angle than would otherwise be possible with a dioptric bull's-eye lens.

The values on this curve are for bright sunlight conditions. Curve b is based on the formula:

$$CP=\frac{0.67\times 350\times d^2}{(0.70)^d} \text{ where} \qquad (13)$$

0.67 is recognized as the standard value of threshold candlepower in sea-mile candles.

d is the distance in nautical miles, and 350 is a multiplier to provide for daylight operation.

Curve c is based on experience in daylight operation of ranges. It will ordinarily serve as a guide to the proper solution of candlepower for range lights.

I. *Determination of range light intensities.*—The ratio of candlepower of the front and rear lights should be considered when designing range lights so that neither light will appear excessively brighter than the other throughout the usable portion of the range. An ideal premise is that neither light be more than twice as bright as the other, irrespective of the observers position on the range. A graphic method of determination of this data follows:

(1) Figure 23–8 is a nomogram which permits the direct determination of the intervisibility of range lights and their apparent intensities at various distances from the observer to the lights. This chart may also be used to determine the optical range of individual lights for transmission constants $T=0.70$ and $T=0.87$ within the limits of the nomogram. A value of 0.70 for T is used when calculating the optical range and apparent brightness of lights in the continental United States. For tropical and semitropical conditions, the value of $T=0.87$ may be acceptable.

(2) The following illustrates the application of figure 23–8 to the selection of candlepowers for a pair of range lights for nighttime use:

Assumption—

Distance between front and rear light	2,000 feet
Distance from front light to extreme end of channel	20,000 feet
Distance from front light to near end of channel	4,000 feet
Transmission constant "T"	0.70 (clear weather)
Assumed minimum acceptable intensity of light received	100 S. M. C.

(*a*) Place a straightedge on the nomogram passing between 100 S. M. C. on right-hand scale and 20,000 feet for $T=0.70$ on the left-hand scale. Read on the center scale 3,500 c. p. the required intensity of the front light.

(*b*) Place the straightedge on the left-hand scale at 4,000 feet (distance from front light to near end of channel) and pass it through 3,500 c. p to read 6,400 S. M. C. on the right-hand scale.

(*c*) As a trial value, select an intensity of 7,000 c. p. for the rear light. Repeat the steps in (*a*) and (*b*), using the distances 6,000 feet and 22,000 feet respectively for the near and far end of the range. It will be seen that the rear light has an apparent intensity of 5,200 sea-mile candles at the rear end and 145 sea-mile candles at the far end.

(*d*) The ratios between the apparent brightnesses are:

At the near end	6400/5200 = 1.23/1
At the far end	100/145 = 1/1.45

(*e*) If the intensity of the rear light were reduced to 6,500, the ratios would become very nearly reciprocal values; however, since the ratios are approximately reciprocal and fall within the limits 1/2 and 2/1, the 7,000 c. p. would be satisfactory.

(3) A second example illustrating the use of the nomogram in arriving at the intensities of lights is given below.

Assumption—

Luminous or optical range	8 miles.
Minimum brightness (at extreme range) (The threshold of visibility of lights in darkness is ordinarily taken at 0.67 SMC.)	0.67 S. M. C.
Transmission constant "T"	0.70 (clear weather).

Question: What candlepower is required at the source?

Solution:

(*a*) Pass a straightedge through 48,640 feet (8 miles) on the left-hand scale of the nomogram for $T=0.70$, and through 0.67 S. M. C. on the right-hand scale. The straightedge will pass through 760 c. p. on the center scale. Accordingly 760 c. p. will be required.

(*b*) Similarly under tropical conditions when $T=0.87$ (very clear) the required light source will be found to be 130 c. p.

(4) The foregoing example is hypothetical and in practice when considering the establishment of a light visible for 8 miles, more candlepower would be required at the source; since 0.67 sea-mile candles is the threshold of visibility for normal vision, therefore that value would not afford a suitable aid to navigation.

(5) Large-size copies of the graph are available by addressing Commandant (ECV), and requesting prints of drawing titled "Graphic Determination of the Brightness of Lights," Drawing No. 102582, sheets 1 and 2.

23–5 ILLUMINATING APPARATUS

23–5–1 Optical System—

A. *Physical aspects.*—In all modern lighthouses, the rays of light from the luminous source are collected and caused to travel along the desired path by:

Reflection	Catoptric.
Refraction	Dioptric.
A combination of the two	Catadioptric.

B. *Catopric* apparatus is that in which the light is only reflected; the reflector being some highly polished surface.

C. *Dioptric* apparatus is that in which the light is refracted or bent by a transparent agent in the direction required. Such an agent is termed a refracting prism or refractor. The dioptric system is used in all modern lighthouse apparatus.

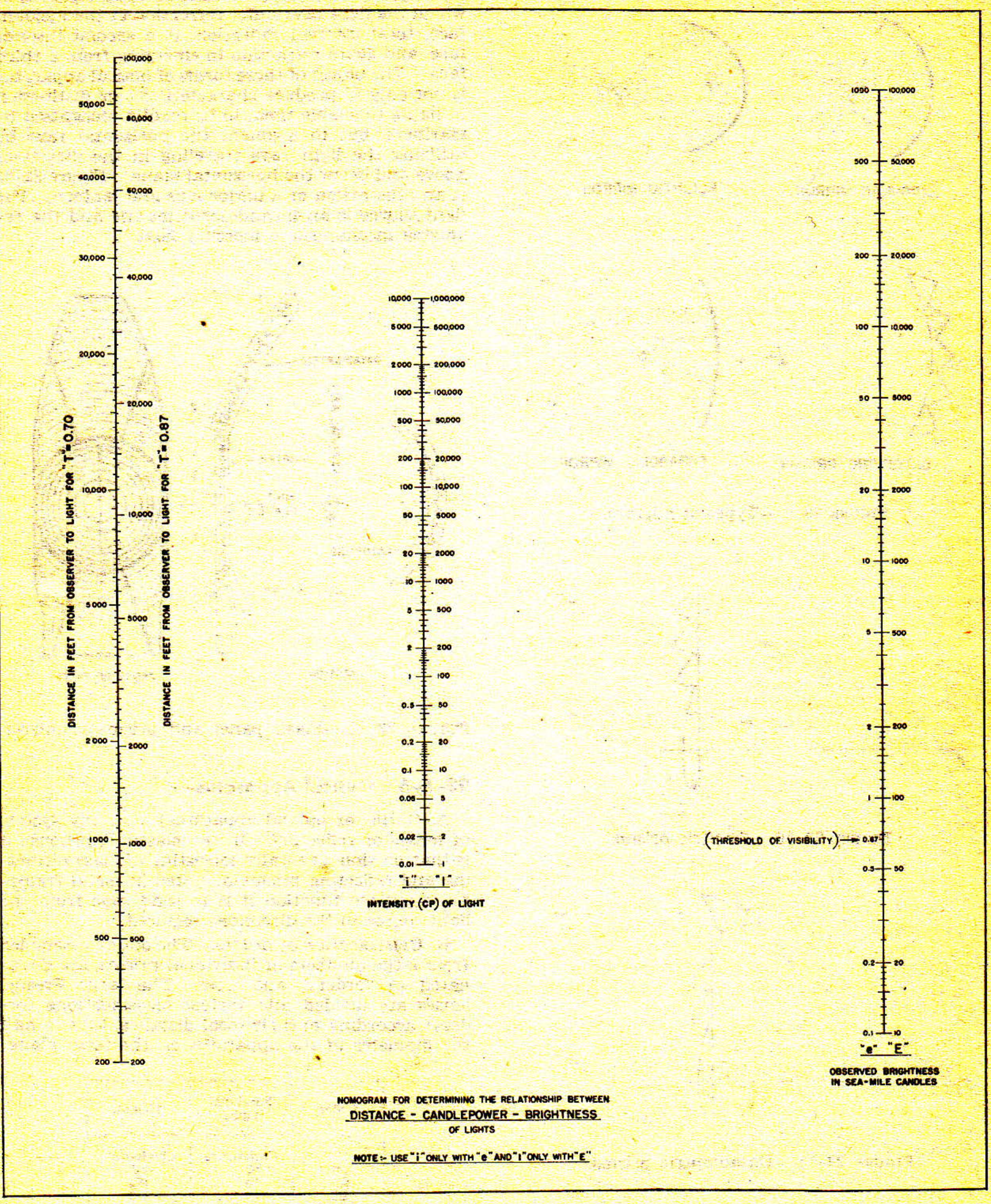

Figure 23–8.—Nomogram for determining the relationship between Distance — Candlepower — Brightness.

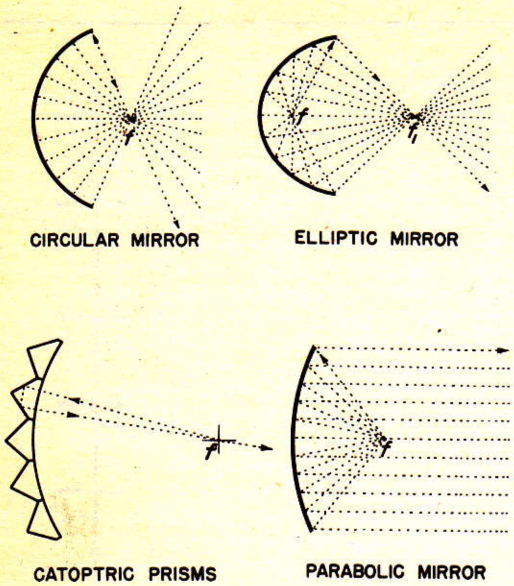

FIGURE 23–9.—Types of mirrors.

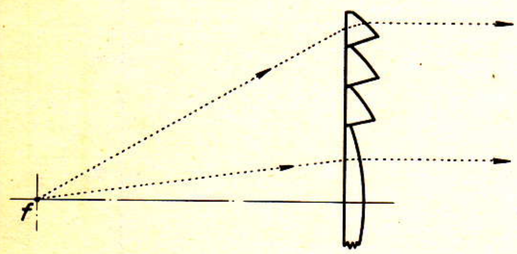

FIGURE 23–10.—Dioptric prisms.

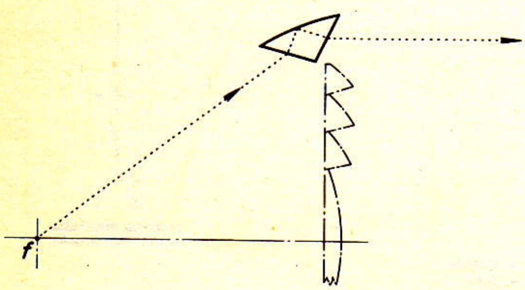

FIGURE 23–11.—Catadioptric prisms.

D. *Catadioptric* apparatus is a combination of the two; that is, it uses both refraction and reflection to bend the rays of light in the direction required. This apparatus usually consists of optical prisms in which the light rays suffer refraction at the incident face, total interval reflection at a second interior face, and again refraction in emerging from a third face. The object of these forms of optical apparatus is not only to produce characteristics or distinction in lights to enable them to be readily recognized by mariners, but to augment the horizontal rays by utilizing the light rays traveling in the directions above and below the horizontal plane. Figure 23–13 is an illustration of a major lens and lantern. The light source is an incandescent mantle and the revolving mechanism, a mercury float.

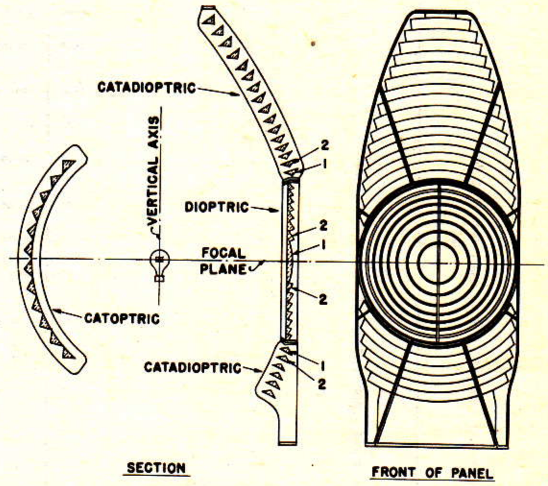

FIGURE 23–12.—Flash panel and prismatic mirror.

23–5–5 Optical Apparatus—

A. Optic (or optical apparatus) . . . any system of lenses or reflectors. In the classic lighthouse it is that portion, generally consisting of glass refracting and reflecting prisms mounted in metal frameworks, whose function it is to send rays from the light source in the directions required.

B. *Classification by orders.*—The optics, assembled from large numbers of individual prisms, are designated in "orders" and sizes. The large Fresnel lenses are divided into various classifications (orders) according to their focal distance, that is, half the diameter of the apparatus on the focal plane:

Order	Focal distance	Height
	Centimeters	*Centimeters*
1st	92	235
2d	70	182
3d	50	140
3½	37.5	110
4th	25	68
5th	18.75	51
6th	15	41

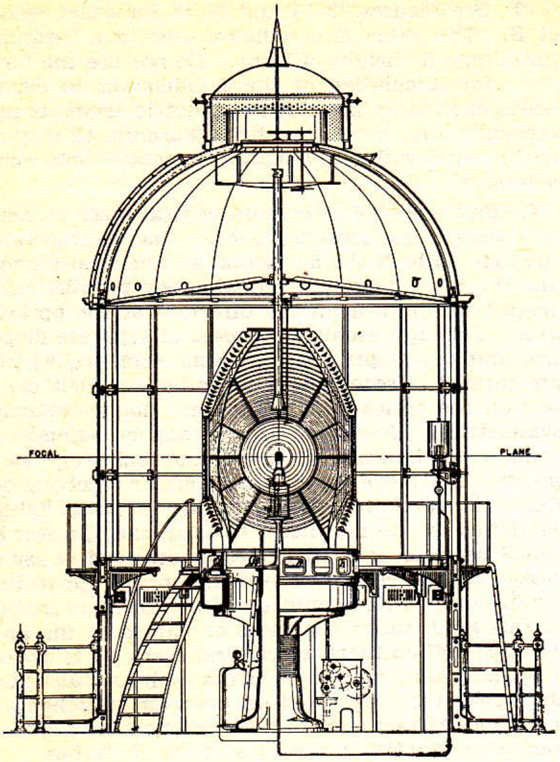

FIGURE 23–13.—A major light.

Classification by diameter.—Small drum lenses used by the United States Coast Guard are designated by their diameter in millimeters:

Diameter	Height
Millimeters	*Centimeters*
500	50
375	37.5
300	24.5
200	16.5
150	13.5
90	9.0

C. The *focal plane* is the horizontal plane through the center of the "belt" or "bull's-eye."

D. The *belt* is the central refractor in a fixed optic.

E. A *flash panel* consists of those optics whose elements are arranged concentrically around one or more horizontal axes passing through the light source. They generate pencil beams along each axis.

F. The *bull's-eye* is the central dioptric element of a flash panel.

G. *Numbering of elements.*—In both fixed[1] and flashing[2] optics the elements are numbered upward and downward, starting with the belt or bull's-eye as No. 1 and working outward. Figure 23–11 shows a vertical section of a typical optic. Each type of prism is indicated.

23–5–10 Classification by Types

A. Besides classification by orders, optical apparatus may be classified as drum lenses, bull's-eye lenses, etc., without regard to size.

B. In general, drum lenses are those optics whose elements are arranged concentrically around the vertical axis of the light source. They generate fan beams.

(1) *Broad definition of drum lenses.*—If of the assembled Fresnel type, containing both dioptric and catadioptric elements, the catadioptric elements are generally arranged in echelon to enable the greatest use of the spherical emission of rays from the source. (See fig. 23–12.) When thus assembled from both dioptric and catadioptric elements, their sizes are still indicated by orders, as shown in the table following paragraph 23–5–5 (B).

(2) If containing only dioptric elements, the lenses are described by inside diameter and are essentially cylindrical in shape. The height-diameter ratio is limited by the angle at which rays may be *refracted* to the horizontal from the source. The ratio will not exceed approximately 1.0, depending on the index of refraction.

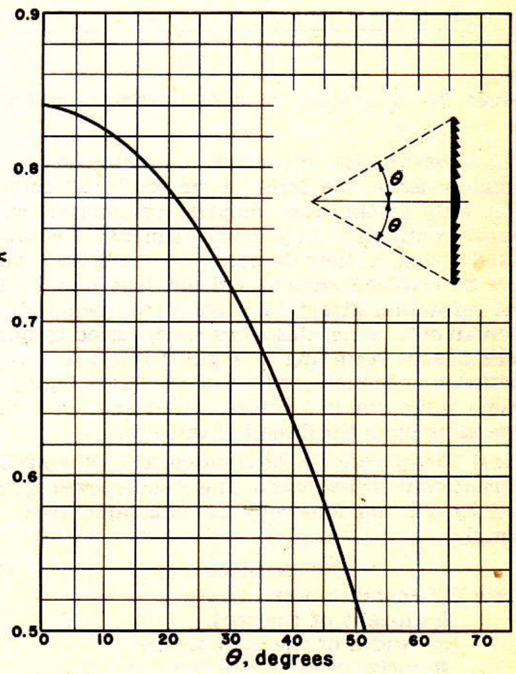

FIGURE 23–14.—Graph of a fan beam dioptric.

[1] One which is constant in intensity when viewed from a fixed point. A continuous steady light.

[2] Showing a single flash at regular intervals, the duration of light always being less than that of darkness (generally adopted for important lights).

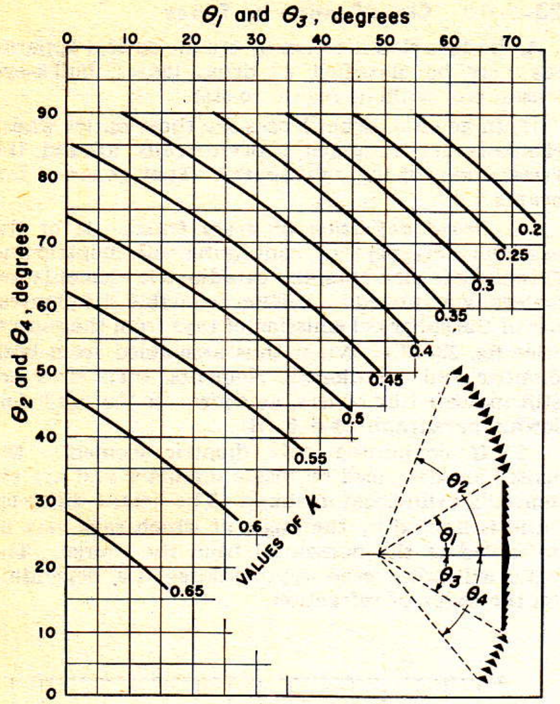

FIGURE 23-15.—Graph of a fan beam catadioptric.

C. *Conventional definition of drum lens.*—By common usage, the term "drum lens" has come to refer only to the later dioptric cylindrical lenses. Lenses containing only drum elements are always "fixed"; that is, they do not revolve. A flash panel may be revolved outside a drum lens and by lateral refraction divert the rays into a pencil beam. Such an optic generates a fan beam varied by one or more flashes recurring at regular intervals. A reduction or complete eclipse of the fixed light (fan beam) will occur just before and after such a flash, depending upon the design of the optic.

(1) *The calculation of candlepower generated by conventional drum lens.*—The candlepower generated by a drum lens may be calculated from the formula;

$$CP = B \times h \times w \times K \qquad (14)$$

where CP=candlepower.
h=height of the lens.
w=width of the light source.
B=brightness of the light source.
K=a factor to account for loss of light through the optic and storm panes. (A safe and practical figure to use is 0.50.)

For average dioptric drum lens.......... K=67%
For combination dioptric and catadioptric lens.............................. K=58%
Multiply by .85 for lantern or storm panes.

(2) See Figures 23–14 and 23–15 for exact value of K. The value K is a figure used in a formula containing h (height of lens). Do not use the formula for calculation of the candlepower in drum lenses containing annular catadioptric elements set vertically one above the other. Formula 14 relates to the lenses without prismatic or metallic spherical reflectors.[1]

D. *Bull's-eye lenses* contain central large refractors (hence the term bull's-eye) that concentrate the light in both the horizontal and vertical planes and project a beam of approximately parallel rays against the horizon in the direction of the optical axis. They are usually composed of separate dioptric and catadioptric transparent elements, which are formed in segments of rings having their centers on the optical axis. They are not necessarily symmetrical. Revolving lenses may be assembled from a combination of drum and bull's-eye elements. Bull's-eye lenses may be either revolving or fixed. If revolving, they generate flashing lights as viewed by the mariner. If fixed, they project a pencil beam of light (deflected or diverged in some cases) along a course. Revolving optical apparatus for flashing lights is built up of one or more lenses of this kind, called the faces or panels of the apparatus. When there are several faces, as is usual, a beam of light is projected from each so that when the apparatus is revolved an observer stationed at a distance can see each of these beams in succession, and the apparatus presents a series of flashes.

(1) *Calculation of candlepower generated by bulls-eye lens.*—The candlepower generated by a bull's-eye lens or a flash panel of a revolving lens may be calculated from the following formula.[2]

$$CP = B \times A \times K \qquad (15)$$

where CP=candlepower.
B=brightness of the light source.
A=area of bull's-eye or flash panel in cm.^{2}
K=constant.

(2) The above formula, similar to that from which the candlepower through drum lenses is calculated, relates to the lenses without reflectors. The increase in candlepower for lenses with special reflecting or refracting arrangements depends on several factors. (See footnote 1, p. 23–15.) The constant K, here as in formula 14, depends on the composition of the flash panel and the angle with the horizontal at which the ray from the source impinges on the elements. Although a value of 0.50 has been used for an over-all reduction factor to account for the average reduction through a composite lens consisting of dioptric and catadioptric elements and the loss through the lantern panes, it must be applied to in-

[1] Since the design of a drum lens is based on direct interception of rays from the light source, any attempt to augment the candlepower must be accomplished by passing the reflected rays back through or adjacent to the light source.

[2] Provided the panel or bull's-eye was designed for a point source and no auxiliary optical devices such as doublet lenses or special reflectors intervene in the light path between the source and the panel.

dividual cases only after the complete design has been studied. The value K varies from 0.45 to 0.85 in dioptric elements. (See figs. 23–16 and 23–17.) It is taken as 0.7 for all catadioptric elements. (See formula 15.) Although candlepower data have been available for several years, based on order, number of flash panels, and type of light source, they proved to be generally inaccurate. There are so many arrangements of elements in use, that to assume arbitrarily, for instance, that because a lens is 3d order, has six flash panels, and the source has, for example, a brightness of 500, the candlepower will be a certain calculated value, is to arrive almost certainly at an erroneous conclusion. When proposing changes in candlepower and/or light source, measure and, if practicable, photograph the panel, ascertain definitely whether prismatic reflectors are installed, and forward the data to Headquarters with Form 2609. Other factors are involved in the problem, such as the relationship existing between the size of optic and proposed source, or, if revolving, the dimensions of the source, etc. These points are treated in paragraph 23–5–40 (A).

E. *Bull's-eye lenses for range lights.*—There is a variety of optical arrangements employed in the design of range light apparatus. It varies from large Fresnel assembled panels containing dioptric and catadioptric elements and prismatic reflectors to simple plated parabolic reflectors with plain cover glass. Several types are mentioned specifically under "Apparatus Assembly"; candlepower data also are given with each where practicable. Formula 15 may be applied in checking the following:

(1) Simple bull's-eye panel in which the normal projected area and focal length are known or can be determined. (Bull's-eye panel and doublet lens if the foregoing data are known. The doublet lens serves both to subtend a greater solid angle of light from the source and to shorten the physical dimensions of the apparatus. It affords a convenient means of obtaining color.)

(2) A parabolic mirror when the area is known and the known or measured angle of divergence of the beam does not exceed approximately 5 percent. The candlepower of combinations involving elliptical, ellipsoidal, circular, paraboloid, or other special types of mirrors, and bull's-eye (with or without doublet-compound lenses) must be measured. The pencil beam from a range light may be diverged (spread) by the design of the panel of bull's-eye or by the insertion of suitable doublets between the panel and the source. The candlepower of the beam decreases in approximately inverse ratio to the spread (angular divergence) of the beam.

23–5–15 Characteristic and Period—

A. The characteristic group of flashes and eclipses which a light repeatedly emits, i. e., single flash, double flash, etc., is called its characteristic. The period is the time which elapses for one complete cycle of flashes and eclipses.

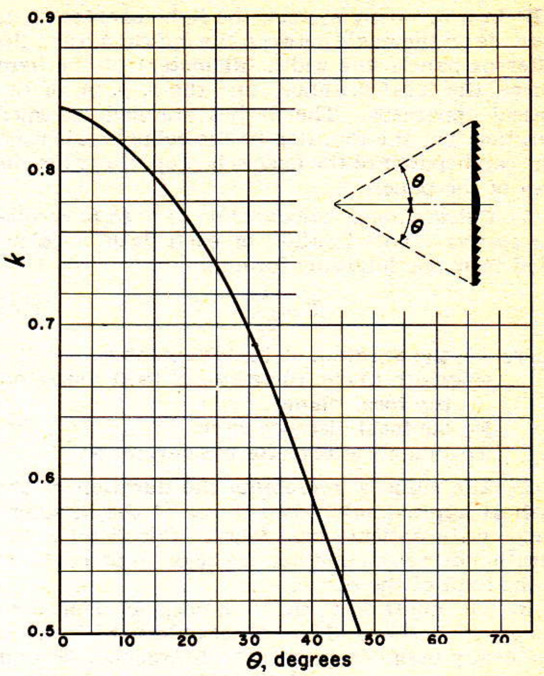

FIGURE 23–16.—Graph of a pencil beam symmetrical dioptric.

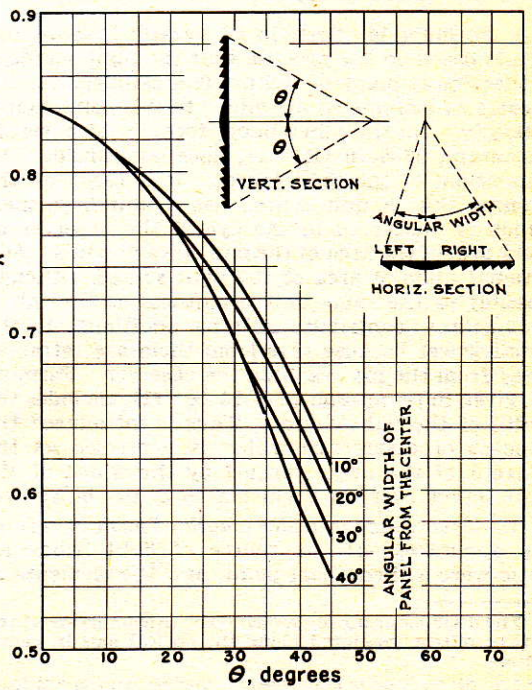

FIGURE 23–17.—Graph of a pencil beam asymetrical dioptric.

B. In a revolving system, the light characteristic depends on the angle between the optical axes of the different panels, the width (diameter) of the light source, the focal distance,[1] and the r. p. m. of the optical apparatus. The flashes are each of equal duration, but the duration of the eclipses can vary. The candlepower of the flashes is proportional to the area of the panels.

(1) *Calculation of the duration of flash in revolving system.*—The duration of each flash is calculated from the following formula:

$$T=\frac{tw}{2\pi F} \qquad (16)$$

where T= the duration of flash in seconds.
w=width in cm. (diameter of light source on the focal plane).
F=the focal distance of cm.
t=time in seconds for one revolution.

(2) The value T represents the duration of the flash at approximately two-thirds of the luminous range in the optical axis. Beyond this distance the duration decreases and may be 25 or 30 percent less at the limit of the range.

(3) The duration of the flash does not depend on the width or shape of the panel unless the latter is specifically designed to provide divergence[2] beyond that occasioned by the width of the light source, but on the period of revolution of the apparatus and on the divergence.

23–5–20 Divergence—

A. Formula 14, given in paragraph 23–5–10 (C) (1), is based on the premise that the light source is a theoretical point of light. The candlepower increases as increments are added to this point source laterally. On the other hand, formula 15, given in paragraph 23–5–10 (D) (1), does not consider the dimensions of the light source. It is based on the premise that a unit source has a unit brightness which is redirected to the eye of the observer by every unit of the area of the bull's-eye or panel. Additional units of area of the light source, although possibly of the same unit brightness as the initial unit source, contribute nothing additional to the candlepower because rays from them are refracted away from the ray reaching the observer. Formula 16, given in paragraph 23–5–15 (B) (1), includes the width of the light source. Thus is introduced the concept of divergence which is expressed as the tangent of the angle formed by the width of the light source over the focal length of the bull's-eye.

(B) *Divergence provides length of flash in revolving apparatus.*—If the source of light inside an optic were a theoretical point, and the elements of the optic were all perfectly designed to receive light from this theoretical point source and to refract and/or reflect it along absolutely parallel paths, in apparatus revolving at ordinary speeds, the beam would pass a point on the horizon in an almost infinitely short period of time. In practice, of course, the light source is of appreciable size and contains the focus within itself; hence the rays coming from the sides, top, and bottom of the light source are incident to each point of the optic at an angle with the ray from the focus. Such rays on passing through the optic emerge at essentially the same angle to those from the focus. The whole beam is therefore divergent. In the case of a flash panel or a bull's-eye, a cone of the light is emitted whose vertical divergence compares to the height of the light source and whose horizontal divergence compares to the width of the light source. The foregoing is well illustrated in figures 23–18 and 23–19.

23–5–25 Lens Design—

A. To clarify the place that the various optics have taken in the development of lighted aids to navigation, reference should be made to certain aspects of the history of navigational lights given at the beginning of this chapter. The table following paragraph 23–5–5 (B) lists the orders of larger assembled prismatic lenses. These lenses, invented early in the nineteenth century and developed and furnished during the early part of that century, were designed to make the best use of the coincident light source—the multiple wick burner. During the latter part of that century they were designed for I. O. V. mantle light. Although modern assembled Fresnel optics are designed for modern electric light sources, such lenses have not been purchased by the Government since the introduction of the electric incandescent lamp; therefore, the large lenses still in use were designed for light sources which have larger projected areas than can be readily furnished by electric sources.

B. The designers of these lenses arbitrarily departed from the theoretical concept of a point source of light. The upper catadioptric elements were ground and assembled to receive rays of light from the back, side, and top of the necessarily large light source and to redirect those rays to the horizon (or into the pencil beam if the optic was a flash panel). The central dioptric portion of the lens was designed to receive the light from the front of the light source, and the lower elements from the front and lower edge of the light source. The designers of these large Fresnel lenses built into the combined system of light source and optic predetermined divergence of the beam of light.

C. The smaller drum lenses, discussed in section 23–5–10, whether made from a pressed medium (glass or plastic) or assembled from ground and polished elements, are designed for a theoretical point source of light. Thus the candlepower for these optics may be calculated with a reasonable

[1] The distance from the focus to the inner surface of the lens or mirror measured along the optical axis in centimeters.

[2] The divergence is expressed in degrees and is approximately the angle whose tangent is $\frac{w}{F}$ where w is width of source and F is focal distance.

degree of accuracy by using formula 14. The vertical divergence of the fan beam varies somewhat proportionately to the height[1] (and *width*) of the light source. Small drum lenses efficiently refract the light from sources having a horizontal dimension of 1/200th of the lens.

23–5–30 Efficiency of Optics—

A. The formulas given for calculation of candlepowers have included the factor K, a figure to account for the loss through the optical media involved. In prismatic lenses there is a loss of light due to absorption in passing through the prism. This absorption will vary with the length of the path of the light ray through the prism. This path is much longer through the catadioptric elements than through the dioptric elements and, in general, longer through the prisms of a large lens than a small lens. In addition, there are losses due to imperfect setting of the prisms and, in pressed lenses, losses due to imperfections in the optical surfaces. The most perfect optic in use is probably the silver-surfaced metallic reflector produced by depositing the metal electrolytically or by spraying upon a ground and polished glass form. Such reflectors are now produced in which the optical imperfections are negligible, and have a reflecting factor, when new, of about 95 to 98 percent. This will decrease rapidly with any dimming of the reflecting surface. Sealed beam reflectors will retain their original high efficiency and are being investigated for possible application as light sources. Silvered glass reflectors, such as Mangin mirrors, are subject to losses by absorption in the glass. Silver-surfaced reflectors molded on glass may be estimated as being about 90 percent efficient, and spun or pressed reflectors and silver-backed glass reflectors at about 66 percent. There is also a loss of some 10 to 15 percent due to absorption of light by the plate glass panes of the lantern housing.

B. *Loss of efficiency due to density of source.*—In the special case of the spherical reflector, which returns the rays of light back through the light source, a further loss of efficiency occurs due to the density of the source. The following values are suggested for this factor:

Acetylene flame	.85
Wick flame	.50
Incandescent mantle	.10
Clear incandescent electric lamp	.25 to .50
Frosted electric lamp	None

(1) By adjustment (design), spherical reflectors may be placed out of focus so as to project their image to the front, back, top, or one side of the source. By this means, the over-all efficiency of a lens system using this type of reflector may be increased. Advantage has been taken of this expedient to widen a light source and thus increase flash length in a revolving system, improve the performance of a light source in a large lens, etc.

(2) A reflector reinforces the light source only through an angle equal to the angle it subtends at the source.

[1] It is readily demonstrated that the area of a horizontal flat light source has apparent height when projected normal to all but the horizontal rays on the axis.

(3) The graphs (Figs. 23–14, 23–15, 23–16, and 23–17) show how K varies with the different prisms and its functional relationship to the angle to the particular element with the horizontal axis.

23–5–35 Color Screens—

A. When a beam is colored by the insertion of a shade, the candlepower is reduced in direct proportion to the transmission factor of the shade for the color temperature of the light source used in the optic. The following table gives the average values as a fraction of the intensity of the corresponding white source.

Average transmission factor for color shades

Light source	Color of beam: Red (Average transmission factor)	Color of beam: Green (Average transmission factor)	Percentage of voltage of electric lamps
Oil flame:			
(1900° K.[1])	0.30	0.12	37
(2100° K.)	.27	.15	46
Acetylene flame: (2360° K.)	.25	.18	61
I. O. V. mantle: (2720° K.)	.22	.20	93
Electric lamp: (2842° K.)	.22	.20	100

[1] Kelvin. Degrees centigrade ~~above~~ absolute zero, or degrees centigrade plus 273.

Yellow 0.60

B. *Specification for transmission of color shades.*—The foregoing values correspond to the transmission characteristics of color shades which will be furnished hereafter by standard procurement methods. Specification An–C–56 and latest amendments thereto will govern procurement of Lighthouse Red and Lighthouse Green glass, which correspond to Aviation Red and Aviation Green.

C. *Previous transmission values.*—The transmission constant of color shades furnished in the past has varied between wide limits, the practice having been to purchase to correspond with samples which gave transmission values of approximately 0.30 when used with acetylene flames. These values gave an indication which was judged to be satisfactory to the needs of navigation at that time.

D. *Effect of color temperature of source on transmission value.*—Reference to the table under paragraph 23–5–35(A) will disclose the obvious fact that an average red shade passes about 40 percent more of the light from an oil lamp than from an electric lamp. Similarly, a green shade will pass only 60 percent as much of the light from an oil lamp than it passes from a 2842° K. electric lamp. Undervoltaging an electric lamp to 37 percent of normal voltage reduces the green transmission factor to 12 percent and increases the red transmission factor to 30 percent.

(1) Undervoltaged lamps should be used with green shades only when other factors outweigh the undesirable loss of beam candlepower.

(2) Green should be avoided in lights which must be observed at the limit of visibility. Green may be incorrectly interpreted at the threshold of visibility.

(3) When ordering color shades for all types of navigational lighting apparatus, always specify "lighthouse" colors. Otherwise, "identification" or "traffic" shades may be furnished.

23–5–40 Relationship Between Size of Optic and Size of Light Source—

A. The formulas are not applicable to the large assembled Fresnel lenses if the light source is appreciably smaller than the source for which the apparatus was originally designed. The following tabulation indicates the relationship which exists between the optic and the light source in the older large lenses.

Order	Focal distance	Width of the source	Source for which designed or suitable to use
	Centimeters	*Centimeters*	
First	92	11	5-wick oil lamp.
Second	70	11	Do.
Second	70	6	3-wick oil lamp.
Third	50	6	Do.
Third	50	5.2	55-mm. I. O. V.
Three and one-half	37.5	5.2	Do.
Three and one-half	37.5	3.3	35-mm. I. O. V.
Fourth	25	3.3	Do.

B. When electric sources are used they should approach the dimensions shown above.

C. It should now be clear to the engineer that a definite relationship must be observed between the type of optic available or to be designed, and the type of light source to be installed in an optic. The relationship which exists between the two is quite definite and any departure from that relationship results in inefficiency and a failure to obtain the candlepower theoretically possible.

23–6 LIGHT SOURCES

23–6–1 Brightness—

A. Brightness is the luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction. The practice recognized internationally is to express brightness in candles per unit area of surface.

B. *Calculation of brightness of source.*—

The formula $$B=\frac{CP}{\frac{A_h+A_v}{2}} \quad (17)$$ where

A_h=horizontal projected area in sq. cm.,

A_v=average vertical projected area in sq. cm.,

CP=average spherical candlepower of lamp,

is used for the calculation of the brightness of the various light sources used in lighted aids. It must be applied to electric sources with caution since it is accurate only when the source is essentially spherical. Given a light source of readily commensurable cross-section and a uniform light intensity, the determination of the brightness is simply a matter of dividing the total candlepower by the projected area of the source. Such a light source produces a beam of approximately uniform intensity. The incandescent mantle approaches closely these conditions and its B may be readily determined. The round wick oil light is a close second, then follow the flat oil flame, the acetylene flame, and lastly, the incandescent electric lamp. All of these sources except the electric lamp have approximately a uniform distribution of light throughout the bright part of the flame. The design of the filament electric lamp does not lend itself readily to calculation by formula (17). For convenience, therefore, and because the results approximate the theoretical values if all factors are carefully considered, the A_v is assumed to be the average of the vertical "outline" areas in two planes and the A_h the "outline" area of the horizontal projection of the filament.

C. *Relation between candlepower and lumens.*—If the lumen output of a light source is available, the average spherical candlepower may be obtained from the formula:

$$CP=\frac{\text{Lumens}}{4\pi} \quad (18)$$

D. *Brightness of various light sources.*—Of the light sources shown in the following table, the acetylene flame, the incandescent mantle, and the electric lamp are of principal importance today. They are described more in detail under Chapters 20, 21, and 22.

Source	*Candlepower per square centimeter*
Candle flame	2–4
Oil lamp	3–5
Kerosene wick lamp	9
Aladdin lamp	4
Acetylene flame, ¼ cubic foot burner	4
Acetylene flame, 1 cubic foot burner	8
Incandescent oil vapor (I. O. V.) 35 mm	22
Incandescent oil vapor (I. O. V.) 55 mm	30
Incandescent lamp	from 5–1500 (depending on design of filament, wattage, etc.)
Sun on horizon	2,000
Sun on zenith	600,000

23–6–5 Group Sources—

A. The candlepower of lenses or reflectors using a *group* of light sources may be estimated in the same manner as for single sources if it is borne in mind that the candlepower from flashing lenses or parabolic reflectors depends on the brightness of the light source, while that from drum lenses depends on the brightness times the *effective* width of the source. Figs. 23–18 and 23–19 are intended to illustrate graphically the effect of grouping sources. Fig. 23–18 illustrates two I. O. V. mantles behind a vertical profile of a drum lens. In a plane 90° from that of the illustration the beam at 3 would assume the form shown at 1. Since the calculation of candlepower in a drum lens uses the width of the source, it is evident that nonuniform character of the source will reduce the calculated candlepower. Fig. 23–19 illustrates two electric filaments behind a horizontal section of a bull's-eye lens. Here again the comments made in regard to the drum lenses apply, with the exception that it should be recalled

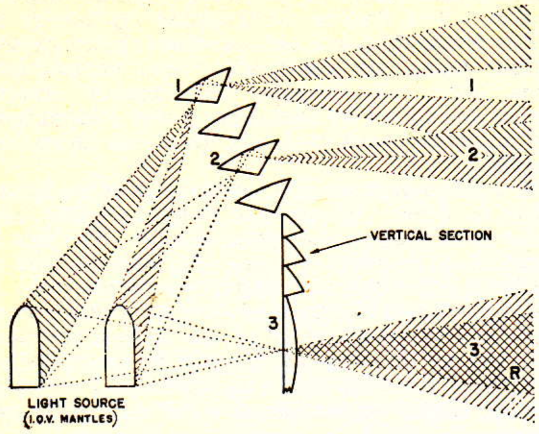

FIGURE 23–18.—Multiple light source in fixed lens.

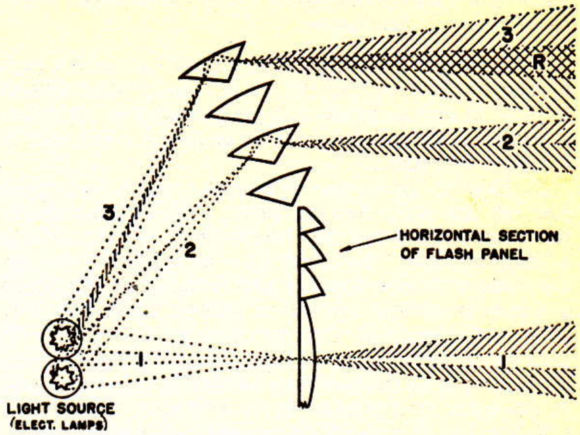

FIGURE 23–19.—Effect of multiple light source on candlepower and flash length in revolving apparatus.

that candlepower in a bull's-eye includes brightness of the source. Obviously, the brightness of the group source has been augmented by the use of two or more sources only in the narrow angle R at 3. On the other hand, use of the group source in both figures has increased the divergence and hence the flash length in a revolving unit.

B. If two or more sources are grouped closely about the focal point of a bull's-eye lens, increase in candlepower will result only in those portions of the optic where rays from more than one source overlap or augment the other. In this connection, see paragraph 23–5–30 (B). By reference to that paragraph, it will be noted that due to their transparency, acetylene flames may be grouped with considerable increase in candlepower. Wick flames may be grouped with partial benefit.

C. Two principal reasons exist for grouping light sources in larger flashing lenses: the first is to properly "fill" the lenses, and the second, to obtain horizontal divergence and thus lengthen the flash length in revolving units. The significance of the first is apparent by reference to paragraph 23–5–40 (B). A group of small sources may thus become equivalent to the source for which the lens was designed, with the reservations discussed below.

D. In drum lenses the increase in candlepower by grouping will be proportional to the effective increase in width, with the reservation that the formula $CP=h\times w\times B\times K$ applies only when w is approximately that necessary to subtend the design source width. Thus in small lenses (up to 500 mm.), when the ratio of source width to lens diameter becomes greater than about 1 to 50, the actual candlepower will be less than the formula value.

E. When grouping sources it is necessary to consider that the increase in candlepower will be proportional to the sum of the individual sources only if in the particular projection the individual sources form a homogeneous large source.

F. If voids exist in the over-all projection of the source, obviously the actual candlepower will, in drum lenses, not equal the product of the lens height times the over-all source width times the brightness. There is no accurate approach to the candlepower of an optic using a group source. An approximation is to calculate the group brightness by dividing the candlepower of the sum of individual sources by one-half of the sum of circumscribed horizontal and vertical projected areas. In this case, the calculation will be lens height times average brightness times the circumscribing width.

23–7 MAJOR ELECTRIC LIGHTS

23–7–1 Light Source—

A. The selection of the light source to be used in a major light depends principally on the lens design. The ratio of source size to lens size indicated in the table under paragraph 23–5–40 (A) and in paragraph 23–6–5 (D) must be observed for efficient and satisfactory electrification. The electric source must "fill" the lens. If the optic consists of revolving flash panels, the source must have sufficient width to provide the published length of flash.

B. *Vertical divergence.*—With the electrification of landfall lights, attended as it has been by material increase in beam candlepower, provision for "foreground illumination" has not been a problem, since the candlepower at the widening angle with the horizontal which occurs as the observer approaches the source has been adequate for the correspondingly foreshortened distances. The early practice of decentering the source upward could be discontinued with few exceptions. On the other hand, the new major lighting apparatus must be so designed as to provide upward divergence to assist a flyer as he approaches the coast. The new designs of major light units have been adopted with this end in view. Likewise, vertical divergence is essential from a lightship lantern, to compensate as far as practicable for roll and pitch of the vessel. (Constant leveling devices have not been applied to the lanterns on United States lightships. Modern developments in the airplane field may make practicable the construction of constant-level lightship optics in the near future.)

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23–7–10 Lampchangers and Standby Light Source—

A. An approved lampchanger shall be made a part of the electric equipment in all major unattended lenses. It should preferably be installed in *all* lenses whether at attended locations or not, if clearance in the lens will permit.

B. Several types are available. Approved types cushion the exchange of lamps. The manufacturer must know the lamp characteristics when furnishing a lampchanger. He must also be advised whether the lamp will burn fixed or will be flashed. Enclosed drum-type optical apparatus will be furnished only with lampchangers. Except when standby or duplicate power supply is installed, a standby light source shall always be in readiness for immediate insertion in the optic at attended light stations. When electrifying, the standby light source may consist of:

(1) Retention of one set of original light source apparatus (I. O. V. or oil wick lamp).

(2) Aladdin lamp.

(3) Small lens lantern with complete light source, battery, etc.

(4) Acetylene standby arranged to move into position automatically or manually.

C. When standby electric power is provided, a lampchanger shall be installed in the lens if clearance permits. The standby light is then omitted.

23–7–15 Main and Standby Power Supply—

A. To adequately "fill" the larger lenses and give beam candlepowers consistent with the importance and range of the light will generally require more energy per day than practicable with battery power. It is therefore necessary to provide commercial connections or install local generation equipment. Electrification of the main light is usually dependent on several factors, which include: Accessibility and reliability of commercial power, power for other navigational aids or domestic purposes, change in attended status of the light, and increase in intensity or change in characteristic.

B. When a request for authorization to increase the intensity of a light involves provision of power supply, that fact shall be covered in the Form 3434, including data and cost estimates for the main power and the standby light source or standby power supply and lampchanger.

(1) Provision of electric standby power depends on several factors, all of which must be considered by the engineer. The primary consideration is the importance of the light. On it depend the economic factors which limit the engineer in striving to attain a high degree of reliability. If the station is attended, the electric equipment should include a standby power source, or in lieu thereof, a standby light source as outlined in the preceding paragraph.

23–7–20 Time Clock—and Light-Sensitive Control Devices

A. The major electric assembly may include means for turning on the light with approach of darkness and means for providing a flashing characteristic. The first is accomplished by means of either a time clock or a light-sensitive control device. Either spring- or electrically-wound escapement-type clocks are suitable. Synchronous electric clocks should not be used, since power interruption or frequency variations will shift the operating period.

B. Light-sensitive control devices are of two types: those in which the response is photoelectric, and those depending on absorption of heat. The first is available in a variety of types. No restriction as to design is stipulated, but reliability is paramount. A desirable design feature is the provision that failure will occur predominantly in the lighted position. The second, the sunrelay, depends on absorption of heat from the light rays. Its mechanical design is similar to that of the sunvalve for controlling gas lights.

(1) A feature common to all light-sensitive control devices is their delicate operation. They are unsuited for handling large currents. Manufacturers' specifications for current rating must not be exceeded. Auxiliary power relays are required in all cases where they are to handle 32- and 115-volt lamps. The sunrelay performs best in low latitudes because the transition from light to dark and the reverse is more rapid in those latitudes. Slow operation accentuates "chattering" during the actual transition period.

(2) Current savings with such devices may be estimated at 30 percent although in some instances this value may be exceeded.

(3) Light-sensitive controls are applied to minor lights as well as to major lights. They are designed to handle low-voltage lamps without auxiliary relays. The design should include such controls only when the estimated savings for electricity will amortize the cost of the control device within a few years. An estimate for that purpose is 4 years, as the use of the controller introduces undesirable complications in the assembly, with attendant reduction in reliability.

23–7–25 Miscellaneous—

A. For a description of *alarm devices* and *flashing equipment* see sections 21–15–25 and 21–15–30 of this manual.

23–8 MINOR LIGHTS (ELECTRIC LENS LANTERNS)

23–8–1 Design Features of Lanterns—

A. *Classification.*—For convenience, the classification of electric lens lanterns is broken into six separate sections. Each is given independent weight although each is dependent on the others. They are lantern and lens, light source, lampchanger, flasher, battery source, and auxiliary devices.

B. *Lantern and lens.*—The trend now is toward a few types and sizes. The drum lens sizes correspond to the dimensions given in paragraph 23–5–5 (B). Both cut-glass and pressed-glass lenses are in use. Cut-glass has been shown by test to give a more concentrated higher candlepower beam in 300- and 375-mm. lenses. The lantern is constructed from homogeneous bronze castings machined as necessary at joints and working surfaces. All designs adhere to standard mounting dimensions. All designs must be waterproof except the post lanterns in use on the Mississippi River System and on protected inland waterways.

C. *Policy on lens design.*—To accomplish standardization, drum lenses in sizes up to 300 mm. will be approved only in pressed glass 375- and 500-mm. drum lenses will generally be approved only in cut glass. If the application justifies the use of 375- or 500-mm. lanterns, it should also justify the use of a cut-glass optic. Lens lanterns for buoys will be approved only in 150-, 200-, and 375-mm. sizes.

D. *Arrangement and application.*—Minor electric drum lanterns are available to provide a horizontal fan beam of narrow vertical divergence and, in the smaller sizes, a combination of horizontal beam and hemispherical distribution of light to provide an obstruction indication for the aviator. The latter type is referred to as the "V. & H." lantern or dual purpose lantern. Minor electric range lanterns make use of both transparent optics and various types of mirrors, to direct light in a pencil beam.

E. *Design conserves electric energy.*—With the exception of a comparatively few minor lanterns in which high voltage lamps are installed, the purpose of the minor electric lantern is to divert as much as possible of the available spherical light emitted from the light source into a narrow horizontal fan beam or along a designated axis. This care in design is to conserve the supply of electricity available in the battery. It was only after the design of all components of the electric lantern had progressed to a high degree of perfection that their application as aids to navigation accelerated apace.

F. *Factors in selection of range apparatus.*—A large variety of range lanterns, which vary in design from Ford automobile headlights to the General Railway Signal Company's type SA duplex lanterns, are in satisfactory operation at the present time. Recommendations as to make and type should be included in work authorization requests. Guiding principles for the selection of the apparatus should include: importance of the range, consistency in design between structure and equipment, weather hazard and exposure, candlepower and divergence desired in the beam, and standby facilities required. In general, except for very unimportant protected locations, it is preferable to use equipment designed specifically for the purpose rather than to adapt apparatus not well suited to continuous exposure. Standard range units are provided with sights for checking alignment. Any tendency to corrosion or sticking of threads, bolts, joints, gaskets, etc., is highly undesirable since the application of force when servicing the lights may easily throw them out of alignment, thus partially or totally destroying their value as lighted ranges. This point is of particular importance with high candlepower, narrow-divergence units.

23–9 CANDLEPOWER

23–9–1 General Policy Concerning Candlepower Calculations—

A. The computation of candlepower is dealt with at considerable length in explaining the design of large assembled optics. Numerous tabulations have been in effect, listing the theoretical candlepower obtainable from various combinations of light sources and lenses. A majority of the items in those tables have proved to be inaccurate. They shall no longer be used as a basis for candlepower determination. Subsequent to their issue many hundreds of photometric measurements have been made, within the government and by commercial organizations, of the combinations of optics and light sources in current use by the Coast Guard. These measurements have indicated desirable and undesirable combinations. No wholly satisfactory electric sources are available for very large lenses, as stated in paragraph 23–5–40 (A).

23–9–5 Calculation of Candlepower—

A. *Large order lenses.*—The table under paragraph 14–1–10 lists the available lamps; the table under paragraph 14–2–35 lists the apparent increase in source size by inside frosting; the table under paragraph 23–5–40 (A) gives the approximate source size necessary to fill the lens; and paragraphs 23–5–15 (A) et seq. give the computations for flash length.

When submitting work authorization requests, state approximate candlepower desired, give complete description of the lens, including photographs and plans if available, speed of revolution, order, number, and size of flash panels, etc. The data contained in this chapter enable the district engineer to determine the approximate candlepower. Headquarters will verify or modify the computation.

B. *36-inch double drum revolving beacons.*—The candlepower listed in paragraph 21–15–35 (B) are obtained with 1,000-watt, 115-volt, C–13 filament, T–20 mogul bipost lamps. Reduced candlepowers are obtainable by using 500-watt lamps otherwise conforming to the same lamp design specifications.

C. *Minor drum lenses.*—The table on p. 23–30 gives the conventional candlepower to be used hereafter with the usual small drum lenses and standard light sources. No distinction is made between pressed-glass and cut-glass optics in assigning candlepower values. Sources of candlepower data are mentioned in paragraph 23–9–1 (A). As so many variables were involved in candlepower determination it was desirable to use mean values of all available measurements when preparing the table on p. 23–30. The table should be used for all candlepowers to which it is applicable.

D. *Range lanterns.*—Manufacturers' candlepower curves are accepted for the combinations of range light units and lamps which they manufacture. Where information is not available locally it will be inserted by Headquarters when processing work authorization requests.

(1) Candlepower data will be supplied by Headquarters for special combinations and service types not otherwise available.

(2) Candlepower tabulations for the types mentioned above are being prepared and will be added when completed.

E. *Candlepowers in color.*—Reduce the candlepower for indication in green or red by the factors shown in the table under paragraph 23–5–35 (A).

F. *Candlepower computation at reduced voltages.*—In special cases where a light source is intentionally under-voltaged to assure long life due to absence of lampchanger or standby source, or for navigational reasons, refer to figure 14–9 for the reduction in candlepower corresponding to the reduced voltage proposed. In selecting a reduced voltage and corresponding reduced candlepower, bear in mind that the reduction must be made in increments which correspond to the unit voltages of standard batteries. The increments of voltage reduction are:

	Volts per cell
Wet primary cells	0.65
Low-discharge cells	2.05
Air cells	1.2

(1) For submission of Forms 3434, the following table shall be used in lieu of figure 14–9 to avoid minor errors that may occur due to the small scale of figure 14–9. The values of the table are listed to two significant figures and are not to be extended by interpolation or otherwise to more than two figures. Where it is found that a lamp is to be operated at a percentage of voltage which is not a whole number, use the nearest whole number in the table. For example: 66⅔ percent voltage would be called 67 percent and the percentage of candlepower would be taken as 22. Where the fraction is an exact half, drop the half. For example: 87½ percent voltage would be called 87 percent and the percentage of candlepower read as 62.

(2) Reduce the candlepowers for indication in green and red by the factors shown in the following table. In applying this table, the method of handling fractions described under (1) above should be followed.

REDUCTION IN CANDLEPOWER OF LAMPS DUE TO REDUCTION IN VOLTAGE

CANDLEPOWER VERSUS VOLTAGE

Percent volts	Percent CP	Percent volts	Percent CP
60	14	90	70
61	15	91	73
62	16	92	75
63	17	93	78
64	18	94	81
65	19	95	84
66	20	96	88
67	22	97	91
68	23	98	94
69	24	99	97
70	26	100	100
71	28	101	103
72	30	102	106
73	32	103	110
74	33	104	114
75	35	105	118
76	37	106	122
77	39	107	125
78	41	108	129
79	43	109	133
80	45	110	137
81	48	111	142
82	50	112	146
83	52	113	151
84	54	114	155
85	57	115	159
86	59		
87	62		
88	64		
89	67		

TRANSMISSION FACTOR VERSUS VOLTAGE [1]

Percent volts	Transmission factor	
	Red	Green
60	0.25	0.18
61	.25	.18
62	.25	.18
63	.24	.18
64	.24	.18
65	.24	.18
66	.24	.19
67	.24	.19
68	.24	.19
69	.24	.19
70	.24	.19
71	.24	.19
72	.23	.19
73	.23	.19
74	.23	.19
75	.23	.19
76	.23	.19
77	.23	.20
78	.23	.20
79	.23	.20
80	.23	.20
81	.23	.20
82	.23	.20
83	.22	.20
84	.22	.20
85	.22	.20
86	.22	.20
87	.22	.20
88	.22	.20
89	.22	.20
90	.22	.20
91	.22	.20
92	.22	.20
93	.22	.20
94	.22	.20
95	.22	.20
96	.22	.20
97	.22	.20
98	.22	.20
99	.22	.20
100	.22	.20

[1] Applies to color shades meeting specification MIL–C–25050 (ASG).

G. *Candlepowers of General Railway Signal range lanterns.*—The following table I gives "basic" values for type SA range lanterns. By "basic" values is meant that no rounding off or approximation has been employed in transferring the data from the actual test curves to the table. They are the values on which percentage deductions for undervoltaging, color, beam spread, etc., are to be made. Table II gives the basic values for type W range lanterns.

hemispherical distribution of light to provide an obstruction indication for the aviator. The latter type is referred to as the "V. & H." lantern or dual purpose lantern. Minor electric range lanterns make use of both transparent optics and various types of mirrors, to direct light in a pencil beam.

E. *Design conserves electric energy.*—With the exception of a comparatively few minor lanterns in which high voltage lamps are installed, the purpose of the minor electric lantern is to divert as much as possible of the available spherical light emitted from the light source into a narrow horizontal fan beam or along a designated axis. This care in design is to conserve the supply of electricity available in the battery. It was only after the design of all components of the electric lantern had progressed to a high degree of perfection that their application as aids to navigation accelerated apace.

F. *Factors in selection of range apparatus.*—A large variety of range lanterns, which vary in design from Ford automobile headlights to the General Railway Signal Company's type SA duplex lanterns, are in satisfactory operation at the present time. Recommendations as to make and type should be included in work authorization requests. Guiding principles for the selection of the apparatus should include: importance of the range, consistency in design between structure and equipment, weather hazard and exposure, candlepower and divergence desired in the beam, and standby facilities required. In general, except for very unimportant protected locations, it is preferable to use equipment designed specifically for the purpose rather than to adapt apparatus not well suited to continuous exposure. Standard range units are provided with sights for checking alignment. ~~Experience with aluminum units has not been satisfactory~~. Any tendency to corrosion or sticking of threads, bolts, joints, gaskets, etc., is highly undesirable since the application of force when servicing the lights may easily throw them out of alignment, thus partially or totally destroying their value as lighted ranges. This point is of particular importance with high candlepower, narrow-divergence units.

23–8–5 Light Source—

A. The optical system in all minor lights is designed for a point source of light. Fig. 23–21 shows the light source types generally used in electric minor lights. The C–2 types are principally used in range lanterns; the C–8 filaments in drum lenses.

B. *The C–2 filament* is designed to face the bull's-eye lens in a range lantern with the plane of the filament in a horizontal position. Thus lateral divergence is combined with high source brightness.

C. *C–8 filaments* are not designed for use in range assemblies. They give a spherical light distribution when burned in a vertical position and are ideally suited to the 360° drum lens, but not to a bull's-eye lens or mirror.

The following table lists all the standard lamps for minor lights that are procurable direct from the

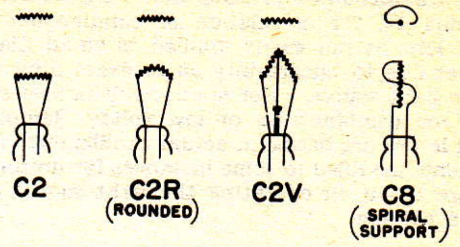

FIGURE 23–21.—Low voltage filament types.

lamp manufacturers having awards on Treasury Procurement Division annual contracts. Special rebased lamps using three-pin bayonet candelabra and miniature screw bases are still required for two or more designs of range lanterns. Procure these special lamps from the manufacturers of the lanterns.

D. *Facts concerning low voltage filaments.*—Certain important aspects of standard low voltage lamps are stressed. C–8 filament lamps are available with several base designs. However, the standard 4-lamp "lampchanger" is designed to carry only single contact, prefocus collar, bayonet base lamps. All C–8 filament lamps shown in the table are of that type.

(1) Single contact bases have proved more reliable at the low voltages involved and are standard. Do not make new installations using double contact bases.

(2) 6.2-volt and lower voltage lamps are better suited to smaller drum lenses; 12- and 14-volt lamps to larger lenses.

Standard low voltage lamps

Description	Volts	Amperes	Life	Remarks
Marine signal, spiral lead, S–8 or S–11 bulb, LCL 1⅛-inch, C–8 filament, S. C. Pf. base.	3.5	1.0	500	All lamps in this group are for drum lenses.
	6.2	.25	500	
	6.2	.46	500	
	6.2	.70	500	
	6.2	1.4	500	
	6.2	1.84	500	
	6.2	2.8	500	
	12	.55	500	
	12	.77	500	
	12	1.15	500	
	12	1.35	500	
	12	2.03	500	

Description	Volts	Amperes or watts	Remarks
Railway signal S–8 or S–11 bulb, LCL 1¼-inch, C–2V or C–2R filament S. C. bay. Cand. base, 1,000 hour.	3.5	0.3A	All lamps in this group are for type SA and W range lanterns.
	4.0	3.0	
	6.0	10.0	
	8.0	.25A	
	8.0	5.0	
	8.0	10.0	
	8.0	18.0	
	10	.25A	
	10	5.0	
	10	10.0	
	10	18.0	
	10	25.0	
	12	.25A	

(3) *Candlepowers in minor lights are measured.*—Formula 14, for calculation of candlepower in a drum lens, is not easily applied to small filament sources due to uncertainty as to exact dimensions of the light source. Hence all candlepowers shown later for combinations of low voltage lamps and small lenses are based on actual candlepower measurements modified in some instances for uniformity. All are based on operating the light source at its design voltage.

23–8–10 Design Features of Lamps—

A. *Design features affecting choice of characteristic and candlepower.*—Factors which must be considered in making a selection of candlepower and characteristic in minor lights include the surge current drawn by the cold filament, the time required for incandescence and nigrescence, available power supply, and service period. They are closely interrelated. A definite relationship exists, for instance, between the apparent length of flash and filament size; that is, time required for the filament to heat up and to cool.

(1) The Blondel-Rey determinations have shown it to be undesirable to shorten the flash below about 0.2 second. Likewise, it may be observed by reference to figure 23–22 that approximately 0.15 second is required for a 1.0 ampere lamp to heat and 0.06 second for it to cool. Correspondingly different sized filaments require different times. From a design standpoint the following tabulation shows the minimum flash length which should be used for different current ratings in small lamps:

	Second
3.0 amperes	0.4
2.0 amperes	.3
1.0 amperes (or less)	.2

(2) It has been necessary to go below the minimum figures given above in the special case of the 1.15-ampere 12-volt lamp in a dual purpose lantern where the flash is, of necessity, only 0.15 second long. Visual tests show this to be an absolute minimum when viewing the unit from close by. The unit will not have the expected theoretical range which corresponds to its candlepower rating.

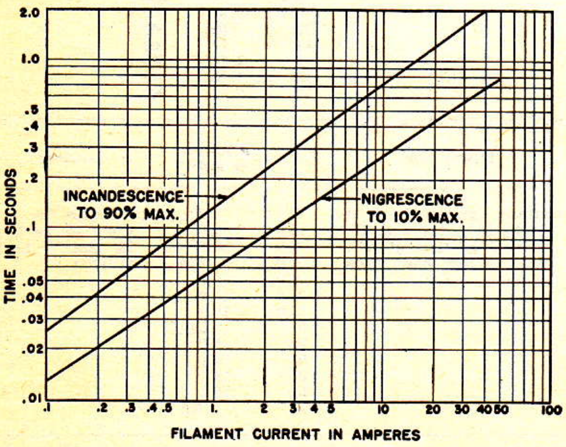

FIGURE 23–22.—Heating and cooling time of gas-filled lamps.

B. *When calculating the service period* the effect of surge current must be considered. Always include the factor for surge current shown in figure 23–23.

(1) *Examples.*—What is the expected service period, using a 2-ampere lamp on the characteristic 0.3–2.7, if the battery has a capacity of 1,000 ampere-hours?

Service period in days

= the ampere-hour capacity of battery divided by light ratio × current × surge factor × 24.

$$P=\frac{1000}{\frac{0.3\times2\times1.36\times24}{3.0}}$$

$$=\frac{1000\times10}{24\times2\times1.36}=153.$$

The example illustrates the application of figure 23–23 and does not include current consumed by the flasher or other auxiliaries.

(2) What is the anticipated service period, using a 2.03-ampere 12-volt lamp, 500-ampere battery, power relay drawing 0.085 amperes, sun relay and standard flasher mechanism? The characteristic is 0.4 second flash, 3.6-seconds eclipse.

Service period in days

$$=\frac{\text{battery capacity}}{\left(\frac{\text{current}\times\text{surge}+\text{relay}}{\text{light ratio}}\right)\times24\times\text{reduction due to sun relay}+\text{flasher.}}$$

$$=\frac{500\times10}{(2.03\times1.28+.085)\times24\times.70}=111 \text{ days.}$$

(The flasher current was negligible.)

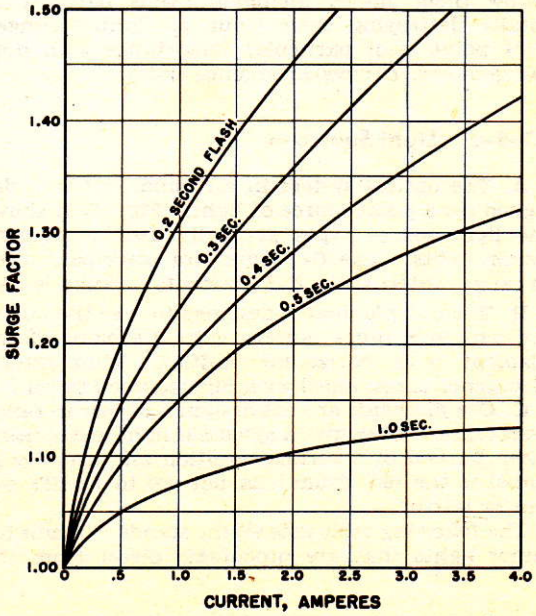

FIGURE 23–23.—Effect of flashing on current consumption of small lamps.

C. *Effect of voltage on candlepower.*—Attention to operation on design voltage is very important. A decrease of 7 percent in voltage is accompanied by a 20 percent loss in candlepower.

(1) The battery sources now available do not maintain invariable voltages. The voltage varies with state of charge, current in amperes, and temperature. High voltages occur at the outset of the service period. The lamps now in use have been designed for the average voltages occurring during the discharge cycle of the batteries.

(2) *Lampchangers protect against lamp failure due to overvoltage.*—For the foregoing reason, lampchangers are standard for drum lenses. They are discussed in Chapter 21. (See also Chapter 21 for battery characteristics.) Lampchangers are not available for all standard types of range lanterns. Outage due to lamp failure when no lampchanger is used is minimized by using duplex range lanterns equipped with change-over relays, or by operating undervoltaged lamps in single units.

(3) *Undervoltaged operation of single-range lanterns.*—If the candlepowers required to light the range suitably are moderate, the preferable method is to use a single lantern and undervoltaged lamp. A practice applied in several instances has been to operate 10-volt lamps on an 8-volt battery or step-down transformer; 8-volt lamps on 6.2-volt circuits, etc. Candlepower reduction from the normal value of range lanterns shown in manufacturers' candlepower curves may be estimated by referring to figure 23–24. The lamp life is extended indefinitely.

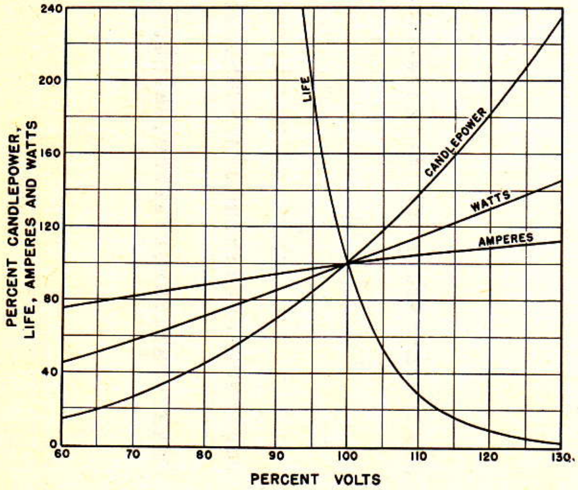

FIGURE 23–24.—Effect of voltage change on characteristics of small lamps.

(4) *Pretesting C–2 type lamps.*—Special rebased lamps furnished by two manufacturers of range lanterns for their units are tested before repacking. This practice culls out those lamps which might fail prematurely due to defective structure or damage in the lamps. This practice should be applied to all C–2 type lamps purchased from Treasury procurement schedules. It will remove one possible cause of failure in single lanterns operated at reduced voltage, which might otherwise justify changeover devices.

23–9 CANDLEPOWER

23–9–1 General Policy Concerning Candlepower Calculations—

A. The computation of candlepower is dealt with at considerable length in explaining the design of large assembled optics. Numerous tabulations have been in effect, listing the theoretical candlepower obtainable from various combinations of light sources and lenses. A majority of the items in those tables have proved to be inaccurate. They shall no longer be used as a basis for candlepower determination. Subsequent to their issue many hundreds of photometric measurements have been made, within the government and by commercial organizations, of the combinations of optics and light sources in current use by the Coast Guard. These measurements have indicated desirable and undesirable combinations. No wholly satisfactory electric sources are available for very large lenses, as stated in paragraph 23–5–40 (A).

23–9–5 Calculation of Candlepower—

A. *Large order lenses.*—The table under paragraph 23–7–1 (C) lists the available lamps; the table under paragraph 23–7–1 (D) (2) lists the apparent increase in source size by inside frosting; the table under paragraph 23–5–40 (A) gives the approximate source size necessary to fill the lens; and paragraphs 23–5–15 (A) et seq. give the computations for flash length.

When submitting work authorization requests, state approximate candlepower desired, give complete description of the lens, including photographs and plans if available, speed of revolution, order, number, and size of flash panels, etc. The data contained in this chapter enable the district engineer to determine the approximate candlepower. Headquarters will verify or modify the computation.

B. *36-inch double drum revolving beacons.*—The candlepowers listed in paragraph 21–15–35 (B) are obtained with 1,000-watt, 115-volt, C–13 filament, T–20 mogul bipost lamps. Reduced candlepowers are obtainable by using 500-watt lamps otherwise conforming to the same lamp design specifications.

C. *Minor drum lenses.*—The table on p. — gives the conventional candlepower to be used hereafter with the usual small drum lenses and standard light sources. No distinction is made between pressed-glass and cut-glass optics in assigning candlepower values. Sources of candlepower data are mentioned in paragraph 23–9–1 (A). As so many variables were involved in candlepower determination it was desirable to use mean values of all available measurements when preparing the table on p. —. The table should be used for all candlepowers to which it is applicable.

D. *Range lanters.*—Manufacturers' candlepower curves are accepted for the combinations of range light units and lamps which they manufacture.

Where information is not available locally it will be inserted by Headquarters when processing work authorization requests.

(1) Candlepower data will be supplied by Headquarters for special combinations and service types not otherwise available.

(2) Candlepower tabulations for the types mentioned above are being prepared and will be added when completed.

E. *Candlepowers in color.*—Reduce the candlepower for indication in green or red by the factors shown in the table under paragraph 23–5–35 (A).

F. *Candlepower computation at reduced voltages.*—In special cases where a light source is intentionally under-voltaged to assure long life due to absence of lampchanger or standby source, or for navigational reasons, refer to figure 23–24 for the reduction in candlepower corresponding to the reduced voltage proposed. In selecting a reduced voltage and corresponding reduced candlepower, bear in mind that the reduction must be made in increments which correspond to the unit voltages of standard batteries. The increments of voltage reduction are:

	Volts per cell
Wet primary cells	0.65
Low-discharge cells	2.05
Air cells	1.2

(1) For submission of Forms 2609, the following table shall be used in lieu of figure 23–24 to avoid minor errors that may occur due to the small scale of figure 23–24. The values of the table are listed to two significant figures and are not to be extended by interpolation or otherwise to more than two figures. Where it is found that a lamp is to be operated at a percentage of voltage which is not a whole number, use the nearest whole number in the table. For example: 66⅔ percent voltage would be called 67 percent and the percentage of candlepower would be taken as 22. Where the fraction is an exact half, drop the half. For example: 87½ percent voltage would be called 87 percent and the percentage of candlepower read as 62.

REDUCTION IN CANDLEPOWER OF LAMPS DUE TO REDUCTION IN VOLTAGE

CANDLEPOWER VERSUS VOLTAGE

Percent volts	Percent CP	Percent volts	Percent CP
60	14	90	70
61	15	91	73
62	16	92	75
63	17	93	78
64	18	94	81
65	19	95	84
66	20	96	88
67	22	97	91
68	23	98	94
69	24	99	97
70	26	100	100
71	28	101	103
72	30	102	106
73	32	103	110
74	33	104	114
75	35	105	118
76	37	106	122
77	39	107	125
78	41	108	129
79	43	109	133
80	45	110	137
81	48	111	142
82	50	112	146
83	52	113	151
84	54	114	155
85	57	115	159
86	59		
87	62		
88	64		
89	67		

(2) Reduce the candlepowers for indication in green and red by the factors shown in the following table. In applying this table, the method of handling fractions described under (1) above should be followed.

TRANSMISSION FACTOR VERSUS VOLTAGE[1]

Percent volts	Transmission factor	
	Red	Green
60	0.25	0.18
61	.25	.18
62	.25	.18
63	.24	.18
64	.24	.18
65	.24	.18
66	.24	.19
67	.24	.19
68	.24	.19
69	.24	.19
70	.24	.19
71	.24	.19
72	.23	.19
73	.23	.19
74	.23	.19
75	.23	.19
76	.23	.19
77	.23	.20
78	.23	.20
79	.23	.20
80	.23	.20
81	.23	.20
82	.23	.20
83	.22	.20
84	.22	.20
85	.22	.20
86	.22	.20
87	.22	.20
88	.22	.20
89	.22	.20
90	.22	.20
91	.22	.20
92	.22	.20
93	.22	.20
94	.22	.20
95	.22	.20
96	.22	.20
97	.22	.20
98	.22	.20
99	.22	.20
100	.22	.20

[1] Applies to color shades meeting specification AN–C–56.

G. *Candlepowers of General Railway Signal range lanterns.*—The following table I gives "basic" values for type SA range lanterns. By "basic" values is meant that no rounding off or approximation has been employed in transferring the data from the actual test curves to the table. They are the values on which percentage deductions for undervoltaging, color, beam spread, etc., are to be made. Table II gives the basic values for type W range lanterns.

TABLE I.—*Candlepower of G. R. S. range lanterns, type SA*

Lamp				No. roundel	8° spreadlite roundel	15° spreadlite roundel	30° spreadlite roundel	20° deflecting roundel
Volts	Watts or amperes	Filament	Bulb	Candlepower	Candlepower	Candlepower	Candlepower	Candlepower
4	3	C–2R	S–11	11,000	2,260	1,230	430	--------
6	10	C–2R	S–11	61,600	10,780	--------	--------	--------
8	0.25A	C–2R	S–8	6,000	1,265	--------	--------	--------
8	5	C–2R	S–11	17,600	4,070	--------	--------	--------
8	10	C–2R	S–11	47,520	9,620	--------	--------	--------
10	0.25A	C–2R	S–8	5,830	1,055	--------	350	--------
10	5	C–2R	S–11	21,560	3,670	--------	1,280	4,450
10	10	C–2R	S–11	38,810	9,880	--------	1,910	--------
10	18	C–2R	S–11	52,710	10,100	--------	2,880	--------
10	25	C–2R	S–11	52,800	14,250	9,900	4,150	16,450

NOTE.—1. All candlepowers are calculated for white light with lamp operated at rated voltage.
2. All lamps are single contact, bayonet, candelabra base.
3. Lamp filaments may be either C–2R or C–2V.

TABLE II.—*Candlepower of G. R. S. range lanterns, type W*

Lamp				Plain roundel	8° spreadlite roundel	30° spreadlite roundel	70° spreadlite roundel
Volts	Watts or amperes	Filament	Bulb	Candlepower	Candlepower	Candlepower	Candlepower
4	3	C–2R	S–11	12,000	2,740	660	590
8	0.25A	C–2R	S–8	3,150	1,530	------	------
8	5	C–2R	S–11	15,290	4,000	------	------
8	10	C–2R	S–11	24,920	9,460	------	------
10	0.25A	C–2R	S–8	4,080	1,700	600	------
10	5	C–2R	S–11	16,500	4,440	1,200	1,000
10	10	C–2R	S–11	20,500	8,170	2,460	2,240
10	18	C–2R	S–11	37,000	19,250	5,250	4,800
10	25	C–2R	S–11	46,500	18,670	6,750	6,400
12	0.25A	C–2R	S–8	6,300	------	------	------

NOTE.—1. All candlepowers are calculated for white light with lamp operated at rated voltage.
2. All lamps are single contact, bayonet, candelabra base.
3. Lamp filaments may be either C–2R or C–2V.

H. *Adjusted candlepowers.*—Before publishing candlepower values in Notice to Mariners or Light Lists, the basic values given in tables shall be "rounded off" in accordance with the "adjusted candlepowers" shown in table III. When selecting an adjusted value, use the nearest candlepower value. For example: In the case of a type SA range lantern equipped with a 10-volt, 5-watt, C–2V filament lamp and an 8° spreadlite roundel, the "basic" candlepower is given in table I as 3,340 in white. Publish this as 3,500.

(1) When computing candlepower values for color combinations and reduced voltage effects, use the tables of "basic" values. Apply the "rounding off" *after the computations are completed.* For example: In the case of a type W range lantern equipped with a 10-volt, 10-watt, C–2V filament lamp operated at 8 volts, a 30° spreadlite roundel and a red color shade, the candlepower would be computed as follows:

(*a*) Candlepower in white at 100 percent voltage is 2460.

(*b*) Percentage of candlepower at 80 percent voltage is 45 percent.

(*c*) Percentage of candlepower in color at 80 percent voltage is 23 percent.

(*d*) Computed candlepower is 2,460 x 0.45 x 0.23 or 254.6.

(*e*) Adjusted candlepower (rounding off) is 250.

TABLE III.—*Adjusted candlepowers*

1	10	100	1,000	10,000	100,000	1,000,000
	11	110	1,100	11,000	110,000	1,100,000
	12	120	1,200	12,000	120,000	1,200,000
	13	130	1,300	13,000	130,000	1,300,000
	14	140	1,400	14,000	140,000	1,400,000
	15	150	1,500	15,000	150,000	1,500,000
	16	160	1,600	16,000	160,000	1,600,000
	17	170	1,700	17,000	170,000	1,700,000
	18	180	1,800	18,000	180,000	1,800,000
	19	190	1,900	19,000	190,000	1,900,000
2	20	200	2,000	20,000	200,000	2,000,000
	25	250	2,500	25,000	250,000	2,500,000
3	30	300	3,000	30,000	300,000	3,000,000
	35	350	3,500	35,000	350,000	3,500,000
4	40	400	4,000	40,000	400,000	4,000,000
	45	450	4,500	45,000	450,000	4,500,000
5	50	500	5,000	50,000	500,000	5,000,000
6	60	600	6,000	60,000	600,000	6,000,000
7	70	700	7,000	70,000	700,000	7,000,000
8	80	800	8,000	80,000	800,000	8,000,000
9	90	900	9,000	90,000	900,000	9,000,000

Table IV.—*Conventional candlepower ratings for small drum lenses*

Electric lamp	Lens size, mm.					
	90	150	200	300	200 mm. Directional	
					Maximum	Minimum
3.5-volt, 1.0-amp. C8	40					
6.2-volt, 0.25-amp. C8	12	12	15		170	11
6.2-volt, 0.46-amp. C8	20	25	30		375	25
6.2-volt, 0.70-amp. C8	30	40	50		640	45
6.2-volt, 0.92-amp. C8		75	90		940	70
6.2-volt, 1.4-amp. C8		110	140		1,450	115
6.2-volt, 1.84-amp. C8		160	190		2,000	160
6.2-volt, 2.8-amp. C8		210	270			
		V&H	*200*	*300*		
12.0-volt, 0.55-amp. C8		55	90		770	45
12.0-volt, 0.77-amp. C8		85	140		1,065	60
12.0-volt, 1.15-amp. C8		130	220	350	1,515	105
12.0-volt, 1.35-amp. C8		180	300	450	2,200	140
12.0-volt- 2.03-amp. C8		260	440	650		
12.0-volt, 3.05-amp. C8		410	700	1,100		
		150	200	300	375	500
32-volt, 36-watt C5			280	400		
32-volt, 60-watt C5A			1,300	2,000	3,000	4,000
32-volt, 100-watt C5			2,500	3,700	5,000	7,500
32-volt, 250-watt C5A				7,500	10,000	15,000
32-volt, 500-watt C5					25,000	35,000
115-volt, 56-watt C5		330	400	600		
115-volt, 94-watt C5			750	1,100	1,700	2,300
115-volt, 11-watt C5			1,300	2,000	3,000	4,000
115-volt, 150-watt C5			2,000	3,000	5,000	6,500
115-volt, 250 watt C5				5,500	7,500	10,000
115-volt, 250-watt 4C8				2,500	4,500	6,000
115-volt, 500-watt C5					15,000	20,000
115-volt, 500-watt 4C8					7,500	10,000
115-volt, 1,000-watt 4C8					15,000	20,000
115-volt, 1,000 watt CC8					10,000†	13,000
115-volt, 1,000 watt 2C5					20,000	25,000
Acetylene burner		150	200	300	375	500
3/16 cubic foot		12	15			
1/4 cubic foot		20	30			
5/16 cubic foot		30	35			
3/8 cubic foot		45	50			
1/2 cubic foot		60	70			
3/4 cubic foot		110	130	200		
1 cubic foot		140	160	250	400	
1 1/4 cubic feet				300	450	600

Note 1.—Reduce the candlepowers "of electric lamps" by 12 percent when stormpanes are used.

2. 200 mm. directional drum lenses give maximum candlepower on the main beam and minimum candlepower around the remainder of 360°.

3. Apply the following average transmission factors to the candlepowers listed above to obtain the corresponding candlepowers for red and green color beams.

	Electrical	*Acetylene*	*I. O. V.*
Red	0.22	0.25	0.22
Green	.20	.18	.20

23–10 TRENDS

23–10–1 Electrification—

A. The past 40-year period has been the I. O. V. and acetylene era. During that time oil wick lamps have been superseded by the I. O. V. mantle, which in turn is being replaced by the electric lamp. It is fortunate that the periods have overlapped. Adaptation of the new concentrated light sources to the large optics has not always been accomplished efficiently. It was attempted with the means at hand, prompted by popular acceptance of electricity. Changes in illuminants have arrived while the original towers and lanterns still continue to serve as practical landmarks for the navigator. They also continue to exert a romantic influence, not only on the seaman but on the landsman, which must continue to be recognized by the engineer. However, long range lights and long range fog signals, unlike radio aids which pierce unerringly through adverse atmospheric conditions, have always been subject, in too great a degree, to the vagaries of the atmosphere.

B. *Replacement of "classic" apparatus.*—Existing high power optical systems should continue to be used only so long as the annual maintenance of the tower and optical apparatus does not become excessive. The engineer should keep two questions always in his mind: (*a*) Is the light so necessary as to justify its maintenance? (*b*) Can better, less expensive apparatus and structure be substituted at a saving to the Government? To that extent the engineer officer must guide the operations officer. New establishments will use equipment designed to utilize efficiently the modern light sources which are tending to become either more diffused or more condensed as their efficiency increases. Thus at this time rotating drum type beacons appear to be suitable, economical, high power light sources if long range lights are actually considered to be necessary. Considerable economies in structural design are possible by their application.

C. *Minor lighting apparatus* has come into existence coincidentally with and by reason of present light sources. For that reason, it has not been subject to the transition in design affecting the large optics. An ample range of candlepowers is available to suit all possible applications.

23–11 STANDARDIZATION AND REDUCTION IN TYPES

23–11–1 Past Complexity in Types—

A. In the early years of the adaptation of electric lighting apparatus to navigational needs, a great many combinations of lighting units and light sources were developed. This process was desirable in the initial stages in that it made quickly available to the navigator expanding numbers of lighted aids and earned for the United States the just claim to the best lighted coasts and waterways in the world. Experience has now indicated which are the best units, also that the existence of too many designs results in confusion and lack of coordination. Every district office has in the past sponsored its own designs or has used those of especially aggressive district units. Much commercial apparatus has been adapted, and many units were designed within the Service. Approximately 300 different electric sources and 100 different lanterns are or have been in use. The number of combinations of assembled Fresnel optics is not known, but approaches the number of such units installed.

B. *Standardization of lamp types.*—Effective with release of this chapter, approximately 31 high-voltage lamps and 25 low-voltage lamps are listed as standard. With the exception of special rebased lamps now used in range lights, types not appearing on that list shall be replaced. Due to the numerous combinations of lamps and lenses it will generally be necessary to cover each case by a Form 2609. This shall be accomplished as an orderly district engineering program.

Replacement of defective Fresnel lenses with minor drum lenses.—Such a program will be especially effective in connection with the smaller orders of assembled Fresnel lenses. A considerable proportion of such optics are imperfect, and in some cases have been "patched" to such an extent that they actually could not emit the characteristic published for them in the light lists. Give consideration in all such cases to the substitution of a pressed- or cut-glass minor drum lens.

C. *Standardization of minor lenses and lanterns.*—Standard minor drum lenses are listed in paragraph 23–5–5 (B). Of these sizes, the 90, 150, 200, 375, and 500 mm. lanterns will find principal application. (See also paragraph 23–8–1 (B). Only 90, 150, 200, and 375 mm. lanterns will be installed on buoys. (See paragraph 23–4–5 (F)).

D. *Standardization of range lights.*—When establishing or modifying range lights, give consideration to standardization, the use of commercial apparatus which is always procurable, and simplification of apparatus, in addition to all points outlined in paragraph 23–8–1 (E). The trend is to single lighting units. The cost of electricity is an important factor in the operation of range lights. Coordinate the design with the operations officer to the end that adequate beam candlepower is had where, and only where, it is needed.

23–12 SPECIAL LIGHTING DEVICES

23–12–1 Testing—

A. Tests of special lighting devices which appear to offer promise as aids to navigation are encouraged. However, before making any tests, request authority from Headquarters, and be sure that answers to the following questions are generally in the affirmative:

(1) Will the devices give more useful light per unit of input energy than existing devices?

(2) Will they be as, or more, reliable?

(3) Are costs comparable, or do they promise to be less with development and service?

(4) Are the devices fully adaptable to the special conditions which must be met by minor lighted aids to navigation?

23–13 LIGHTED BUOY DESIGN

23–13–1 General Principles—

A. The general design of buoys follows the accepted principles of ship hull design in that the center of gravity, the center of buoyancy, and the metacentric height are factors in determining stability. The distance between the metacenter and the center of gravity determines the stability of the buoy. A buoy must maintain a position in a seaway that is normal to the horizon to obtain the optical requirements necessary for an aid to navigation. This is accomplished by designing lighted buoys to float (ride the waves) with an up and down motion instead of rolling to and fro. In principle, the behavior of a buoy in the sea is regarded as that of a free pendulum exposed to the effects of the wave action and is determined by (*a*) its moment of stability, (*b*) its moment of inertia, (*c*) fluctuations of the displacement due to the wave motion, (*d*) frictional resistance, (*e*), the relative size of the buoy with respect to the magnitude of the waves, (*f*) the type of the mooring and (*g*) the relation between the pendular period of the buoy to the wave period. In actual practice the waves break over the deck (top head) of buoys having relatively long periods. This does not endanger their seaworthiness for the reason that all properly designed buoys have adequate weight stability. Therefore, lighted buoys are designed to ride as steadily as possible with an up and down motion and without excessive rocking motion. Knowing the conditions, a problem will now be worked.

23–13–5 Buoy Design Problem—

A. Design a buoy to fill the following requirements:

Depth of water	15 fathoms.
Height of light	13 feet.
Service period	Once per year.

(1) If the buoy is to be in 15 fathoms (90 feet of water) and the size of the chain to moor the buoy is 1¼'', then the total weight of the chain will equal about________________________________1,300 pounds.

(2) There will also be required, chain bridle, shackles, swivels, etc., for mooring the buoy; the total weight of which will equal about___400 pounds.

(3) If the light is to be 13 feet above the water, the tower to support the light should be about 10 feet, the difference between 10 feet and 13 feet being the height of the lantern plus the freeboard. For our trial we will use a 4-legged tower design conforming to standard structural engineering practice. Such a tower should weigh about_______800 pounds.

(4) If the service period is 1 year; that is, if the buoy must remain on station without relief for 1 year, there must be sufficient acetylene gas to maintain the light for that period. Two type A–300 (1060 cubic feet) acetylene cylinders will therefore be required. Assume that each cylinder weighs 1,350 pounds or about________________2,700 pounds.

(5) If cylinders of this size are to be used, it will be necessary to furnish two pockets to hold them. Conforming to standard cylinder construction for these pockets, the estimated weight will be about ______________________________ 1,600 pounds.

(6) Then the total weight so far is__6,800 pounds. (See fig. 23–25.)

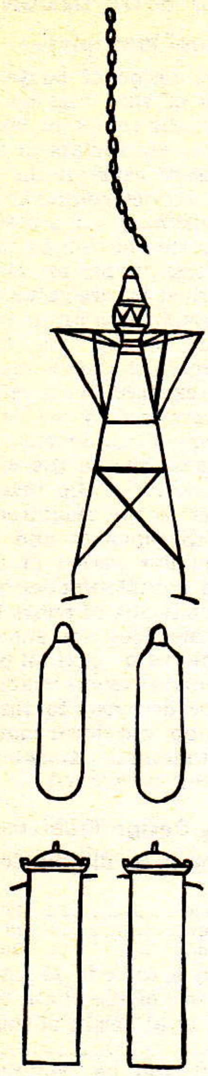

FIGURE 23–25.—Weights which a buoy must support.

B. The main body must be of sufficient size to support the total weight so far, plus an additional allowance for a reasonable freeboard, say of 18 inches. Let us assume a body, following standard tank or boiler practice of 7 feet in diameter with a 5-foot wrapper. This would appear to meet the weight requirement. Such a body will support 12,300 pounds. We are correct in our assumption, *but* we have overlooked the fact that the tower must remain vertical. Our buoy so far then would lie upside down in a useless position. It is therefore necessary to attach sufficient counterweights to force the buoy to an upright position and to stabilize it to sea action.

C. To bring the buoy to a vertical position, let us try a weight slightly less than the weight to be offset, say 5,500 pounds, suspended about 7 feet from the bottom of the buoy. This rights the buoy satisfactorily but the weight is too great for the buoyant volume of the body. There are two things to be done: 1—Reduce the counterweight, or 2—Increase the buoy body size. As the counterweight is reasonable to expect for the total topside weights, and the 7-foot diameter body barely permits the removal of the acetylene gas cylinders from the pockets, it is evident that the body must be increased. (See (fig. 23–26.)

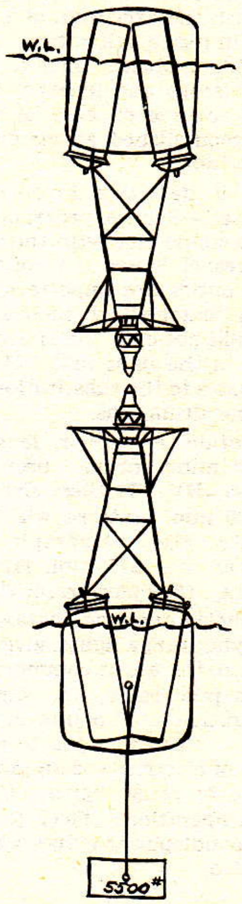

FIGURE 23–26.—Why a counterweight must be added.

D. So, we will try a body 8 feet in diameter with a 5-foot 9-inch wrapper plate. This volume supports all topside weights, the trial counterweight, and produces a reasonable freeboard. The above conclusion is from rough quick "rule of thumb" or table conclusions in consideration of all the main parts. We have drawn the sketch shown in figure 23–27 to clearly illustrate these facts. This trial indicates that a buoy 8 feet in diameter by 26 feet long (tower + body + counterweight tube + counterweight) will fill the requirements specified in the problem. We are now ready to make calculations and develop a design of an 8 × 26 acetylene buoy.

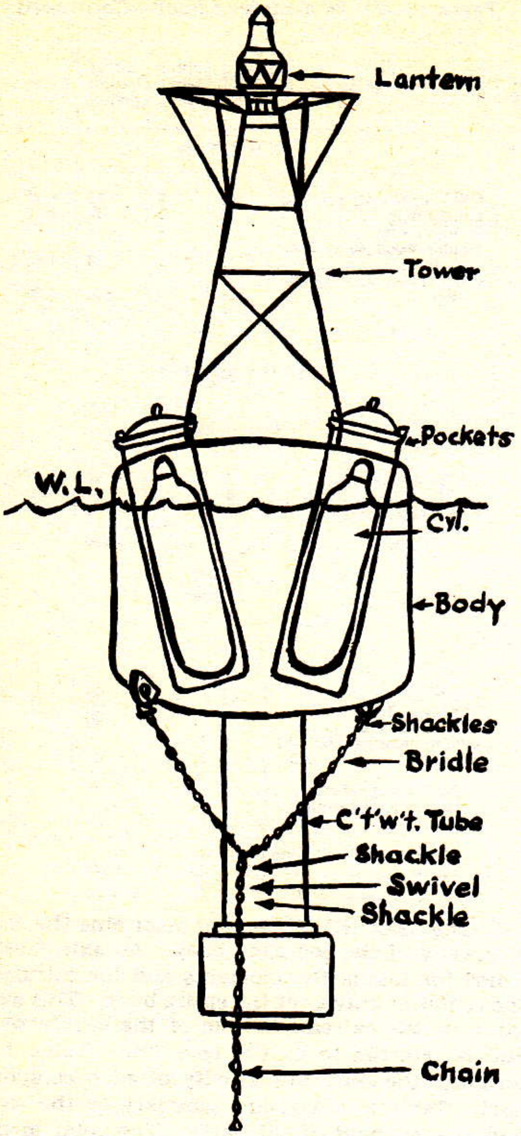

FIGURE 23–27.—Sketch of a buoy fulfilling requirements of buoy problem.

23–13–10 Example—

A. A drawing is prepared (fig. 23–28) to the dimensions found to fill the requirements of the problem. The calculations are in tabular form and are shown by progressive steps.

B. The FIRST STEP is the determination of the weight of the various parts and center of gravity of each part. With the buoy drawn to scale (fig. 23–28) the weights and center of gravity of its component parts may be calculated. An axis is established for taking the moments and calculating the center of gravity of each part. This axis is taken at the extreme bottom of the part to determine the length of the moment arm to the center of gravity of all pieces comprising the parts. The center of gravity of each part is determined and listed in table 1, with the exception of part No. 8 (mooring chain). Part No. 8 has been figured for obtaining the effective weight due to gravity after deducting the displacement of the moorings. This weight is taken at its point of suspension from the buoy mooring lugs. The component parts are listed below and are shown in figure 23–28 by corresponding numbers.

Part No.

1 Lantern, 200 mm. acetylene.
2 Lantern tower.
3 Cylinder pockets.
4 Cylinders.
5 Buoy body.
6 Counterweight tube.
7 Counterweight.
8 Moorings.

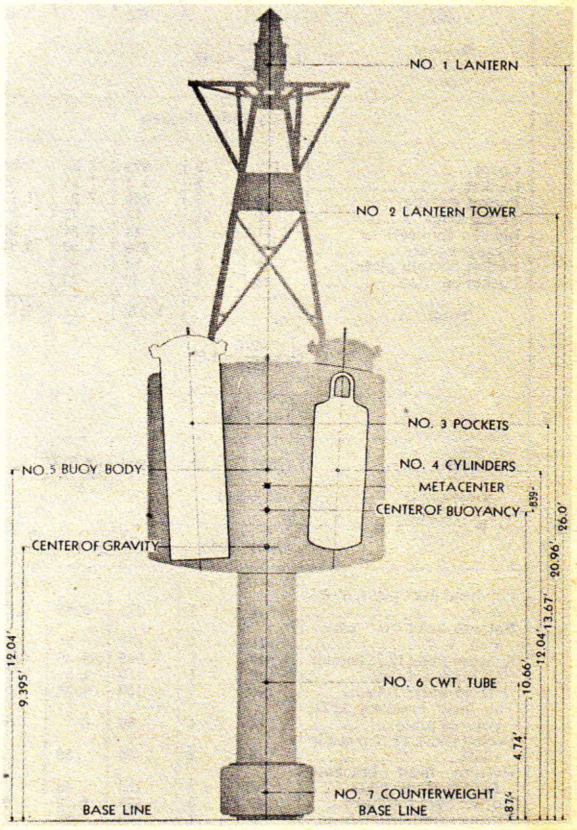

FIGURE 23–28.—An 8×26 buoy.

TABLE 1.—*8 × 26 acetylene buoy*

Part No.	Description	Unit pounds	Number of units	Total weight, pounds	Lever	Moment
1	Lantern, 200 mm—acetylene ¾′ burner. C. G.—.87′	112	1	112	0.87	------
2	**Tower**					
	Lantern guard ring	71	1	71	9.8	696
	Lantern guard long braces	10.4	8	83	8.6	714
	Lantern guard short braces	6.5	4	26	9.6	250
	Lantern plate 15.3 pounds	17	1	17	9.5	162
	Lantern plate gusset 10.2 pounds	5	4	20	9.2	184
	Daymark plate 7.65 pounds	20	4	80	6.1	488
	Top step	1.7	4	7	4.5	32
	Bottom step	.75	8	6	2.3	14
	Tower bolts	.75	16	12	0.6	7
	Clips for tubing and piping 1 hole	.2	40	8	5.0	40
	Acetylene piping and fittings	15	1	15	5.0	75
	Vent tubing and vents with fittings	6	1	6	5.0	30
	Tower legs	44	4	156	4.9	764
	Tower braces	10.70	8	86	3.2	275
	Tower foot brackets	23	4	92	0.3	28
	Welding material	------	------	15	5.0	75
	Total	------	------	700	------	3,834
	C. G. $=\frac{3834}{700}=5.48$					
3	**Cylinder Pockets**					
	Cover	112	2	224	7.36	1,649
	Gasket	3	2	6	7.25	44
	Pocket casting	123	2	246	7.2	1,771
	Swing bolts	1	24	24	7.25	174
	Interior connections	11	4	44	6.34	279
	Wrapper plate	464	2	928	3.60	3,341
	Pocket bottom plate	32	2	64	.05	3
	Pocket cushion	20	2	40	.23	9
	Total	------	------	1,576	------	7,270
	C. G. $=\frac{7270}{1576}=4.61$					
4	**Cylinders**					
	Cylinder	1,350	2	2,700	2.71	------
	C. G. $=2.71$					
5	**Buoy Body**					
	Top head 5/16″ plate, 8′–0″ o. d.	811	1	811	6.83	5,539
	Bottom head 5/16″ plate, 8′–0″ o. d.	811	1	811	.34	276
	Wrapper plate, 12.75 pounds	1,840	1	1,840	3.58	6,587
	Top inner L brace	150	1	150	4.5	675
	Bottom inner L brace	150	1	150	2.58	387
	Top head brackets, 12.75 pounds plate	15	4	60	6.7	402
	Pocket chock, 12.75 pounds plate	15	2	30	.58	17
	Bottom head brackets, 12.75 pounds plate	83	2	166	.58	96
	Lifting eyes, top head	46	3	138	6.75	932
	Lifting eyes, bottom head	46	1	46	.58	27
	Mooring lugs, bottom head	80	2	160	.60	96
	Manhole ring, cover, bolts, and gasket	60	1	60	6.8	408
	Total	------	------	4,422	------	15,442
	C. G. $=\frac{15442}{4422}=3.49$					
6	**CWT. Tube**					
	CWT. tube body brackets	16	6	96	8.25	792
	Fender bars	16	2	32	4.62	148
	Fender rivets	1	4	4	4.62	18
	Fender wood, 40 pounds cu. ft.	38	1	38	4.62	176
	CWT. tube, 12.75 pounds plate	690	1	690	4.27	2,946
	Total	------	------	860	------	4,080
	C. G. $=\frac{4080}{860}=4.74$					
7	**Counterweight**					
	CWT. wedge	40	1	40	2.25	90
	CWT. seat	40	1	40	.08	3
	C. I. counterweight	3,500	1	3,500	.87	3,045
	Total	------	------	3,580	------	3,138
	C. G. $=\frac{3138}{3580}=.87$					
8	**Mooring**					
	Chain bridle	227	1	227	------	------
	Shackles—1st class	27	5	135	------	------
	Swivel—2d class	51	1	51	------	------
	Chain mooring 1¼″ (83 feet)	1,184	------	1,184	------	------
	Total weight of chain	------	------	1,597	------	------
	Deduct for mooring displacement	------	------	211	------	------
	Effective weight of moorings	------	------	1,386	------	------

C. The SECOND STEP is to determine the center of gravity of the complete buoy. An axis is established for taking the moments and for calculating the center of gravity of the entire buoy. This axis is taken at the extreme bottom of the counterweight and is referred to as the base line. Table 1 determines the center of gravity of each component part. Table 2 is a group summary of the weight and the moment of all parts. The total moment divided by the total weight equals the center of gravity of the buoy.

TABLE 2.

Part No.	Description	Total weight pounds	Lever	Moment
1	Lantern	112	26.0	2,912
2	Lantern tower	700	20.96	14,672
3	Cylinder pockets	1,576	13.67	21,544
4	Cylinders	2,700	12.04	32,508
5	Buoy body	4,422	12.04	53,241
8	Counterweight tube	860	4.74	4,076
7	Counterweight	3,580	.87	3,115
8	Moorings, effective weight	1,386	8.67	12,017
	Total	15,336	------	144,085

$$\text{Center of gravity}=\frac{\text{Total moments}}{\text{Total weights}}=\frac{144085}{15336}=$$

9.395 feet above the base line axis.

D. The THIRD STEP is to determine the displacement of the total weight. The displacement may be calculated either for fresh or salt water. This buoy is figured for salt water having a weight of 64 pounds per cubic foot. Displacement in salt water

$$=\frac{\text{Total weight of buoy}}{64}=\frac{15336}{64}=239.63 \text{ cubic feet}$$

E. The FOURTH STEP is to determine the center of buoyancy. The axis remains at the base line established in step 2, which is at the extreme bottom of the counterweight. The parts submerged must be equal in volume to the displacement found in step 3. Table 3 shows the displacement of the wetted parts and the group summary of the moments. The total moments divided by the total displacement=the center of buoyancy.

TABLE 3

Part No.	Description	Displacement in cubic feet	Lever	Moment
7	Counterweight	7.96	.87	6.93
6	Counterweight tube	1.68	4.74	7.96
6	Counterweight tube fender	.80	4.62	3.70
5	Buoy body bottom head	22.25	8.96	199.36
5	Buoy body under water plane	206.94	11.29	2,336.35
	Total	239.63	--------	2,554.30

$$\text{Center of buoyancy}=\frac{\text{Total moments}}{\text{Total displacement}}=$$

$$\frac{2554.30}{239.63}=10.66 \text{ feet above the base line axis.}$$

F. The FIFTH STEP is to find the water plane. The water plane is a plane through the buoy at the water line. In table 3, it was found that the displacement of the wetted buoy body was 206.94 cubic feet. The cross sectional area of the cylinder (body) is $\pi r^2 = 3.1416 \times 4^2 = 50.28$ square feet. The displacement in cubic feet of the wetted buoy body divided by the cross sectional area of the cylinder equals the length of the cylinder submerged or $\frac{206.94}{50.28} = 4.11$ feet.

  4.11 feet (distance on cylinder)
\+ .70 feet (height of bottom head)
\+ 6.69 feet (length counterweight tube)
\+ 1.85 feet (height of counterweight)

Then the water plane is 13.35 feet above the base line.

The water plane of the buoy has been calculated without taking into consideration the downward pull on the moorings which may be encountered in currents or wind and wave forces.

G. The SIXTH STEP is to find the focal plane of the lantern above the surface of the water (water plane). The focal plane is a plane through the lantern at the center of the light, parallel to the horizon. From figure 23–28, the overall dimension from the bottom of the counterweight (base line) to the focal plane is 26.29 feet. From the fifth step it was determined that the water line was 13.35 feet; therefore, the height of the focal plane is the difference between the overall length and the draft of the buoy or 26.29−13.35=12.94 feet.

H. The SEVENTH STEP is to find the freeboard. The freeboard is the distance from the water line to the center of the shoulder of the top head. By measurement on figure it is 15.10 feet from the base line to the center of the shoulder of the top head. The freeboard is therefore determined by subtracting the draft found in the fifth step from this overall distance, or 15.10−13.35=1.75 feet or the freeboard is 21 inches.

I. The EIGHTH STEP is to determine the metacentric height above the center of buoyancy. The metacentric height is required to determine the stability of the buoy. The distance between the center of gravity and the metacenter is a measure of the stability. The metacenter is the point of intersection marked by a vertical line drawn through the center of buoyancy of a floating body in equilibrium, and a vertical line drawn through the center of buoyancy when the body is slightly inclined from the position of equilibrium. The metacentric height above the center of buoyancy is found by dividing the moment of inertia of the buoy at the water plane, by the total displacement found in step 3. The moment of inertia (I) is found as follows:

$$= I \quad \frac{\pi d^4}{64}=\frac{3.1416 \times 8^4}{64}= 201.0624$$

d=diameter of buoy at the water plane=8 feet

Then, the metacentric height above the center of buoyancy

$$=\frac{I}{D}.$$

I=the moment of inertia=201.0624

D=the total displacement of the buoy=239.63

Metacentric height above center of buoyancy=

$$\text{Bm} =\frac{201.0624}{239.63}=0.839 \text{ foot.}$$

J. The NINTH STEP is to determine the metacentric height above the center of gravity ($Gm.$). The metacentric height above the center of gravity is found by adding the metacentric height above the center of buoyancy to the distance between the center of gravity and the center of buoyancy, or $Gm = 0.839 + 1.265 = 2.104$ feet.

K. The TENTH STEP is to find whether the buoy as designed will heel over under an assumed wind velocity of 50 miles per hour, to such an extent that the light will no longer be visible from the horizon. The heeling angle is determined by comparing the wind moment with the righting moment. The wind moment is found by taking moments of all exposed areas above the water line with the axis taken at the mooring point. Table 4 is a tabulation of the exposed projected areas and their moments.

TABLE 4

Description of exposed areas	Area, square feet	Lever	Moment
Lantern, 200 mm. acetylene	2.1	17.33	36.4
Lantern tower	17.2	12.82	220.5
Cylinder pockets exposed	4.2	7.21	30.3
Top head	3.8	6.75	25.7
Buoy shell exposed above water plane	13.0	5.70	74.1
Total	40.3	----------	387.0

Center of Wind Pressure $= \dfrac{\text{Total moments}}{\text{Total projected areas}} =$

$\dfrac{387}{40.3} = 9.6$ feet above the mooring point

The righting moment is determined by using the formula:

$Mr = D \times Gm$ sine a

D= total displacement in pounds

Gm= metacentric height above the center of gravity in feet

Angle a = deviation of the buoy from the perpendicular equal to half the angle of divergence of the light.

(1) To determine the angle of inclination which will permit the light to be visible from the horizon at all times, it is necessary to know the height of the light source and the size of the lens of the lantern. The above angle must not exceed one-half the angle of divergence of the light. The angle is found as follows:

(2) The tangent of angle a (figure 23–30) is determined by dividing the effective height of the light source by twice the focal distance of the lens. When using a ¾ cubic foot burner with an effective height of 22.8 mm in a 200-mm. lens, angle a is calculated to be about 6½°.

Tangent $a = \dfrac{22.8}{200} = 0.1140$

thus sine $a = 0.11320$

therefore: $Mr = 15336 \times 2.104 \times 0.11320 = 3652.62$ foot pounds

(3) To determine the velocity pressure expressed in pounds per square foot, the moment of rigidity (Mr) is divided by the total projected wind area times the center of wind pressure above the point of mooring. Thus by comparing the wind moment with the moment of rigidity, the velocity pressure can be calculated which will heel the buoy at an angle equal to half the angle of divergence of the light.

$\dfrac{Mr}{40.3 \times 9.6} = \dfrac{3652.62}{386.88} = 9.44$ pounds per square foot

9.44 pounds per square foot is equivalent to a wind velocity of about 50 statute miles per hour. Wind velocities exceeding 50 miles will incline the buoy to the extent that the light will not always be visible from the horizon.

L. The ELEVENTH STEP is to find the period of oscillation, which is the time in seconds required of the buoy to roll from side to side and back again, completing one full cycle. The formula for calculating the time period is as follows:

$$T = \frac{2\pi \sqrt{k^2}}{Gm\ g}$$

T=time in seconds.

π=3.1416.

k=transverse radius of gyration in feet.

Gm=metacentric height above center of gravity.

g=is the acceleration of gravity.

$$k = \sqrt{\frac{I}{W}}$$

I=the moment of inertia, found by adding together the products of each weight and the square of its distance from the axis taken through the center of gravity.

W=the weight.

K=the radius of gyration or $k^2 = \dfrac{I}{W}$

The following tabulation shows the method of determining I. The group summary of weights and moments determine the moment of inertia about an axis taken through the center of gravity of the buoy.

Description	Wt. in lbs.	Lever	Distance from C. G. squared	Moment
Lantern	112	16.6	275.6	30,867
Lantern guard ring	71	15.87	251.9	17,885
Lantern guard ring long braces	83	14.67	215.0	17,845
Lantern guard ring short braces	26	15.67	245.6	6,386
Lantern plate	17	15.57	242.0	4,114
Lantern plate gussets	20	15.27	233.0	4,660
Daymark plate	80	12.17	148.0	11,840
Tower steps	13	9.47	89.7	1,166
Tower legs	156	11.0	121.0	18,876
Tower foot brackets	92	6.37	40.6	3,735
Tower bolts	12	6.67	44.5	534
Piping and fittings	30	11.0	121.0	3,630
Tower braces	100	9.27	85.9	8,590
Cylinder pocket cover	224	7.0	49.0	10,976
Pocket casting	246	6.9	47.6	11,710
Swing bolts and gaskets	30	6.9	47.6	1,428
Interior connections	44	6.0	36.0	1,584
Wrapper plate	928	3.24	10.5	9,744
Pocket bottom	64	.3	.09	6
Pocket cushions	40	.13	.02	1
Cylinders	2,700	2.65	7.02	18,954
Top head	811	6.0	36.0	29,196
Bottom head	811	.12	.01	8
Buoy body wrapper plate	1,840	2.72	7.4	13,616
Top inner brace	150	3.64	13.2	1,980
Bottom inner brace	150	1.72	2.96	444
Top head brackets	60	5.84	34.1	2,046
Bottom head brackets	200	.30	.09	18
Lifting eye, top head	138	5.84	34.1	4,706
Lifting eye and mooring lug, bottom head	206	.25	.06	12
Manhole ring and cover	60	5.94	35.3	2,118
Cwt. tube brackets	92	1.15	1.3	120
Fender bars, rivets and wood	74	4.78	22.8	1,687
Cwt. tube	690	5.13	26.3	18,147
Cwt. wedge	40	7.15	51.1	2,044
Cast iron hundredweight	3,500	8.53	72.8	254,800
Cwt. seat	40	9.32	86.9	3,476
W=	13,950	--------	----------	I=518,949

$$k^2=\frac{518949}{13950}=37.2006$$

The time period $=\frac{2\pi\sqrt{k^2}}{Gm\,g}=2\pi\sqrt{\frac{37.2006}{2.104\times32.2}}=$

$6.2832\times\sqrt{\frac{37.2006}{67.7488}}=6.2832\times\sqrt{.549096}=$

$6.2832\times.74=4.7$ seconds

M. The TWELFTH STEP is to determine the greatest heeling angle due to wave action. Assuming that a wave has a certain length from crest to crest and reaches a certain maximum height and that the period of oscillation of the buoy is known, then the greatest heeling angle of the buoy may be expressed by the formula.

$$C=\frac{bT^2}{T^2-t^2}$$

C=angle of deviation from the vertical. (See figs. 23–29 and 23–30.)

b=maximum angle of the wave slope (that angle the water surface makes with the horizon). (See figs. 23–29 and 23–30.)

T=wave period in seconds.

t=pendular period of the buoy in seconds.

Example A

Assuming a wave 260 feet long with a maximum height of 17 feet and a period of 7 seconds, and knowing the period of the buoy to be 4.7 seconds, the above formula may be applied. The slope b will be the tangent of an angle having the ratio

$\frac{17}{130}$ or tan. $2 \doteq 0.130769$ approximately $7\frac{1}{2}°$

Then: $$C=\frac{7.5\times7^2}{7^2-4.7^2}=\frac{367.5}{26.91}\doteq13.7°$$

Example B

Assuming another wave having a length 600 feet and a maximum height of 26 feet with a period of 10.8 seconds,

tan. $b=\frac{26}{300}=0.08667$=approx. 5°, then:

$$C=\frac{5\times10.8^2}{10.8^2-4.7^2}=\frac{5\times116.64}{116.64-22.09}=\frac{583.20}{94.55}=6.17°$$

(1) With reference to example A, the buoy light would not be visible from the horizon at all times because the angle of inclination is greater than half the angle of divergence of the light.

(2) In example B, the angle of inclination is less than half the angle of divergence of light, therefore, the light is visible at all times from the horizon.

(3) If t is greater than T, the buoy will incline slightly towards the crest as it rides the waves. If t and T are equal, excessive oscillation due to synchronization will occur. If t is less than T, the buoy will incline away from the crest of the wave and will have a tendency to assume the time period of the wave and the angle of deviation from the vertical will be at right angles to the slope of the surface of the water.

(4) The formulas used in steps 11 and 12 are theoretical and their use should be limited to small angles of inclination. Reference is made to E. L. Attwood and H. S. Pengelly's "Theoretical Naval Architecture," new edition May 1939.

N. The THIRTEENTH STEP is to determine the service period for the buoy, using a three-fourths cubic foot acetylene burner and two A–300 cylinders. Assuming a characteristic of 0.5 second flash and 2.0 seconds eclipse (one-fifth luminous time ratio), inspection of the table under section 20–19–15 of this manual indicates a service period of approximately 475 days, which is amply in excess of the 1 year service period required in the example.

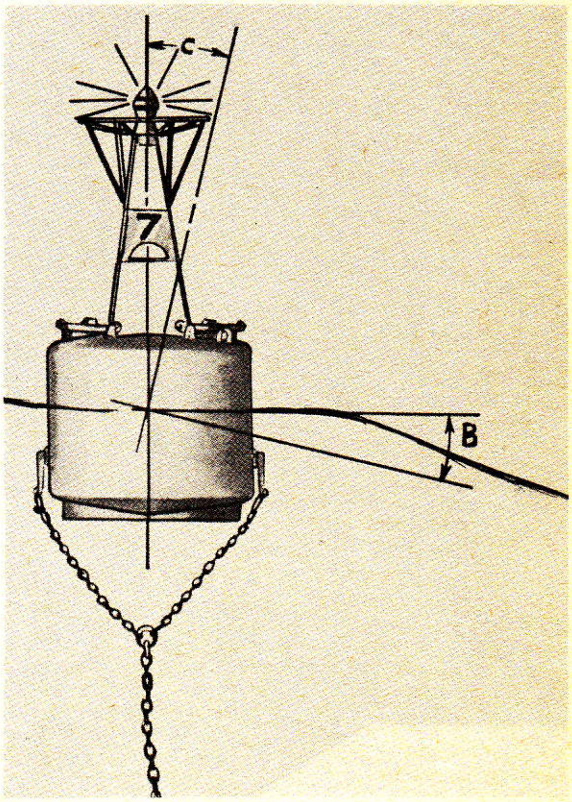

FIGURE 23–29.—A 7 FE buoy in a seaway.

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23–13–15 Conclusion—

A. A buoy has been designed to satisfy the requirements of the problem.

1. Depth of water—15 fathoms. In the seventh step it was found that the freeboard would be 21 inches, which provides for ample displacement.[1]

2. Height of light—13 feet above water line. In the sixth step it was found that the focal plane of the lantern is 12.94 feet above the water, which is within three-fourths inch of the desired height.

3. Service period—once per year. In the thirteenth step, it was found that two A–300 cylinders would provide ample acetylene gas for more than a year.

[1] Liberal allowance of freeboard is made for added weight caused by the sea growth anticipated over the service period of 1 year.

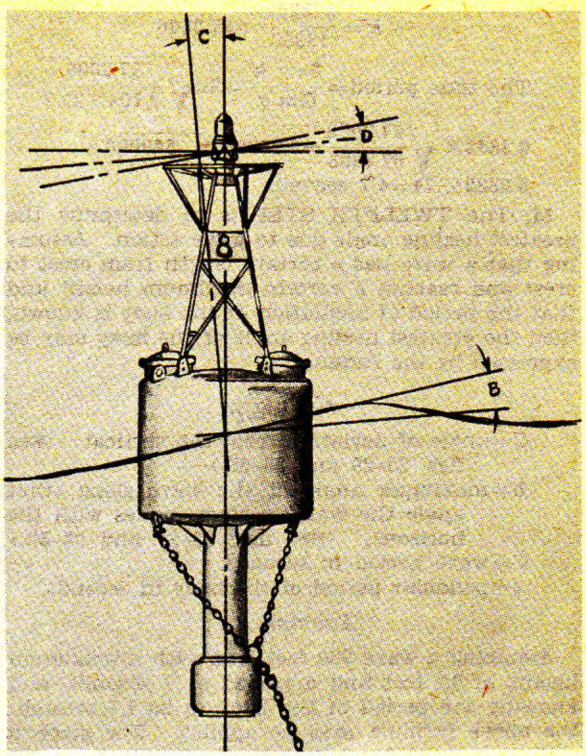

FIGURE 23–30.—An 8 x 26 buoy in a seaway.

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