Optics of Searchlight Illumination

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INTRODUCTION

In this paper the optical features of searchlight illumination are analyzed in considerable detail. Experimental measurements and calculations are given which led to quantitative answers to the questions, how does the range at which an object can be seen in the searchlight illumination vary with, (a) the portion of the searchlight beam used to illuminate the object, (b) the distance of the observer from the searchlight, (c) the candlepower of the searchlight, and (d) the haze in the atmosphere.

The results given here depend entirely on experimental facts. Pertinent numerical facts of vision, attenuation and scattering of light by haze, geometry of a searchlight beam, and the distribution of light in the beam were brought together and from these the answers to the above questions were worked by calculation for the Navy 36-inch searchlight and the Army 60-inch searchlight. In addition, a few direct observations were made of the brightness of searchlight beams which were found to be in fair agreement with the calculations.

Since the searchlight is a visible light apparatus designed to be employed by observers using their eyes, the range at which an object can be seen in the searchlight illumination is essentially a problem in vision. The optical properties of searchlights and of atmospheric haze have been known for some years, but the necessary facts of vision have not been known, and have become available only recently. These facts, however, are for small objects which subtend less than 5 minutes of arc at the observer. Therefore the present conclusions refer only to such small objects. Larger objects can be considered when suitable vision data concerning them are forthcoming.

SUMMARY OF RESULTS

The general results are summarized below, although there is some risk of over-simplification in such brief statements. The results apply to the Navy 36-inch and the Army 60-inch searchlights. $x$ is the maximum visual range of an object illuminated by a searchlight at night viewed by an observer alongside the searchlight and at a distance $d$ from it. A homogeneous atmosphere and a small object are assumed. It was found that,

(a) The range $x$ of the object illuminated by the "near" side of the beam (the portion of the beam near the observer) is about 20 percent greater than when the object is illuminated by the "far" side of the beam, for a clear atmosphere. With increase of haze the difference decreases. (See Fig. 9.)

(b) For a clear atmosphere the range $x$ increases about 25 percent as the observer moves from $d=30$ feet to 100 feet from the searchlight, and about 50 and 75 percent when he moves to $d=200$ and 500 feet, respectively. The percentage increases in $x$ remain approximately constant with increasing haze. (See Fig. 10.)

(c) The range $x$ increases with the fourth root of the area and reflectivity of the illuminated object and with the eighth root of the candlepower of the searchlight, for a clear atmosphere. With increase of haze the increases of $x$ are even less rapid. (See Fig. 11.)

The general conclusion was reached that by means of the present detailed manner of calculation the effectiveness of a searchlight in revealing small objects can be calculated completely from the distribution curve of light in the searchlight beam.

BRIGHTNESS OF SEARCHLIGHT BEAM

Referring to Fig. 1A, let $AB$ be the axis of the beam of the searchlight $A$. At point $P$ in the beam

![Fig. 1. Geometry of searchlight beam.](image-url)
let $\psi$ be the angle between $AP$ and $AB$. Assume
the beam to be a circular cone with light distri-
bution $\eta$ across the beam given by Fig. 1B; $\eta$ is
symmetrical with $\psi$ and is 1 for $\psi = 0$. Let $AP$ be
$x_1$, and assume $x_1$ so great (more than, say, 100
times the diameter of the searchlight mirror) that
the $\eta$, $\psi$ curve is independent of $x_1$. Let $c$ be the
maximum beam candlepower, and $i$ the illumina-
tion at $P$.

Then

$$i = c\eta x_1^{-2} \exp(-\beta x_1),$$  \hspace{1cm} (1)

where $\beta$ is the attenuation coefficient of the
atmosphere for collimated light. Equation (1) is
the definition of $\beta$.

Let the line of sight $DB$ of an observer at $D$
pass through $P$. Let $DE$ be parallel to $AB$;
$AD = d$; $DP = x_2$; and angle $PDE$ be $\phi$. Let the
conventions of the signs of $\psi$ and $\phi$ be those
shown in Fig. 1A. Let all lines be in the same
plane $BAD$.

$\eta$ is a function of $\psi$ and hence of $x_2$. To de-
termine the relation we note from the geometry
of Fig. 1A that

$$\gamma = \psi + \phi,$$

and

$$(\sin \gamma)/d = [\sin (90^\circ - \psi)]/x_2. $$

Whence, eliminating $\gamma$,

$$\tan \psi = (d/x_2) \sec \phi - \tan \phi. $$  \hspace{1cm} (2)

The brightness $\Delta b$ of an element of the beam at
$P$ as seen by the observer at $D$ is

$$\Delta b = \sigma b \exp(-\beta x_2) dx, $$  \hspace{1cm} (3)

where $\sigma_b$ is the coefficient of scattering by the
atmosphere backward toward $D$.

Assuming that $\beta$ and $\sigma_b$ are constant through-
out the region of the atmosphere under considera-
tion, the brightness $b$ of the beam seen by the
observer in the direction of $P$ is

$$b = \int_0^\infty \sigma_b \exp(-\beta x_2) dx. $$  \hspace{1cm} (4)

Substituting (1) into (4) gives

$$b = \sigma c \int_0^\infty \eta x_1^{-2} \exp[-\beta(\alpha x_1 + x_2)]dx. $$  \hspace{1cm} (5)

Since in all cases considered here $\alpha$ and $\phi$ are
small, i.e., not greater than $3^\circ$ and usually less
than $1^\circ$, we have to a close approximation
$x_1 = x_2 = x$. (2) and (5) reduce, respectively, to

$$\psi = d/x - \phi, $$  \hspace{1cm} (6)

$$b = \sigma c \int_0^\infty \eta x^{-2} e^{-2\beta x} dx. $$  \hspace{1cm} (7)

The brightness $b$ was determined from (6) and (7)
by graphical integration for stated values of
$\beta$, $d$, $\phi$, $\eta$, and $c$. No examples of the graphical
integrations are given; they are elementary and
tedious.

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**TABLE 1. Atmospheric attenuation and transmission.**

<table>
<thead>
<tr>
<th>Weather, amount of haze</th>
<th>Visual range $\gamma$ sea miles</th>
<th>Attenuation $\beta$ sea mile$^{-1}$</th>
<th>Transmission $\alpha$ per sea mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exceptionally clear</td>
<td>37.3</td>
<td>0.105</td>
<td>0.9</td>
</tr>
<tr>
<td>Clear</td>
<td>14.4</td>
<td>0.273</td>
<td>0.8</td>
</tr>
<tr>
<td>Light haze</td>
<td>11.0</td>
<td>0.356</td>
<td>0.7</td>
</tr>
<tr>
<td>Light fog</td>
<td>7.67</td>
<td>0.511</td>
<td>0.6</td>
</tr>
<tr>
<td>Thin fog</td>
<td>5.65</td>
<td>0.693</td>
<td>0.5</td>
</tr>
<tr>
<td>Light fog</td>
<td>4.28</td>
<td>0.916</td>
<td>0.4</td>
</tr>
<tr>
<td>Clear</td>
<td>3.25</td>
<td>1.204</td>
<td>0.3</td>
</tr>
<tr>
<td>Light haze</td>
<td>2.44</td>
<td>1.608</td>
<td>0.2</td>
</tr>
<tr>
<td>Thin fog</td>
<td>1.70</td>
<td>2.303</td>
<td>0.1</td>
</tr>
<tr>
<td>Thin fog</td>
<td>1.31</td>
<td>2.997</td>
<td>0.05</td>
</tr>
</tbody>
</table>
ments in this connection other than those already referred to.

It may be clarifying to give the details of the determination of \( K = 3.72 \times 10^{-2} \). Referring to Fig. 2 a beam of incident light in the direction shown is scattered by an element of the atmosphere at \( P \). \( \sigma_b \) is the fraction of the incident light scattered per unit solid angle at angle \( \theta \) with the direction of the incident light. The curve is a plot of the values of \( \sigma_b \) derived from the measurements of the brightness of a searchlight beam for \( \theta \) from 20° to 160°. The strong forward scattering is clearly shown in Fig. 2. \( \sigma_b \) is the back scattered light. Since the lower atmosphere reduces the beam by scattering only, with no absorption,

\[
\beta = \int_0^\pi \sigma_b 2\pi \sin \theta d\theta, 
\]

From a graphical integration of (11), with \( \sigma_b \) given by the curve of Fig. 2, one found \( \beta = 26.9 \sigma_b \), or \( K = 1/26.9 = 3.72 \times 10^{-2} \).

Light distribution curves, in the present notation the \( \eta, \psi \) curves, are given in Fig. 3 for the Army 60-inch and the Navy 36-inch searchlights. Data of these searchlights are in Table II. The values of the maximum beam candlepower are lower than values sometimes stated, but are probably fairly representative of the searchlights in actual use.

Figures 4 and 5 are photographs of the beam of the Army 60-inch searchlight. The beam was directed at the sky about 5° above the horizon, the camera being 5 feet from the searchlight in the case of Fig. 4 and 40 feet in the case of Fig. 5. The night was normally clear; \( \alpha \) was estimated to be about 0.7. The times of exposure were 30 seconds; the light streaks in the beam were caused by insects and moths fluttering in the

\begin{table}[h]
\centering
\caption{Searchlight data.}
\begin{tabular}{|c|c|c|c|c|c|}
\hline
& & & & & \\
\hline
\textbf{Amperes} & \textbf{Volts} & \textbf{Kilo-watts} & \textbf{Max. beam} & \textbf{Lumens} & \\
\textbf{Army-60 inch} & \textbf{Navy-36 inch} & & \textbf{candlepower} & \textbf{per watt} & \\
\hline
150 & 78 & 11.7 & 400,000,000 & 6.2 \\
195 & 90 & 17.5 & 340,000,000 & 7.2 \\
\hline
\end{tabular}
\end{table}

\footnote{1 E. O. Hulburt, J. Opt. Soc. Am. 31, 467–476 (1941).}

\footnote{2 Reference 1, Fig. 4.}
light. A scale of $\phi$ is marked in each picture. It will be realized that the most useful part of the searchlight beam is the small circular area at the end of the beam of radius about $1^\circ$ or less, for this is the place where distant objects are illuminated by the searchlight.

From the foregoing equations and data the brightness $b$ of the searchlight beam was calculated for a number of cases and is plotted in Figs. 6 and 7. All values of $b$ were for the axial plane of the searchlight which passes through the eyes of the observer, i.e., plane $BAD$, Fig. 1. Each value of $b$ was calculated from Eqs. (6) and (7) by graphical integration. Figure 6 gives the variation of $b$ with $\phi$ for $d = 7.5$ feet and for the atmospheric transmission $\alpha = 0.3$ and 0.7. Figure 7 gives the variation of $b$ with $d$, for $\phi = 0$, for several values of $\alpha$. The circumstance that the $b, \phi$ curves of Fig. 6 fall rather sharply to zero at a certain value of $\phi$ provides the explanation of the familiar observation that the beam comes to a definite end when viewed by an observer near the searchlight. The finite end of the beam is clearly shown in the photographs of Figs. 4 and 5.

As the observer moves away from the searchlight the end of the beam becomes less distinct, and when he is several miles away the beam fades out imperceptibly in the distance, if the atmosphere is homogeneous.

In general the $b$ curves of Figs. 6 and 7 were of no great interest in themselves, for their trends are about what one would expect from simple consideration. Their importance was in their use in the calculation of ranges of objects. A point of minor interest was the approximate constancy of $b$ with $\phi$ for $\phi$ greater than about $1^\circ$, shown in Fig. 6. The relation can be stated as a theorem in physical optics; the theorem can be proved and the conditions under which it is exact and under which it becomes inexact can be laid down. It appears to be a new theorem. However, it is not used here, and we leave its elucidation to the student.
Two sets of experimental observations of the brightness of a searchlight beam were made in which \( b \) was measured for \( \phi = 0^\circ \) for several values of \( d \). One set was made with a 60-inch Army searchlight and the other with a 24-inch Navy searchlight. The observations are plotted as crosses in Fig. 8, the upper four referring to the 60-inch and the lower three to the 24-inch searchlight. \( b \) was measured with a calibrated Macbeth illuminometer with a blue filter over the illuminometer lamp to obtain a color match with the beam. The illuminometer had an objective lens of 12 inches focal length which made the central field about 1\(^\circ\) in diameter. The instrument was used to measure the brightness \( b \) of the beam at the point \( \phi = 0^\circ \), as shown in the photographs of Figs. 4 and 5. The use of the illuminometer of 1\(^\circ\) field to measure \( b \) at the end of the beam where \( b \) fell from a maximum value to zero in about 1\(^\circ\) could only be expected to give an average value of \( b \).

In the case of the 24-inch Navy searchlight the maximum beam candle power \( c \) and the atmos-

![Fig. 7. Brightness of beam at various distances.](image)

![Fig. 8. Observed and calculated brightness of beam.](image)pheric transmission were measured at the same time that \( b \) was observed. \( c \) was 50.3 \( \times 10^6 \) candles and \( \alpha \) was 0.70. \( \alpha \) was measured by means of a telephotometer and a known light at a known distance. The \( \eta, \psi \) curve of the distribution of light in the beam was not known for the 24-inch searchlight. However, since the searchlight was well designed, its \( \eta, \psi \) curve was assumed to be approximately that of the Navy 36-inch searchlight of Fig. 3. On this assumption the \( b, d \) curves for \( \phi = 0^\circ \) and \( +1^\circ \) were calculated and are plotted in the dotted curves of Fig. 8. One would expect the observed points, the crosses, to lie on the \( \phi = 0^\circ \) curve or perhaps between the two \( \phi \) curves. They do this tolerably well, indicating fair agreement between the direct measurement of \( b \) and the values obtained by calculations from measurements of haze and data of the searchlight.

In the case of the 60-inch Army searchlight the atmospheric transmission was not measured. However, the night seemed normal (it was the same evening that the photographs of Figs. 4 and 5 were taken) and \( \alpha \) was estimated to be 0.7. On
this basis with $c = 4 \times 10^8$ and the $\eta, \psi$ curve of Fig. 3, the calculated $b, d$ curves of Fig. 8 were determined for $\phi = 0^\circ$ and $1^\circ$. They agree about as expected with the four observed points shown by the crosses.

In comparing the observed and calculated values of the brightness of the Army searchlight it was assumed that the brightness was caused by atmospheric haze and not to the insects flying around in the beam which are so noticeable in the foreground of the photograph of Fig. 4. The assumption was probably correct because the region at the end of the beam where the brightness was measured was several hundred feet above the ground where there were few insects.

**RANGES OF OBJECTS IN SEARCHLIGHT ILLUMINATION**

An object illuminated by a searchlight appears to an observer who is not too far from the searchlight to be surrounded or immersed in the luminous beam of the searchlight. Usually the object appears brighter than the surrounding field of light; in fact, under the supposition of this report, namely, that the beam is caused by an optically homogeneous atmosphere throughout the length of the beam, an object, even if painted with ordinary black paint, is always brighter than the searchlight beam surrounding it. It is assumed that the object is so small and so far away that its longest linear dimension subtends an angle less than about 5 minutes of arc at the observer. Thus the illuminated target is approximately a point source of light surrounded by a luminous field. In this case the threshold illumination of the point source at the eye is known from an earlier investigation and the maximum ranges at which the object can be seen can be calculated.

A plane object is assumed of area $A$ square feet and of diffuse reflectivity $R$. It is assumed that the plane of the object is normal to the axis of the searchlight beam, and that the observer is so near the searchlight and the object so far from the searchlight that the line of sight of the observer is also approximately normal to the plane of the object. It is assumed that the illumination $i$ on the object is mainly caused by the searchlight and that the illumination on the object from other sources, as night sky light, stars, aurorae, moon, etc., are relatively weak. Then, if $x$ is the distance from the searchlight to the object, $i$ is given by (1), or

$$i = \sigma \eta x^2 e^{-\beta x}. \tag{12}$$

The illuminated object is a source of light of candlepower $iAR/\pi$ in the direction of the observer, $i$ being in foot candles. Since the object is assumed to appear to the observer approximately as a point source, the illumination $j$ which it produces at the observer is

$$j = iAR\pi^{-1}x^{-2}e^{-\beta x}. \tag{13}$$

The earlier experiments showed that the illumination $j$ at the visual threshold, for young observers with good vision, from a point source in a field of brightness $b_f$ was given approximately (within a factor of 3) by

$$j = 10^{-10} (1 + 3.38 \times 10^6 b_f)^3, \tag{14}$$

where $j$ is in footcandles and $b_f$ is in candles per square foot. (14) was found to hold for $b_f$ ranging from zero to about 1500 c/ft.$^{-2}$. We shall use (14) in the present searchlight case. There is a possible error in doing this. (14) referred to the case of a uniform field of diameter about 25 minutes of arc or greater surrounding the point source. The field of the searchlight beam around the illuminated object is in general not uniform, as shown by the $b, \phi$ curves of Fig. 6. It was considered that the error due to the nonuniformity was not serious.

Substituting (12) and (13) into (14) leads to

$$(x^{-2}e^{-\beta x})^2 = 10^{-10} (1 + 3.38 \times 10^6 b_f)^3 (\pi/AR\eta), \tag{15}$$

where $x$ is the maximum visual range of the object, or simply the "range" of the object. In the case of the searchlight the field brightness $b_f$ is the sum of the brightness $b$ of the beam and the brightness $b_f$ of the night sky. Then (15) is

$$(x^{-2}e^{-\beta x})^2 = 10^{-10} \times [1 + 3.38 \times 10^6 (b + b_f)]^3 (\pi/AR\eta). \tag{16}$$

From (16) the range $x$ was calculated for various conditions of haze, positions of target and observer, and types of searchlight, using the values of the beam brightness $b$ from Figs. 6 and 7. (16) is of the form $x^2 e^{-ax} = n$ which cannot be

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solved explicitly for \( x \). A nomograph of this function was prepared to facilitate numerical solution.

The brightness of the horizon sky on clear, moonless nights is about \( 3 \times 10^{-5} \, \text{cu ft}^{-2} \), and is less than this if there is much haze, fog, or clouds. It is seen from Figs. 6 and 7 that the values of \( b \) are usually much greater than \( 3 \times 10^{-6} \) unless there is considerable haze \( (\alpha < 0.3) \) and the observer is at a considerable distance from the searchlight \( (d > 200 \, \text{feet}) \). Therefore \( b \) is usually less than \( b_s \).

For an object on the axis of the searchlight \( \eta = 1 \). Approximately \( b_s \) and the number 1 on the right-hand side of (16) are usually negligible. Therefore (16) may be written approximately

\[
(x^{-2}e^{-\beta x})^2 \propto b^1(ARc)^{-1}. \tag{17}
\]

From (7) approximately for \( \beta \) small \( b \propto c \). Then (17) becomes

\[
(x^{-2}e^{-\beta x})^2 \propto (AR)^{-1}c^{-1},
\]

or

\[
x^{e^{\beta x/2}} \propto (AR)^{1/8}. \tag{18}
\]

From (18) it is seen that for \( \beta \) small the range \( x \) increases approximately with the fourth root of the size and reflectivity of the object and with the eighth root of the candlepower of the searchlight; with increasing haze, i.e., increase of \( \beta \), the increase of \( x \) is even less. This explains why great increases in the candlepower of the searchlight yield only moderate increases in the visual ranges of illuminated objects.

In the following numerical calculations we shall assume throughout an object for which \( AR = 100 \) and whose angular diameter at the observer is not greater than about 5 minutes of arc. Since we shall be concerned with ranges greater than 1 sea mile such a target is, for example,

<table>
<thead>
<tr>
<th>Length</th>
<th>Width</th>
<th>Reflectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 feet</td>
<td>10 feet</td>
<td>1.00</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>1.00</td>
</tr>
<tr>
<td>25</td>
<td>20</td>
<td>0.20</td>
</tr>
</tbody>
</table>

It is also assumed throughout that \( b_s = 3 \times 10^{-5} \) candle per square foot.

**RANGE OF OBJECT IN VARIOUS PARTS OF THE BEAM**

We take \( d = 7.5 \, \text{feet} \), which means that the observer is 7.5 feet from the axis of the searchlight. The range at which he can see the target was calculated from (16) for various values of \( \phi \) with the values of \( b \) from Fig. 6. The results are given in Fig. 9 for the Navy 36-inch searchlight for a clear \((\alpha = 0.7)\) and a hazy \((\alpha = 0.3)\) atmosphere and for the Army 60-inch searchlight for \( \alpha = 0.7 \). It is seen from the curves of Fig. 9 that when the object is illuminated by the portion of the beam on the side of the axis nearest to the observer, i.e., \( \phi \) is negative, the ranges are greater than when the object is illuminated by the portion of the beam on the side far from the observer, i.e., \( \phi \) is positive. The reason, of course, is that in the "near" case the portion of the beam is less bright than in the "far" case, as seen from the curves of Fig. 6. The fact is familiar to operators of searchlights who know from experience that they can see objects somewhat better in the near side than in the far side of the searchlight beam. The difference, however, becomes less as the haze increases.

An important simplifying result appears from the curves of Fig. 9, namely, the range is relatively constant for \( \phi \) from about \(-0.1^\circ\) to \(+0.3^\circ\). This means that we may make subsequent range calculations for \( \phi = 0^\circ \) with the realization that the ranges obtained are not sensitive to the exact positioning of the axis of the beam on the object, as long as the object is within \( \phi = -0.1^\circ \) to \(+0.3^\circ\).
In this case $x$ was calculated from (16) as a function of $d$ for various amounts of haze, for a night sky brightness $b = 3 \times 10^{-3} \text{ cu ft}^{-2}$, and for $\phi = 0^\circ$, using the values of $b$ of Fig. 7. The results are in Fig. 10. It is seen that there is an increase in range as the observer moves away from the searchlight, the increase being, for a clear atmosphere, about 25 percent as the observer moves from 30 feet to 100 feet from the searchlight, and about 50 percent when he moves to 200 feet. The value of $x$ given in Fig. 10 for no beam were of academic interest, and were obtained by putting $b = 0$ in (16).

The curves of Fig. 10 are true only for a homogeneous atmosphere. In the case of a searchlight turned upward to view objects in the sky the atmosphere is usually non-homogeneous, and often the non-homogeneity consists in relatively heavy haze in the first few thousand feet above sea level, and a relatively clear atmosphere above. In such case the $b$, $d$ curve is quite different from the $b$, $d$ curves of Fig. 7 for a homogeneous atmosphere, and the improvement in range occasioned by the observer moving away from the searchlight follows a curve different from those of Fig. 10. For example, $b$ may be very bright due to haze in the first few thousand feet, and then with increasing distance may fall to low values. In consequence, as the observer moves away from the searchlight he may obtain at first only a small improvement in range; then, as he continues to move away he may suddenly find the range much increased because of the fact that he has reached a position in which his line of sight to the object passes alongside of, and not through, the bright section of the beam.

**RANGES FOR SEARCHLIGHTS OF VARIOUS CANDLEPOWERS**

In this case $x$ was calculated from (16) as a function of $c$ for various amounts of haze, for $\phi = 0^\circ$, and for two positions of the observer $d = 20$ and 100 feet. The $\eta$, $\psi$ curve of the Navy 36-inch searchlight was used. The $x$, $c$ curves are in Fig. 11, and illustrate the relatively slow increase of range with increase of candlepower. The slow increase is indeed obvious from (16) or (18).
LETTERS TO THE EDITOR

Although this report is not primarily concerned with the design of searchlights it is of interest to remark on the effect of width of beam brought out by the calculations of the Army 60-inch and the Navy 36-inch searchlights, the 60 inch having a beam width of about 7/10 of that of the 36 inch, as seen from Fig. 3. We have ascribed to the Army searchlight a maximum beam candlepower $c$ of 400 million and to the Navy searchlight 340 million. Assume that $c$ for the Navy searchlight were 400 million; the values of the ranges of the Navy searchlight of Fig. 9 would be increased by about 4 percent for $\alpha=0.7$. We see then from Fig. 9 that the widths of the flat maxima of the $\chi, \phi$ curves are roughly in proportion to 7/10 and hence to the beam widths given by the $\eta, \psi$ curves of Fig. 3 for the two searchlights. In other words the angular width of the most effective portion of the searchlight beam as judged by seeing objects at maximum ranges is roughly proportional to the angular width of the beam as determined by the light distribution curve $\eta, \psi$. It has sometimes been surmised that narrowing the beam might give greater increase in range than might be expected from the increased light intensity occasioned by the greater concentration of light. It appears that the surmise is not correct for the two searchlights under consideration.

In conclusion it is well to emphasize again that the ranges of Figs. 9–11 refer to objects that are small enough to appear approximately as point sources. The ranges of larger objects cannot yet be worked out because visual thresholds of larger objects are not available. Also, it may be mentioned again that the present results are restricted to the axial plane of the searchlight $BAD$, Fig. 1. The case of the searchlight tipped upward or downward so that it illuminates the object in a portion of the beam above or below the axial plane has not been worked out. The case may readily be calculated by the present methods, but it appeared that no important new facts were to be learned from its consideration at this time.

It is a pleasure to acknowledge the cooperation of the Army Engineer Board, Fort Belvoir, Virginia. The Board, through Major O. P. Cleaver, Lieutenant F. J. Millican, and Mr. C. F. Cashell, operated the 60-inch searchlight for the purpose of the photographs of Figs. 4 and 5 and the measurements of Fig. 8.

Letters to the Editor

The Basic Sensation Curves of the Three-Color Theory

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MR. HL. DE VRIES has described determinations of the "basic sensation curves of the three-color theory" based on observations of the visibility of a small test stimulus of one color viewed foveally against an adapting field, generally, of another color. As Mr. de Vries claims his method to be a new one, may I point out that closely similar measurements were used to derive the spectral sensitivity curves of the three-cone mechanisms in a paper previously published under the title "The directional sensitivity of the retina and the spectral sensitivities of the rods and cones." The derivation of the spectral sensitivity curves was only a part of a much wider investigation, and it may have escaped the attention of Mr. de Vries on this account.

A comparison of Mr. Vries' results with my own may be of interest. In Fig. 1 the broken-line curves are those obtained by de Vries for a color normal subject G.W.N. (Curves 1, 2, and 3 in his Fig. 3), except that here log (sensitivity) instead of sensitivity has been plotted. The full-line curves are taken from Fig. 41 of my 1939 paper, and have been reduced to the value 1 (log value = 0) at their re-

FIG. 1. Log (spectral sensitivity) curves for the three mechanisms of foveal cone vision.