HIGHWAY RESEARCH BOARD

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# *Night Visibility 1958*



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# Contents

# A Color Comparator for Lights in the Vicinity Of Traffic Signals

D. M. FINCH, Professor and Research Engineer, and JERRY HOWARD, Jr. Research Engineer, Institute of Transportation and Traffic Engineering,
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In city driving conditions there exists the problem of advertising signs of the same or nearly the same color and in close proximity with traffic signals causing the driver to confuse the two.

An instrument designed to be used in the comparison of the colors of distracting lights with established color limits is to be discussed. The color limits, suggested by the National Bureau of Standards, delineate those which are considered unlikely to be confused with traffic signal colors, red and green. The device utilizes an optical system that contains neutral density wedges, a field splitting prism and a standard reference source consisting of a tungsten source operated at a specific color temperature and selected glass filters.

In use, a light source such as a neon advertising sign, in close proximity with a traffic light, is selected. It is then to be determined whether the source is within the range of allowable colors. The instrument is aimed at the source and the nearest matching color from the reference source is selected by means of a rotating filter holder. Then the field brightness or the reference source brightness is adjusted by means of the density wedge associated with it until a brightness match is obtained in the split image field. The reference source impinges upon two semicircles separated by a small distance and the remainder of the circular field contains the source to be measured. It is then determined whether the external source is within the range of allowable colors. In the case of the green limit, for example, whether the external source is bluer or greener than the reference source.

Relating this to the standard ICI color triangle, the green limit is a line given by $y = x + 0.040$ and the red limit is a line given by $6 = x - 0.240$. These lines are established by three filters for each line. If the color to be measured falls in between any two reference colors, the observer must use his experienced judgement to make a determination.

Some field observations are to be presented and discussed.

Confusion of sign colors with traffic signal colors is a real problem in city driving and the subject requires further study so that practical limits can be established that are not unduly restrictive yet will avoid the distractions that now exist.

● COLORED LIGHT from advertising and display sources has reached such extensive use and variety of color that there is a definite possibility of interference of these light sources with the traffic signals. In some instances the color of the background advertising and display sources is so close to the color of a traffic signal that they render the signal practically invisible. In Contra Costa County, California, a proposal has been made to limit the color of advertising and display signs to colors outside the range of traffic signals, thereby reducing the loss of visibility of traffic signals due to color interference.[1]

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[1] Ordinance 1009, Sec. XIII, Illuminated Signs.

Subsection 1. All outdoor advertising structures wherever situated in the unincorpor-

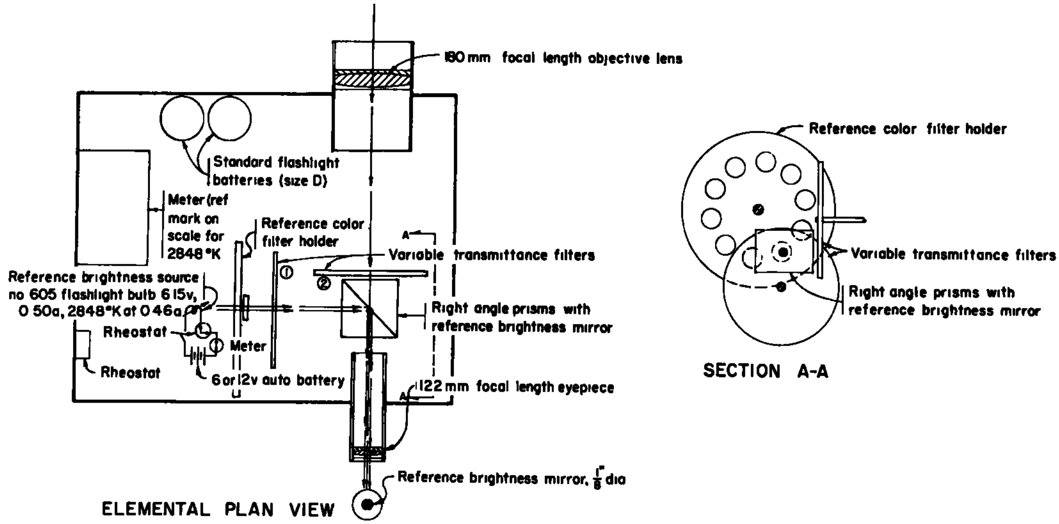


Figure 1. Color comparator for lights in the vicinity of traffic signals.

In order to evaluate the range of colors permitted for advertising and display signs the Public Works Department, Contra Costa County, Martinez, California arranged to have a color comparison meter and a field procedure developed by the staff of the ITTE in the Illumination Laboratory of the University of California. The results of the investigation are presented herein and the instrument that was developed is described. This instrument allows the operator to determine the relative color of a sign or light with respect to the adjacent traffic signal, and it enables the operator to determine whether or not the color of the sign is within the allowable limits.

## Design of a Color Comparison Meter

The characteristics desired in the instrument were as follows:

1. The specified limit colors shall be accurately reproduced.
2. The brightness of the limit colors shall be variable and capable of being made comparable to those found in advertising signs and displays.
3. The instrument must be portable.
4. The reference colors shall be defined in terms of the ICI trichromatic color coordinate system.

The instrument design is shown in Figure 1. The variable transmittance neutral

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ated territory of Contra Costa County which are within the descriptions of Subsection 2 hereof, shall not have a light source or surface which fails to meet the color specifications of Subsection 4 hereof.

. . . .

Subsection 3. Color specifications. Colors are defined herein in terms of the chromaticity coordinates defined on April 11, 1951, by the American Standards Association, Incorporated, 70 East 47th Street, New York 17, New York in their standard designated "American Standard Method for Determination of Color Specifications Z58. 7. 2-1951."

Subsection 4. Color specifications for illuminated signs.
The chromaticity coordinates for colors which are not confusible with traffic signal colors must be as follows:
Y must be greater than X minus 0. 240 (to avoid confusion with red traffic signal).
Y must be less than X plus 0. 040 (to avoid confusion with green traffic signal).

filter (1) satisfies the condition that the brightness of the limit colors can be made comparable to the brightness of adjacent advertising signs. The variable neutral filter (2) in the path of the object serves to reduce the object brightness to a desired level, thus permitting a brightness match between the object field and the reference brightness source. The color filters are inserted between the reference brightness source and the variable filter (1) to permit a color match. The variable transmittance filters are of the evaporated aluminum type and are very nearly neutral. The reference light source is a No. 605 flashlight bulb operated at 0.46 amps to give the spectral distribution of Std. Illuminant A (2848 K).

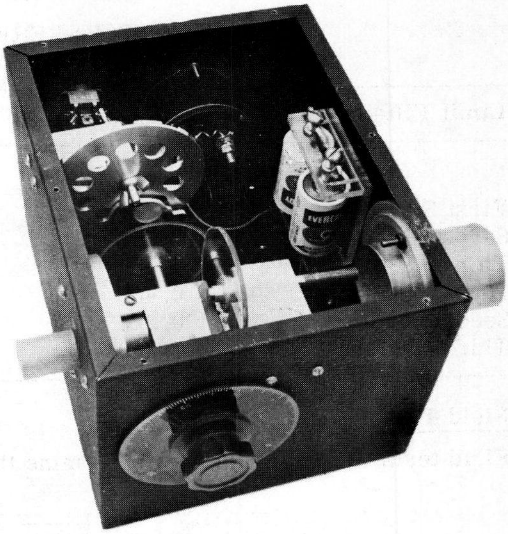

Figure 2. Color comparator instrument.

The optics consist of a coated achromat objective lens of 180 mm focal length with a coated achromat eyepiece lens of 122 mm focal length. A mirror is placed at the focal plane of the objective lens at 45 deg to the main optical path and forms a ⅛-in. diameter split field image of the reference brightness source. The mirror is an ellipse at 45 deg to the principal focal plane so that it projects as a circle in the focal plane. The circle of the mirror is split with a clear central strip so that a color comparison may be made between two areas of the reference color and the color of the advertising or display source to be evaluated.

A photograph of the instrument is shown in Figure 2.

## Procedure for Use of the Instrument

1. Adjust both variable filters for maximum transmittance and then focus the optics on the scene.
2. Match the brightness of the questionable light source in the scene to the brightness reference source in the instrument by selecting the correct color filter and then rotating either or both variable mirrors until a visual brightness match is made. Select the color filter that is the nearest in hue to the source being evaluated.
3. Look at the questionable light source in the field to view and determine its chromaticity in terms of the reference color.

The steps will give a qualitative evaluation of the color of the advertising sign with respect to the adjacent traffic signal if both are approximately the same brightness. The color of the sign can be approximately located on the trichromatic color chart of Figure 3.

## Limit Filters

The instrument incorporates the color filters suggested by D. B. Judd of the National Bureau of Standards in a letter to Francis J. Collins, District Attorney, Contra Costa Co., Martinez, California, dated October 19, 1955, as being those which will not be confused with traffic signal colors.

In the ICI system the recommended color limits are:

1. $y$ must be greater than $x - 0.240$ to avoid confusion with the red traffic color.
2. $y$ must be less than $x + 0.040$ to avoid confusion with the green traffic signal.

The National Bureau of Standards suggested the use of Lovibond glass filters with the specifications shown in Table 1 as color limits. The actual filters that were obtained were quite close to these limits and are shown plotted in the ICI color triangle in Figure 3.

TABLE 1

LOVIBOND REFERENCE COLOR FILTERS
(Used with Standard Illuminant A)

| Limit Filter | Chromaticity | Coordinates | Lovibond Notation | | |
|---|---|---|---|---|---|
| | x | y | R | Y | B |
| First Red | 0.615 | 0.375 | 13.5 | 20.0 | 0 |
| Second Red | 0.580 | 0.340 | 14.0 | 0 | 0 |
| Third Red | 0.540 | 0.300 | 23.0 | 0 | 5.5 |
| First Green | 0.400 | 0.440 | 0 | 5.0 | 5.0 |
| Second Green | 0.320 | 0.360 | 0 | 1.5 | 8.0 |
| Third Green | 0.240 | 0.280 | 0 | 2.5 | 14.5 |

Field Tests

Field tests were conducted to determine the effectiveness of the meter. Two areas

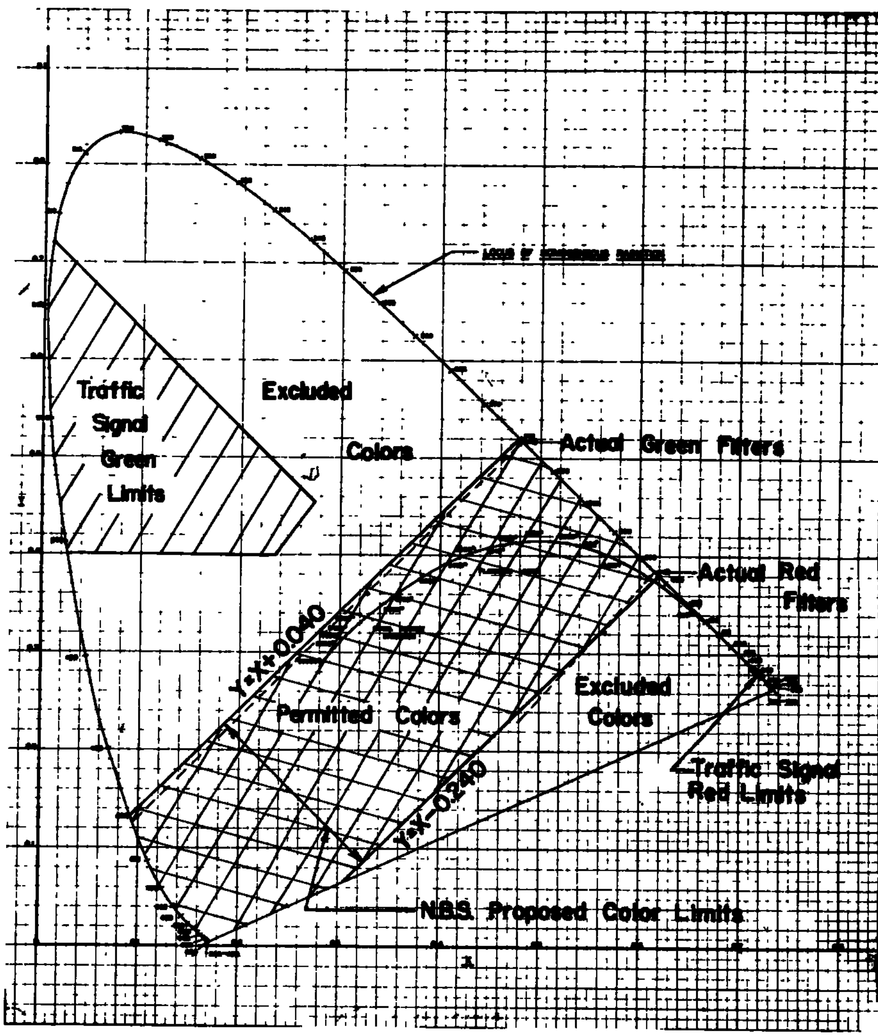


Figure 3. Trichromatic color chart.

were selected, one being a congested downtown intersection having a high concentration of advertising and display signs and traffic signals on every corner. The second area was a retail business district with less sign density than the above intersection area and had random placement of traffic signals.

## RESULTS

It was determined that the meter gave a good indication of the chromaticity of the colors observed but that several additional limiting color filters would be desirable.

Approximately 90 percent of the reddish, greenish or blueish signs fall within the excluded area on the chromaticity diagram of Figure 3.

## DISCUSSION

Strict enforcement of the Contra Costa County Ordinance would mean the elimination of a very large number of advertising and display signs in the vicinity of traffic signals.

The problem resolves itself into two conditions, namely (a) signs being mistaken for signals and (b) signal lights being invisible in a confusion of background signs. In the former case (a) it is felt that the color limits used in the experimental meter give a fair indication of colors that might be mistaken for signal lights. There is the question though of whether this condition has much importance. The error of seeing too many signals, while somewhat discomfiting to the driver, should cause no serious harm. It is the second condition; namely, signals becoming invisible in a background confusion of similarly colored signs, that is the important problem.

The instrument as it is now designed will give an answer to problem (b) but we are not satisfied that the answer is correct. The meter indicates that almost all of the red, green or blue hues used in advertising and display signs would cause the signal to be mistaken or missed by a driver. The color limits for permitted colors seem to be too narrow but there is not sufficient data to recommend where the limits should be located. The permitted colors could be somewhat closer to the traffic signal color limits (see Fig. 3).

There are several variables that could not be isolated in the preliminary investigations with the instrument. They are as follows: 1. Time factor—Since the investigators were consciously searching out both signals and signs that might be confused with traffic signals, the actual condition of the average driver with the many distractions of driving was not reproduced. For an average driver the time available for detecting signals is much more restricted. 2. Familiarity—There are cues that suggest the existence of traffic signals over and above their actual visibility. For example, in a downtown area one would expect signals on every corner; one may note other stopped cars presumed to be at a traffic signal. Other cues, although somewhat unreliable, are pedestrians. 3. Color blindness—What the normal observer would not confuse, the color-blind person might, and conversely. Since about 5 percent of the population is color-blind, their number is significant.

There is still another element in the discrimination of signal lights, in a maze of other lights—brightness differences. A bright light of a given hue (say a blue-green signal light) may be visible although somewhat desaturated in color when it is surrounded by less bright lights of a similar hue even though the surrounding lights may be quite close to the color of the signal and within the area of excluded colors. In this instance the brightness of the signal rather than its hue is the primary factor in its detection. The signal may or may not be seen depending upon the brightness differences. In the opposite situation where the surrounding lights are much brighter than the signal lights, the color of the signal again tends to lose its importance since the glare of the surrounding lights masks the signal and makes it very difficult to detect even when the colors of the two are grossly different. It is mainly the condition where the signal and the background signs are of approximately equal brightness that color differences or similarities are important.

## CONCLUSIONS

The work that has been done so far indicates that a field technique to compare actual advertising and display colors with reference limit colors is practical.

It appears that the color limits suggested by the NBS are unduly restrictive. It would seem that the blue-green and red limit for advertising and display signs could be set closer to the signal green and signal red colors (see Fig. 3).

Before the actual limits can be unequivocally set, further research must be conducted and the aforementioned variables held constant insofar as possible in controlled laboratory experiments.

# Optical Properties of the Atmosphere and Highway Lighting in Fog

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The light transmission and polar scattering properties of natural and artificial fogs have been measured. Since polarization effects in scatter are very large, considerable effort has been devoted to obtaining complete polarization information.

These data will be used to design and evaluate improved lighting systems for use on the highway in fog. For each proposed system, the luminances and contrasts of objects as seen through the fog can now be computed.

The scattering curves have already suggested some improvements which might be made, and these have been viewed in a 3:1 scale model simulator at the Pennsylvania State University and in a 25:1 simulator at the University of Michigan.

These tests have demonstrated that visibility in fog can be improved by changing the candlepower distribution of street lights to avoid forward scatter, by employing vehicle fog lights which are mounted as far as possible away from the driver's line-of-vision, and by increasing the candlepower of taillights. Polarization techniques may also prove to be valuable. Quantitative information about the improvements to be gained by these and other changes will be obtained in an improved simulator now under construction.

●THE OBJECT OF the research to be briefly described here was the development of methods for improving visibility on the highway in fog by lighting installations of special design. This research was a portion of a coordinated program initiated by the Illuminating Engineering Research Institute. In addition to the research to be reported here, Charles R. Marsh of Pennsylvania State University conducted closely related tests during the same time period. Marsh employed a 3:1 scale model of a short section of highway to evaluate various types of street lights and vehicle lights, in an artificially generated water fog. At the University of Michigan, the principal effort was the measurement of the complete light-scattering properties of natural and artificial fogs. In addition, a relatively small effort was devoted to construction of a 25:1 scale model simulator, employing artificial fog as in Marsh's simulator. A complete account of the results of these studies may be found in a University of Michigan report (1).

## SCATTERING MEASUREMENTS

In clear air, rays of light follow straight line paths, for example from a street light to the pavement and thence to a driver's eyes. In the presence of fog, however, some of these rays are intercepted by the droplets, so that the amount of light following the direct paths is attenuated. Furthermore, the light intercepted by the fog is scattered, and proceeds in new directions (Fig. 1). Some of this scattered light enters the driver's eyes in the form of a veiling luminance, thus reducing the apparent contrast of objects on the highway. It is evident that the development of improved lighting systems for use in fog depends upon the availability of exact information about the scattering and attenuation processes of actual fogs.

Scattering and attenuation measurements were made with a Recording Polar Nephelometer (Fig. 2) and a Portable Transmissometer (Fig. 3). Description of the construction and calibration of these instruments is contained in a University of Michigan report (2).

Figure 4 shows the optical system of the Polar Nephelometer. A projector at the left directs a narrow beam of light across the center of the instrument into a light trap at the right. Light is scattered in all directions by the fog droplets within the light beam, as shown in Figure 1. That which is scattered in the direction of the receiver (lower right) is measured by the photomultiplier. As the arm on which the receiver is mounted rotates slowly about the illuminated fog sample, the amount of light scattered

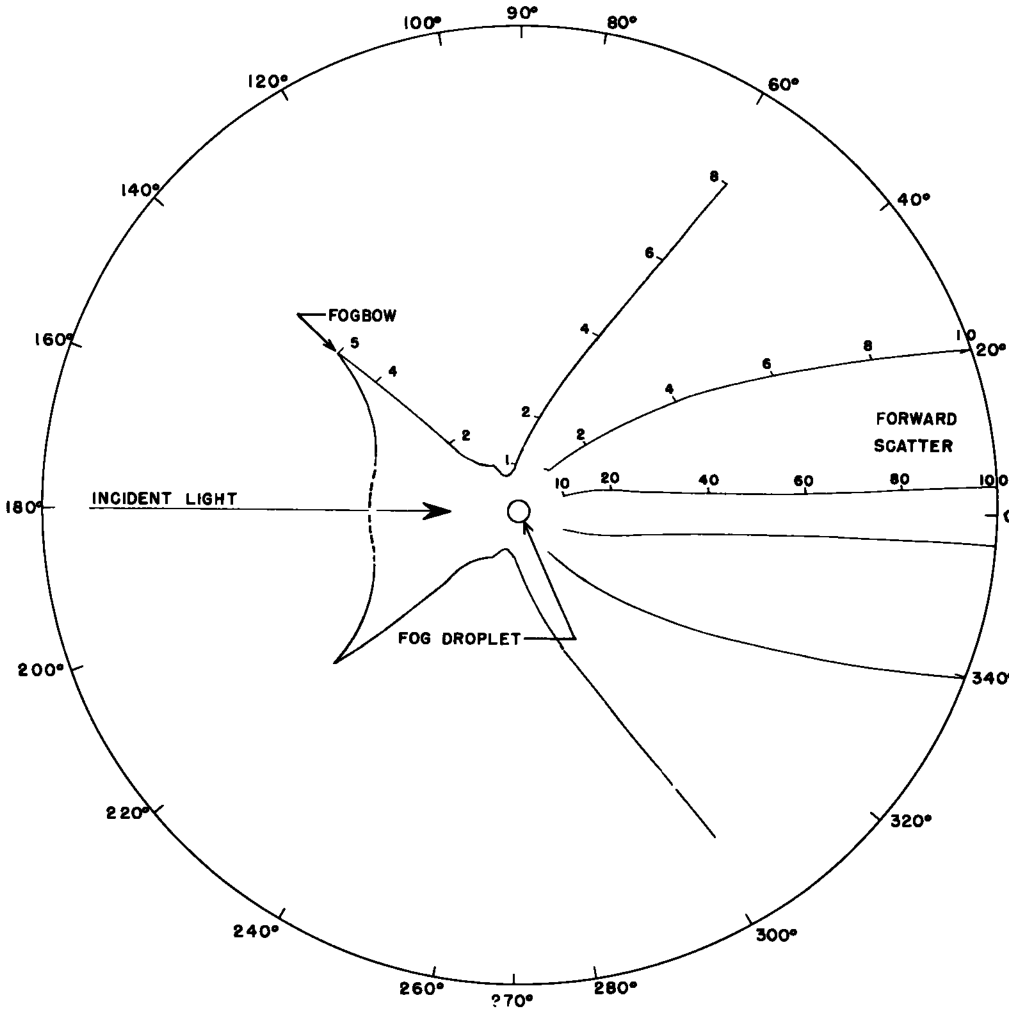


Figure 1. The amount of light scattered by an average fog droplet in various directions is plotted on circular coordinates. Forward scatter is so large in comparison with right angle and back scatter that it is necessary to change the radial scale factor in two steps of ten each.

at various angles with respect to the projector beam is recorded.

The Transmissometer measures the amount by which the intensity of a narrow beam of light is reduced after transmission through a long fog path. The projector (on the left in Fig. 3) and the photoelectric receiver (on the right) face each other with a separation of about one hundred feet. From the measured transmittance and the length of the path employed, it is possible to compute the attenuation coefficient and the meteorological range, or the "visibility".

Figure 5 is a picture of the station wagon which has been equipped to transport the two instruments to the measurement site. With the gasoline-driven generator in the trailer to provide electrical power, atmospheric measurements can be made in any convenient location.

Figure 6 shows a set of polar scattering diagrams obtained in a natural fog in Ann Arbor on February 26, 1957. When the receiver of the instrument nearly faces the projector, the scattering angle, plotted on the abscissa, is small, and the photomultiplier signal is very large, as shown at the upper left. The minimum scatter occurs at

## TABLE 1

## VOLUME SCATTERING INDICES OF FOG MEASURED ON FEB. 26, 1957

| Scattering Angle φ (Degrees) | $\beta'_{VV} \times 10^4$ (ft.$^{-1}$) | $\beta'_{HH} \times 10^4$ (ft.$^{-1}$) | $\beta'_{HV} \times 10^4$ (ft.$^{-1}$) | $\beta'_{UU} \times 10^4$ (ft.$^{-1}$) |
|---|---|---|---|---|
| 1.33 | 810 | 810 | | 810 |
| 2 | 260 | 260 | | 260 |
| 4 | 68 | 68 | | 68 |
| 6 | 40 | 40 | | 40 |
| 8 | 36 | 36 | | 36 |
| 10 | 25 | 25 | | 25.2 |
| 15 | 17 | 17 | | 16.9 |
| 20 | 9.6 | 10.6 | .005 | 10.1 |
| 25 | 7.0 | 7.8 | .004 | 7.4 |
| 30 | 5.2 | 5.5 | .003 | 5.3 |
| 35 | 4.0 | 4.0 | .003 | 4.0 |
| 40 | 2.85 | 2.85 | .002 | 2.85 |
| 45 | 1.95 | 2.17 | .002 | 2.06 |
| 50 | 1.32 | 1.62 | .001 | 1.47 |
| 55 | .86 | 1.16 | .001 | 1.01 |
| 60 | .56 | .75 | .001 | .65 |
| 65 | .39 | .49 | .0009 | .44 |
| 70 | .295 | .33 | .0008 | .31 |
| 75 | .238 | .227 | .0007 | .233 |
| 80 | .192 | .170 | .0006 | .181 |
| 85 | .159 | .117 | .0006 | .138 |
| 90 | .136 | .100 | .0006 | .118 |
| 95 | .110 | .076 | .0005 | .093 |
| 100 | .103 | .064 | .0005 | .084 |
| 105 | .101 | .052 | .0005 | .077 |
| 110 | .097 | .060 | .0005 | .079 |
| 115 | .111 | .067 | .0006 | .088 |
| 120 | .141 | .074 | .0006 | .108 |
| 125 | .191 | .084 | .0009 | .138 |
| 130 | .158 | .085 | .0011 | .122 |
| 135 | .22 | .104 | .0015 | .163 |
| 140 | .82 | .165 | .006 | .50 |
| 145 | .52 | .255 | .006 | .39 |
| 150 | .42 | .255 | .0085 | .35 |
| 155 | .37 | .35 | .0095 | .37 |
| 160 | .28 | .33 | .014 | .32 |

about 100 deg, and the fogbow (first cousin to the rainbow) shows as a large peak at about 140 deg.

The variety of curve shapes shown was obtained, all in the same fog, by inserting various types of polarizers in the instrument. The first symbol on each curve stands for the polarizer in the projector, and the second for that in the receiver. V, H, D, R, and U stand for vertical linear, horizontal linear, 45 deg diagonal linear, right circular, and unpolarized, respectively. The curve which would have been obtained if both the projected light and the receiver had been unpolarized is very nearly equal to the average of the VV and HH curves. Values are given in Table 1.

The volume scattering index is defined by the following equation (3):

$$\beta' = \frac{I}{E\,v}$$

in which I is the intensity (in flux per steradian) of the light scattered in a particular direction by a fog sample of volume v, and the illumination on the sample is E (flux per unit area). In the Polar Nephelometer the volume of the scattering sample is defined by the intersection of the projector and receiver beams. The volume changes as the receiver swings around, but corrections are made for this effect during data analysis. (If these corrections were not made, the curves would rise even higher at both ends.)

The University of Michigan report (2) presents a much more complete description of these two instruments, along with a detailed analysis of the difficult calibration procedures.

The same report also presents the results of measurements of other natural fogs and of two artificially-produced fogs. They are not repeated here, as it is sufficient for present purposes to state that all water fogs measured to date produced generally the same shape curves when plotted on logarithmic scales. Curves for fogs of different densities differ from each other principally in the height of the curves on the paper. Only the data of February 26, 1957 are presented here, these being the most accurate and complete which have been obtained.

To date, only a green filter has been employed during fog measurements, as the effects of color in fog are known to be very small. On the other hand, much effort was devoted to obtaining complete information about polarization effects. These are very important in most scattering phenomena, yet they have never been measured before in either fog or clear air except at isolated scattering angles. It is evident that knowledge of the polarization properties of fog is needed when consideration is being given to the use of polarized vehicle lights and street lights, but it is not so obvious that it is important when no polarizers will be employed. However, there are many natural sources of partial polarization present everywhere. If ones eyes were sensitive to these effects as they are to color, would be observed that light reflected from most surfaces at large angles of incidence becomes strongly polarized, that portions of the blue sky are highly polarized, and that rainbows and fogbows are almost 100 percent polarized. Polarization effects cannot be ignored in any optical system which includes more than one polarizing element, and the scattering data for unpolarized source and receiver must be used with discretion.

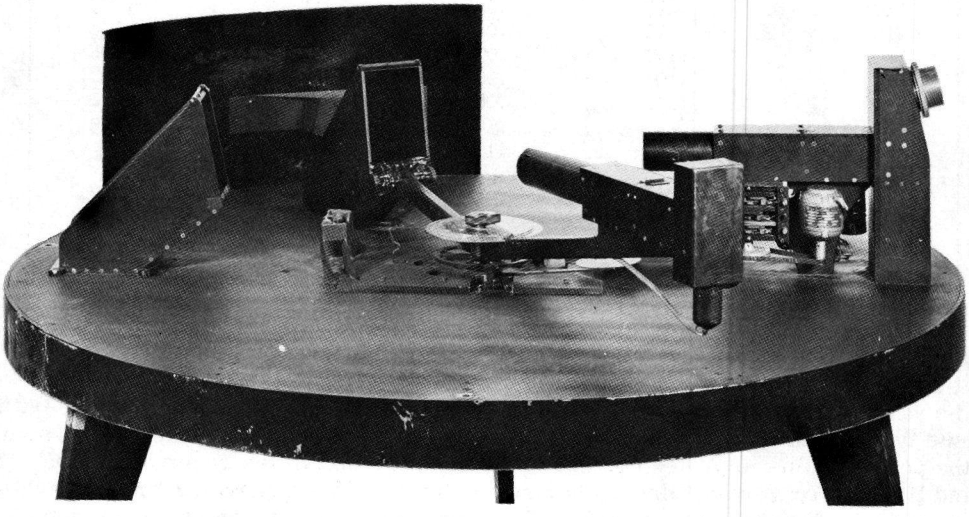

Figure 2. The Recording Polar Nephelometer measures the polar scattering diagrams of natural atmospheres.

## EVALUATION OF METHODS OF STUDY

The following methods may be used in designing improved highway lighting systems for fog:

1. Full scale tests of proposed designs in natural fogs. This method has the greatest

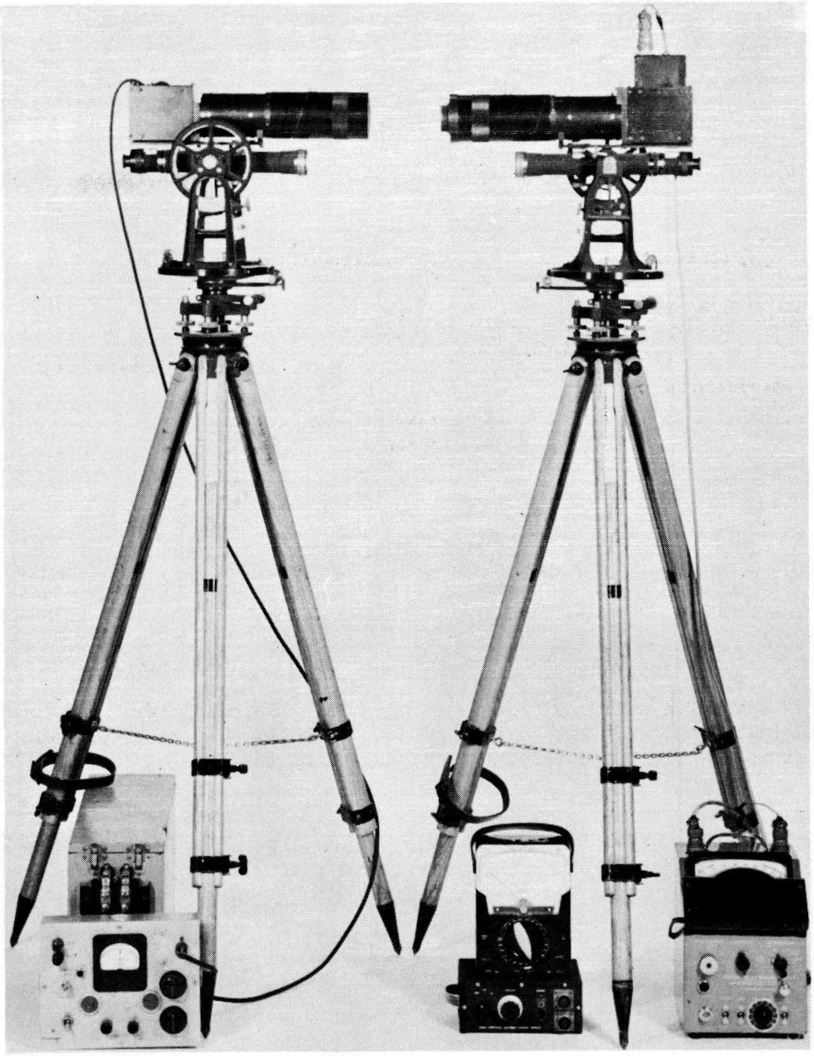

Figure 3. The Portable Transmissometer measures fog densities. Under the projector (on the tripod at the left) is the storage battery and current-control box for the 6 volt lamp in the projector. Under the photoelectric receiver (on the right) are the power supplies, amplifiers, and meters which indicate the current output of the photomultiplier.

validity when used properly, but it suffers from the disadvantage that fogs rarely occur when they are wanted, and even when they do occur the fog density cannot be controlled.

2. Scale model simulator tests with artificial fog. Good control of conditions can be obtained easily and rapidly. It has been shown that the visibility aspects of the fog driving problem can be very closely simulated.

3. Computation. From the scattering data presented above it is possible to compute the luminances and contrasts of objects on the highway in fogs of various densities, for any proposed or existing lighting arrangement. Available visual data (4) can then be used to predict the visibility of any given object. One advantage of this method is that a more thorough understanding is obtained of the reasons why one design is better or worse than another, and the increased understanding naturally leads to improved designs. For single scattering, the method is fast and simple, but when light which is

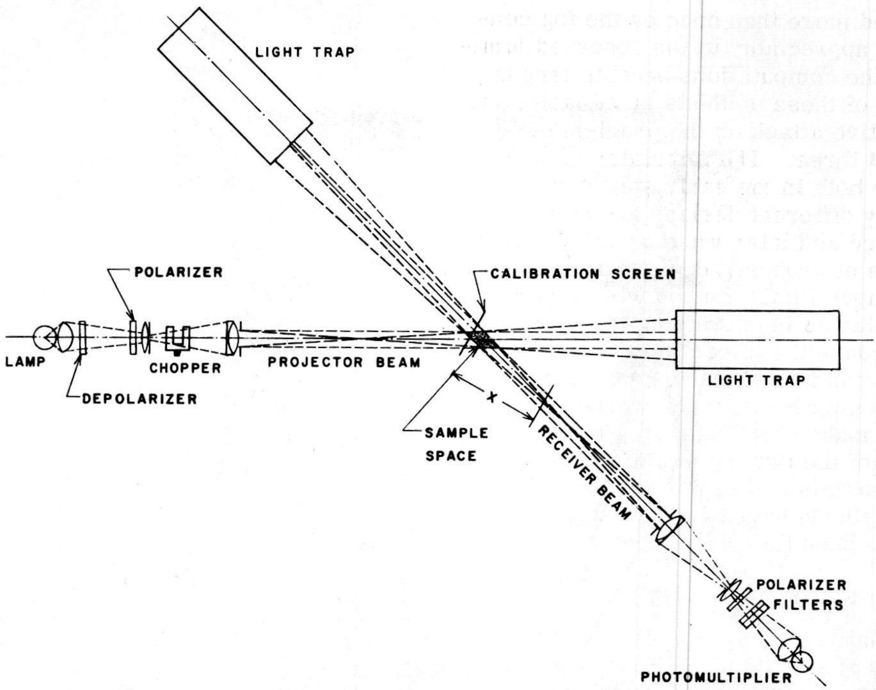


Figure 4. The optical system of the Recording Polar Nephelometer. The projector at the left illuminates the fog within the projector beam. The receiver, at the lower right, receives the light scattered from a portion of the beam at a variable angle.

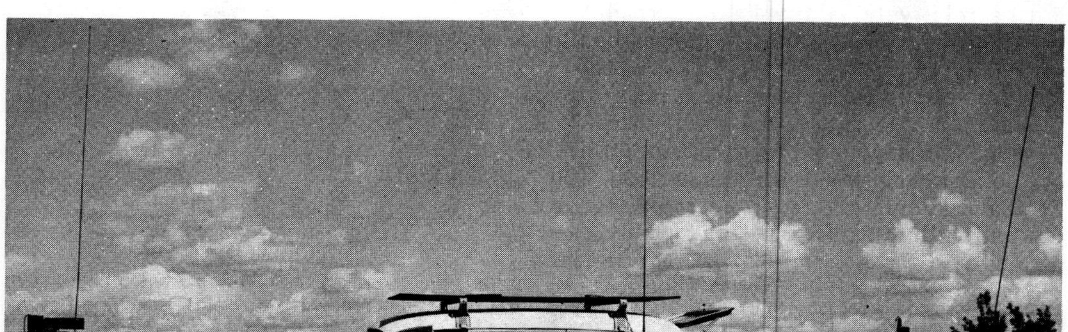

Figure 5. The amplifier controls and recorder for the Recording Polar Nephelometer, which is shown on the ground, are rack-mounted behind the front seat of the vehicle. When the two units of the Portable Transmissometer are used at long separation distances, radios (the antennae of which are visible in the picture) are used for communication.

scattered more than once by the fog contributes appreciably to the observed luminance, the computations become lengthy.

Each of these methods is valuable, and an effective attack on the problem employs all three. The simulator method is valuable both in the early stages when radically different designs are being investigated and later when quantitative comparisons of proposed designs are necessary. The computational method will be particularly valuable in optimizing the final design because the effects of making small changes can be assessed accurately. Road tests should also be made whenever possible to make certain that no important aspects of the driving situation are omitted. The potentials and limitations of each of these methods have been investigated but none has been fully exploited as yet.

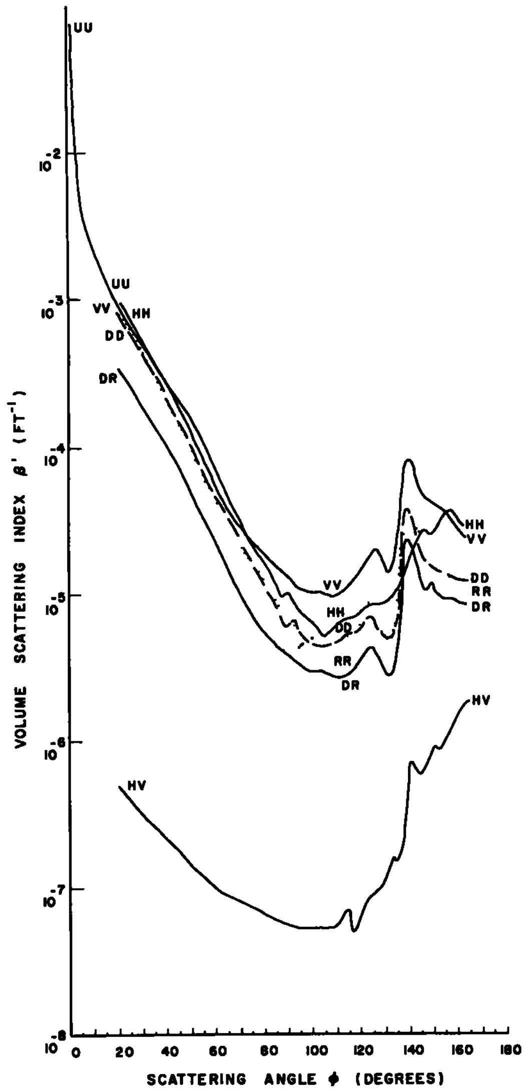


Figure 6. Polar Scattering Diagrams on rectangular coordinates with logarithmic ordinate scale.

## SIMULATOR STUDIES

A relatively simple simulator was constructed at a scale of 25:1, with which qualitative visual comparisons were made of various lighting systems (Figs. 7, 8, and 9). The following general conclusions were reached:

1. A street light for use in fog should have a relatively narrow beam spread, with the beam approximately perpendicular to the driver's line-of-sight. The units could be either overhead or at a lower elevation on the side of the road. This concept was suggested by the large dip in the polar scattering diagrams at about 100 deg, and simulator tests confirmed that the veiling luminance was appreciably reduced by this change in street light design. Many more lamps would be needed to achieve the present road coverage, but the total power consumed would probably not be increased if the units were efficiently designed.

2. Vehicle lights for use in fog should be mounted as far as possible away from the driver's line-of-sight, and there should be a sharp cutoff in the candlepower distribution curve to avoid illuminating the fog immediately in front of the vehicle.

3. Veiling luminance can be reduced and the contrasts of most objects increased by the use of a polarized fog light (only one can be used effectively) and an orthogonal viewing polarizer. It is not yet certain, however, that the gains are enough to outweigh the attendant disadvantages.

4. Vehicle taillights should have increased candlepower for use in fog, in accordance with the fact that self-luminous objects of high intensity are usually visible at much greater distances than reflecting objects.

5. Use of polarized street lights with orthogonal viewers should be investigated further, although initial tests have been unfavorable. The veiling luminance caused by the fog is reduced; but the luminances of most other objects are also reduced, not only by the normal polarizer losses but also by the fact that most objects do not depolarize the

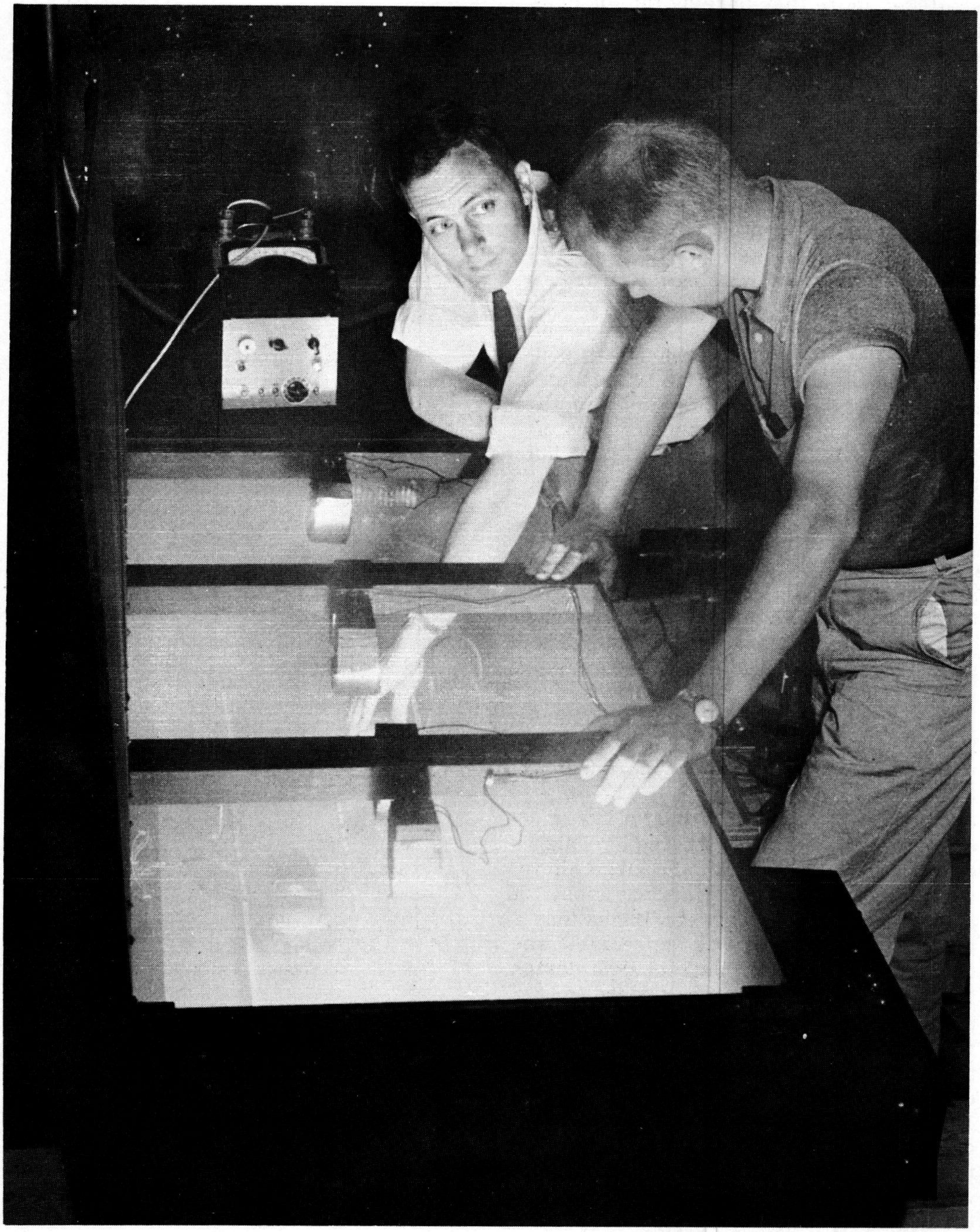

Figure 7. The covers of the "fog box" have been raised to attempt to show the 25:1 scale model cars immersed in artificial fog. The "peep hole" through which one obtains a driver's-eye view of the roadway is in the near end of the box.

Figure 8. Improved highway lighting in fog. This photograph was taken through the peep hole in the fog box, with the taillights of increased candlepower on the receding car at the right, narrow beam street lights and "cross-eyed" low-mounted fog lights on the approaching car and the driver's car.

Figure 9. Normal highway lighting for comparison with the previous figure. (Glare from the overhead lights is exaggerated by the photographic reproduction process.)

light that they reflect, especially when the surfaces are wet and the angles of incidence are large. Possibly some combination of polarized and unpolarized lights will prove effective in future tests.

## FUTURE PLANS

Work has started on a trial installation on the New Jersey Turnpike to evaluate some of the suggestions which have been made to date. At the same time, it is planned to construct at the University of Michigan an improved simulator at a scale of 10:1. Candlepower distributions will be more carefully controlled than previously, and quantitative measurements will be made of the improvements achieved by the various proposed changes.

## SUMMARY

"The solution" to the problem of visibility on the highway in fog has certainly not been obtained, but the ground work has been carefully laid for future studies which will lead to improved lighting systems. Basic information about the light-scattering properties of fog has been obtained, the capabilities of various methods of approach to the problem have been evaluated, and methods of simulation have been developed. Simulator tests at the Pennsylvania State University and the University of Michigan have confirmed the fact that contrasts of objects on the roadway can be improved if a new concept of street light design, suggested by the scattering data, is adopted.

## ACKNOWLEDGMENT

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## REFERENCES

1. Pritchard, B. S., and Blackwell, H. R., "Preliminary Studies of Visibility on the Highway in Fog." Engng. Res. Inst. Rpt. No. 2557-2-F, Univ. of Mich., (July 1957).
2. Pritchard, B. S., and Elliott, W. G., "Two Instruments for Measurement of the Optical Properties of the Atmosphere." Engng. Res. Inst. Rpt. No. 2144-250-T, Univ. of Mich., (1958).
3. Middleton, W. E. K., "Vision Through the Atmosphere," Univ. of Toronto Press, (1952).
4. Blackwell, H. R., "Brightness Discrimination Data for the Specifications of Quantity of Illumination." Illum. Engr., N. Y., 47, 602, (1952).

# Experimental Studies of Night Vision as a Function of Age and Changes in Illumination

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● NIGHT VISION depends upon a pattern of variables all of which interact to produce an extremely complex pattern of visual conditions of the utmost importance to vehicle operators. This in turn means that highway engineers, and vehicle designers should consider the facts of night vision in order to design highways and vehicles in such a way as to enhance the night vision function.

For instance, it is well known that color, placement of light sources, spacing of luminaries, radiation surfaces of light sources, duration, intensity, and frequency of illumination changes are all important. Thus, below certain levels of illumination sodium light does not appear to be superior to mercury or incandescent light; above certain levels, however, sodium light has been shown to be superior to either mercury or incandescent light as measured by its influence on visual efficiency (9, 10, 11). Further experimentation has shown that glare from sodium light produces less deleterious effect than glare from tungsten light sources (28). Acuity and depth perception have been found to be unfavorably influenced by some color bands, especially when green or bluish glass is combined with pink ophthalmic lenses to form a complex filter. Visual acuity may be reduced as much as 20/60 by such a combination (38). Equally important is the night vision recovery time, that is, the rate at which the sensitive cells of the eye adapt to decreasing illumination. This has been shown to be a function of several variables such as the time and duration of pre-exposure, and color.

However, night vision efficiency varies among persons of the same age, among persons of different ages, and it also varies with the physiological state of the viewer. Low blood sugar levels, oxygen deprivation, CO poisoning, and dietary deficiencies, all tend to reduce the final level of night vision and the time required to achieve it (31, 32, 33, 34, 17).

Therefore, night vision or dark adaptation is a function of the nature of the visual stimulus and the physiological states of the viewer. This is important to know because of the consequences associated with either an increase or decrease in the level of efficiency and because of the necessary control and management of this function.

To illustrate, in studies of highway accidents it has been shown that when probability of accident exposure has been held constant that night-time accident fatalities are three times greater than day-time fatalities (1, 49, 41). That this is not circumstantial is suggested by several studies. One study (47) was controlled and carried out in Kansas City, Missouri. The evidence from these several investigations is the same, i. e., when street and road illumination is improved, night-time accidents are reduced (4, 39, 46).

It seems reasonable to assume that as the control of environmental conditions, visual stimuli, and physiological states of the viewer increases, that further improvements in night vision should result, and therefore a measurable reduction in type, frequency, and severity of accidents.

Efficient, scientific control of the variables of which night vision is a function depends upon reliable knowledge of (a) the relevant variables, (b) their magnitude, (c) how they interact, and, (d) how they are distributed in the population.

## THE NIGHT VISION OR DARK ADAPTATION PHENOMENON

The night vision or dark adaptation phenomenon is that process which allows the viewer to take maximum advantage of decreasing amounts of light. It is a remarkably stable function, although it becomes progressively less efficient as age increases. It depends upon two types of cells (a) cone cells which are in the minority, and function best under relatively high levels of illumination, and (b) rod cells that function best under low levels of illumination. However, rod cells never acquire the same proficiency as cone cells do, being particularly inefficient in the perception of form and color. The rod cells take over the function of the cone cells when the latter are no longer efficient under low levels of illumination.

When the eye is deprived of light the cone cells adapt to this loss in about 5 to 10 minutes depending upon the degree of pre-exposure to light. Then the rod cells assume the light sensing function of the cone cells and adapt to very low levels of illumination in about 30 to 50 minutes. Any further change beyond this time is negligible, although it is of great theoretical interest.

However, it is seldom that anyone is required to function for any length of time at very low levels of illumination, but in instances when this is necessary, the greater the degree of night vision efficiency, the better. Mostly persons are required to function at a point somewhere between high and low levels of illumination that is not constant but decreases and increases incessantly. Thus, the level of adaptation must also change to accommodate visual efficiency to the ever changing level of illumination. When illumination is high, the rate of adaptation to moderate change is rapid, but when illumination is successively reduced, the rate of change slows down, and equal degrees of adaptation require more and more time. Therefore, the most proficient viewer is the one who can adapt to the most efficient level in the shortest possible time.

Since drivers function most of the time at intermediate illumination levels, they cannot depend upon their ultimate night vision efficiency because they do not reach it. Under these conditions the rate of adaptation becomes more important than final level when tasks must be carried out under intermediate amounts of illumination, especially when continuous momentary adjustment is necessary. This mesopic or middle range, just about at the point where the cone cells have ceased to function, and before the rod cells have acquired adequate efficiency, therefore becomes extremely important in the study of night vision.

It has been possible to analyze this phenomenon in considerable detail. Consequently, a number of important observations have been made that have direct bearing upon both the theoretical and practical problems pertaining to the management of night-vision efficiency. Hammond and Lee (18) became interested in the relationship that one part of the dark adaptation process might have to another part. They found that the rate of adaptation of the cone cells to lowered illumination was not correlated with the final level of night-vision proficiency. But they found that the level of night-vision efficienty after ten minutes in the dark was correlated 0.76 with the rate of adaptation to the dark. They were able to show that the mean log I of time between 10 and 40 minutes was correlated 0.84 with the final level of adaptation, a relatively high degree of relationship. With their 22 young adult subjects they also demonstrated that the time required to reach a visual efficiency level of 4 uul was correlated 0.90 with the rate at which the adaptation was taking place. This is an extremely high relationship. Thus, some but not all phases of the adaptation process are associated.

However, Hammond and Lee did not relate their discoveries to the age of their subjects, and they did not thoroughly investigate the cone cell adaptation process.

Since the process of adaptation to night vision is so stable, and in itself important, it is often used to study the effect of certain variables upon perception or upon the process of seeing. Some of the more important variables known to have a profound effect upon the degree of night vision, and the rate at which it is attained will be discussed herewith. However, several recent unpublished studies will be reviewed independently in a separate section of the paper.

## INFLUENCE OF PRE-EXPOSURE ON NIGHT VISION

It has been experimentally demonstrated that the time required to adapt to low levels of illumination is a function of the degree of exposure to different levels of illumination (55). Night vision is considerably less efficient after the eye has been exposed to high levels of illumination, and the reduced efficiency persists for several hours. The practical importance of this point can be demonstrated by the fact that after hours of driving in bright sunlight or after hours spent at the beach in bright sunlight, visual efficiency is reduced (12, 34). If the persons involved were to drive during twilight and early evening, they would do so with less night vision proficiency than others who had not been exposed to bright light for several hours.

## INFLUENCE OF LIGHT-WAVE FREQUENCY ON NIGHT VISION

There is evidence that the rate of attaining night vision efficiency is a function of light-wave frequency or color. Wolf (53) has shown that ultra-violet light even for relatively short periods of time results in delaying the rate of adaptation to low levels of illumination. Hecht and Hsia (25) demonstrated that when red and white light were equated for photopic vision and then used to study dark adaptation that adaptation to night vision following pre-exposure to red light was significantly faster than adaptation following pre-exposure to white light. When violet light rather than white light is used as a test stimulus the separation between the cone cell adaptation and the rod cell adaptation to low levels of illumination increases. This was demonstrated by Hecht (20).

## INFLUENCE OF DIFFERENT LEVELS OF ILLUMINATION ON VISUAL ACUITY

Acuity, or the capacity of the eye to resolve and discriminate objects decreases as illumination decreases. For instance, Hecht and Mintz reported "..... the visual angle occupied by the thickness of the line when it is just resolved varies from about 10 minutes at the lowest illumination to 0. 50 seconds at the highest illumination, a range of 1, 200 to 1." (23) Obviously, the capacity to discriminate objects is an important one and every precaution must be taken to maintain this function at the highest possible level.

## INFLUENCE OF CHANGES OF ILLUMINATION ON DEPTH PERCEPTION

Depth perception has been shown to vary with changes in degree of illumination. McFarland and Wolf (37) have shown that when illumination was reduced by 30 percent with a filter that stereopsis was reduced from 12. 5 to 37. 5 percent in the test sample. The average reduction was found to be about 25 percent. Serious reductions in depth perception should be avoided because the greater the accuracy with which objects can be located in space, the greater the latitude of control the viewer has over his choice of actions. In some instances failure to perceive allows the operator of a vehicle to enter a fatally dangerous traffic condition from which he cannot extricate himself. Depth perception, important in itself, becomes even more critical when the viewer is traveling at high speeds.

Small but significant differences between accident-free drivers and accident repeaters have been found. The accident-free group was found to be superior in visual acuity, lateral ocular balance, and depth perception. (45)

## INFLUENCE OF GLARE ON NIGHT VISION PROFICIENCY

When the field of vision contains a source of light much brighter than the surrounding area, objects reflecting less light become impossible or nearly impossible to see. And when glare is eliminated the rate at which the retina can recover maximum sensitivity is dependent upon the brightness of the exposure, the duration of the exposure, and the area of the retina most stimulated by the glare. Apparently older persons are more susceptible to the glare effect than younger persons (2, 27). In one study it was found that females took longer to recover from glare than males (51). Simonson, Blankstein and Carey (48) found that in three experienced subjects cone cell recovery was faster after exposure to a light source, the spectral range of which had been reduced at both ends, that is, the red and violet ends, as compared with exposure to the usual frosted lamps. The shape of the dark adaptation curve did not seem to be influenced, but the rate of recovery increased after exposure to the experimental light. The comparative effect was not a function of pre-adaptation brightness, daily variability, or individual differences. Thus, the glare effect also seems to vary with the area of the color band used in pre-exposure.

The effect of age on the ability to see under night driving conditions was determined by the use of a Night-Sight Meter. The repeat reliability of the apparatus was high, and the improvement in scores as a result of practice and dark adaptation was not serious, thus, these experimental variables did not influence the validity of the data. The test was administered to 474 men and 806 women (age range 15 to 89 years) of which one-fifth of the persons were 50 years of age or older.

Scores were obtained from two conditions: (a) the amount of illumination necessary to make the test target just visible, and (b) the change of illumination necessary to make the target visible in the presence of glare. The intensity of the glare source was comparable to the intensity of approaching headlights at 100 to 150 ft, and the angle between the glare source and the test target was similar to an angle between an approaching car at 150 ft and a pedestrian walking on the edge of a 20-ft pavement in front of the driver. Both glare and night vision scores became poorer as age increased. The trend was slight but consistent up to 50 years of age, quite pronounced from 50 to 70, and very pronounced after 70. Without glare interference the amount of light needed to identify the target was much less, so that the increase in illumination necessary to make the test target just visible was four times as great when glare was present as when it was absent.

On both the glare and night vision test the persons who had abnormal visual acuity (one or both eyes at 14 in. or 20 ft) had poorer than average scores on all age levels. About 22 percent of the persons tested had abnormal visual acuity. There was no significant difference in scores made by men and women at all age levels on both the night vision and the glare test. Table 1 shows the increases in illumination necessary to see a standard, briefly viewed, moving stimulus with increasing age.

TABLE 1

CHANGE IN ILLUMINATION NECESSARY TO SEE A STANDARD, BRIEFLY VIEWED, MOVING STIMULUS WITH INCREASING AGE (Adapted from ref. 2)

| | Relative Illumination Necessary | | |
|---|---|---|---|
| Age Group | (x) in Presence of Glare Source | (y) Without Glare Source | x - y |
| 15 - 19 | 1.00 | 1.00 | 0.00 |
| 20 - 24 | 1.15 | 1.10 | 0.05 |
| 25 - 29 | 1.28 | 1.17 | 0.11 |
| 30 - 34 | 1.36 | 1.20 | 0.16 |
| 35 - 39 | 1.54 | 1.27 | 0.27 |
| 40 - 44 | 1.78 | 1.33 | 0.45 |
| 45 - 49 | 2.24 | 1.48 | 0.76 |
| 50 - 54 | 2.83 | 1.94 | 0.89 |
| 55 - 59 | 3.42 | 2.32 | 1.10 |
| 60 - 64 | 5.18 | 2.92 | 2.26 |
| 65 - 69 | 10.25 | 4.47 | 9.78 |
| 70 and up | 17.12 | 10.13 | 6.99 |

N. B. No pupillary control.

## INFLUENCE OF LIGHT "SHOCK" ON NIGHT VISION

Light "shock" occurs when a bright light is presented briefly to the retina. In every day life this is a common event, especially prevalent in night driving. Unless the tachistoscopic presentation is repeated frequently the recovery from light shock is "rapid". Repeated presentations lead to cumulative effects, and the greater the frequency, the greater the delay in recovering night vision proficiency. In one experiment (54) a two-degree square field was presented ten degrees below center. After 30 minutes of adaptation to the dark, a bright light (370 millilamberts) was presented for 0.04 seconds. Night vision was quickly reduced, although not completely, and the time required to recover a two-log unit loss was about 40 seconds.

Generally, the vehicle operator will be repeatedly stimulated with flashes of bright light, a special instance of the condition of glare. The consequence is largely the same; a reduction of visual efficiency accompanied by the necessity of continuous adjustment to an unstable level of illumination.

## INFLUENCE OF AGE ON ADAPTATION TO NIGHT VISION

Pinson (42) examined the night vision or dark adaptation process of 204 subjects between 20 and 50 years of age and found that the major part of the adaptation curve, the rod cell curve of adaptation to reduced light, was correlated with age. And although he found that subjects age 40 and above had 30 to 60 percent reduction in night vision efficiency he stated, "The trend toward a decline in average dark adaptation proficiency with age is of minor significance in comparison with individual variations in the dark adaptation proficiency." He also reported that age and the point where the rod cell curve of adaptation began, the mesopic range, was "... the only characteristic of the curve of night vision efficiency which was independent of age."

Hecht and Mandelbaum (22) and Robertson and Yudkin (43) have reported marked differences in night vision efficiency with age. Robertson and Yudkin studied 758 English shoe factory workers, an unusually large sample with ages 14 through 74 years. Birren (7) found that pupil size reduced significantly as age increased under both light and dark conditions, thus limiting the amount of light that could reach the retina of the eye. Birren, Bick, and Fox (5) reported significant changes with age of the dark-adapted eye in a sample which ranged from 18 through 83 years. Birren and Shock (6) found no correlation between rate of adaptation to night vision and age, but a significant decrease on the final level of proficiency with older subjects.

McFarland and Fisher (35) conducted an extensive study of alterations in dark adaptation as a function of age. In a preliminary study 200 males between 20 and 60 years of age were tested on the Hecht-Schlaer adaptometer, with pupil size controlled. The mean levels of final adaptation for five age groups showed a regular increase with age, and the intensity of illumination required by the age group 40 to 47 was about 150 percent greater than that required by the youngest group. In the second part of the experiment, additional subjects were tested, particularly those under 24 years of age, and those above 47. Final adaptation levels were calculated for all subjects, and correlated with age. The coefficient obtained was 0.895, and from the data, it was estimated that for each increase of 13 years in age, the intensity of illumination must be doubled for a light to be just seen. The rate of dark adaptation was approached by a graphic solution based on the "decay" characteristics of the dark adaptation curve. Rate was not found to bear a linear relationship to age. The limitation in the ability to see at night is quite marked in older subjects, and the experimental findings may help to explain the difficulties persons over 55 or 60 years of age have in driving or flying at night. The changes in dark adaptation are believed to be related to certain basic physiologic functions in the nerve cells of the retina and brain.

## INFLUENCE OF CHANGES IN PHYSIOLOGICAL STATES ON VISUAL SENSITIVITY

To emphasize the fact of the interaction between the environment and human physiological processes, certain variables now known to have marked influence on the dark adaptation process and night vision will be reviewed (31, 32, 33, 34, 17).

The alteration of certain visual functions by anoxia and other physiological stresses has yielded results of considerable theoretical interest and practical significance. The study of vision under such conditions is important, not only because of the role of this sense in driving or flying, but also because certain visual functions are believed to reflect changes in the central nervous system, of which the retina of the eye is essentially a part.

The series of experiments to be described are concerned with four main problems: (a) the effects of oxygen deprivation on differential brightness sensitivity; (b) the effects of insulin hypoglycemia on differential brightness sensitivity; (c) the role of high blood sugar levels in counteracting the effects of oxygen lack; and (d) carbon-monoxide anoxia at sea level and at simulated high altitudes. An additional area took dietary deficiencies into account.

### The Effects of Oxygen Deprivation on Differential Brightness Sensitivity (31)

Earlier experiments on dark adaptation have revealed that one's ability to see dim objects against a very dark background is markedly impaired by oxygen lack. In practical situations, however, it is rarely necessary to distinguish objects against a totally dark background.

In this study, measurements were made of the sensitivity of the eye to foveal stimuli presented against backgrounds which varied in intensity over a range of about 1:100,000. It was found that anoxia affects visual sensitivity to the greatest extent when the background is most dimly illuminated. The effect becomes less marked as the intensity of the background increases. At very high light intensities, as in sunlight, oxygen lack produces practically no change in visual sensitivity.

Effects of Insulin Hypoglycemia on Differential Brightness Sensitivity. (34)

The concentration of blood sugar is intimately related to the functioning of the central nervous system. This is true because glucose is practically the only substance which can be utilized by the central nervous system as a fuel, or metabolite. If the supply is deficient, the oxidative processes are slowed, and the effect should be equivalent to that of a reduced sypply of oxygen. The retina behaves very much like the central nervous system in regard to its metabolism.

In a normal subject under ordinary conditions, the blood sugar level did not become sufficiently low to impair visual sensitivity. Such impairment occurred only when the blood sugar concentration fell below about 65 to 70 mg. per 100 cc. However, these findings are important in explaining the results of the following experiments which are more directly applicable to practical situations.

In the present experiments, differential visual sensitivity underwent the same changes when the blood sugar was reduced by intravenous injection of insulin as when the oxygen supply was reduced. The differential threshold was affected most acutely when the background illumination was dim. Furthermore, it was found that inhalation of 100 percent oxygen counteracted a large portion of the adverse effect caused by hypoglycemia.

Role of High Blood Sugar Levels in Counteracting the Effects of Anoxia. (33)

The results of the preceding experiments suggested the possibility that high blood sugar levels might have an opposite effect. Studies were made, therefore, of the differential sensitivity during oxygen lack equivalent to altitudes of 12,000 to 16,000 ft, before and after the administration of 50 gm of glucose. A dim background was again employed.

It was found that elevation of the blood sugar level from a fasting value of about 100 mg per 100 cc to a peak value of about 180 mg counteracted about one-third to one-half of the impairment caused by anoxia. The effect of an oxygen tension corresponding to 16,000 ft altitude, for example, was reduced to that ordinarily caused by 10,000 to 12,000 ft altitude. Visual sensitivity varied in a manner parallel with the blood sugar level. Similar results were obtained whether the sugar was given during oxygen deprivation or whether it was given before oxygen deprivation in order to prevent its effect. During control experiments, on the other hand, a saccharin solution had no effect. It was found also that high blood sugar levels improved visual sensitivity only when this function had first been impaired by anoxia or hypoglycemia, and then only to its original value.

Carbon-Monoxide Anoxia at Sea Level and Simulated High Altitudes. (32, 17)

Carbon monoxide may be absorbed from at least two sources: engine exhaust gas and tobacco smoke. When carbon monoxide combines with hemoglobin, the oxygen-carrying capacity of the blood is reduced. Furthermore, carbon monoxide displaces the oxygen dissociation curve to the left, thus inhibiting the release to the tissues of even this decreased amount of oxygen. As a result, there is a marked lowering of the tissue oxygen tension. This accentuates the anoxia caused by exposure to high altitude.

Theoretical considerations have led to the conclusion that the venous (or even tissue) oxygen tension, which is associated with the loss of a given percentage of the oxygen capacity of the blood due to saturation with carbon monoxide, is the same as that caused by a similar decrease in arterial oxygen saturation at high altitudes. On this basis, five percent saturation with carbon monoxide would be expected to have an effect equal to that of an altitude of about 8,000 to 10,000 ft, on those functions which depend on the tissue oxygen tension.

Earlier attempts to determine the least amount of carbon monoxide capable of producing impairment of psychological functions have yielded no clear results. Even with 30 to 35 percent saturation, causing numerous subjective complaints such as headaches, there was no clearly demonstrable impairment in psychological tests. This was probably due to the fact that the tests employed were not sufficiently sensitive and that the subject could mask a considerable degree of impairment during such tests by exerting additional effort. In the measurement of visual sensitivity, on the other hand, compensation is not a factor. The subject merely reports whether or not he sees a flash of light and is not aware of the intensity required.

A series of experiments was carried out to determine the effect of carbon monoxide on visual thresholds, both in normal air and in combination with varying degrees of oxygen deprivation. The results were entirely consistent with the theoretical expectations. It was found, for example, that five percent saturation with carbon monoxide depresses visual sensitivity to as great an extent as anoxia at 8,000 to 10,000 ft altitude. Fifteen percent saturation caused an impairment corresponding to that at about 15,000 to 19,000 ft. At various simulated altitudes, the addition of carbon monoxide, causing a given percentage of saturation, produced an effect equal to that at an altitude sufficient to produce an additional loss of arterial oxygen saturation of the same amount.

The test proved to be so sensitive that even the effects of the small quantities of carbon monoxide absorbed from cigarette smoke were clearly demonstrable. Inhalation of the smoke from a single cigarette caused a carbon monoxide saturation of almost two percent. After inhaling the smoke of three cigarettes, the saturation of the blood with carbon monoxide was approximately four percent and the effect on visual sensitivity was equal to that at an altitude of about 7,500 ft. The loss of arterial oxygen saturation at this altitude is about four percent. The absorption of a similar amount of carbon monoxide at 7,500 ft altitude causes a combined loss of sensitivity equal to that at 10,000 to 11,000 ft. (32)

The inhalation of 100 percent oxygen was found not only to accelerate the elimination of carbon monoxide but also to produce an improvement in visual thresholds at any given point after inhalation. The improvement was equivalent to a decrease of about 5 to 7 percent carboxyhemoglobin when breathing oxygen as compared to room air. If, instead of oxygen, the subject breathed atmospheric air throughout the recovery period, the visual thresholds failed to recover as rapidly as the percentage of carboxyhemoglobin declined. (17)

These studies indicate that carbon monoxide may be harmful in much smaller amounts than previously supposed. The importance of guarding against the entry of exhaust gases into an automobile or airplane and of adequate removal of gases liberated by gunfire is therefore intensified. The importance of refraining from excessive inhalation of tobacco smoke and the value of the use of oxygen in flight is obvious. Theoretical considerations had led to these same conclusions previously, but these studies represent an objective demonstration of the dangerous effects of small quantities of carbon monoxide, especially if combined with anoxia or low blood sugar.

## Effect of Vitamin A Deficiency on the Dark Adaptation Process or on Night Vision Efficiency.

Alcoholism is often associated with cirrhosis of the liver which in turn is frequently characterized by Vitamin A deficiency. Since Vitamin A deficiencies supposedly increase the visual threshold in dark adaptation and night vision, it would be expected that acute alcoholics would show a disturbance of night vision. Haig, Hecht, and Patek (16) studied the dark adaptation process of 14 alcoholics suffering from cirrhosis of the liver, and 13 of them plainly showed evidence for disturbances in dark adaptation or night vision. After 105 to 127 days of Vitamin A treatment both the cone cell and rod cell sensitivity had increased significantly, that is, dark adaptation and night vision proficiency had increased. The authors stated:

"The most striking aspect of these changes is the fidelity with which the cone thresholds vary with the rod thresholds. Since the rod thresholds apparently are changing in response to alterations in Vitamin A concentration, the concomitant cone threshold variations indicate a similar dependence upon the presence of the Vitamin."

An important observation was that those persons suffering from cirrhosis of the liver and Vitamin A deficiency simultaneously also showed a delay in cone cell adaptation, and a delay in the initiation of rod cell adaptation. However, Hecht and Mandelbaum (21) showed that this delay is not present in normal subjects deprived of Vitamin A but not suffering from cirrhosis of the liver. This may mean that there is a connection between cirrhosis of the liver and blood sugar deficiency which is known to independently influence night vision adversely. Whether this involves a delay in the rate of cone cell adaptation is not know. It does involve an increase of sensitivity threshold.

One year later Hecht and Mandelbaum (22) reported a study of the dark adaptation or night vision process of 110 university subjects. They stated that age increases the cone sensitivity threshold, that is, that older subjects are less sensitive, but that rod threshold is only slightly influenced by age, and that rod-cone transition time is not affected at all. Of the 110 subjects, 4 young men were deprived of Vitamin A. Following this experimental condition, both cone and rod vision were decreased in sensitivity, and this reduction of sensitivity continued throughout the two weeks of Vitamin A deprivation. Although the restoration of a normal diet was followed by an initial improvement in dark adaptation or night vision proficiency, nearly two months were required before a return to complete normality was achieved.

Wald and Steven (52) studied one subject, age 22, who was first saturated with a high Vitamin A diet for 18 days. During this time some improvement in night vision was apparent. Following this phase, the subject was deprived of Vitamin A. Then, the sensitivity of night vision decreased. By the 34th day of Vitamin A deprivation, the cone sensitivity had decreased by a factor of nearly 4, and the rod sensitivity by a factor of 9. The authors state that the night blindness of the subject was completely reversed by a single administration of carotene. Wald and Steven suggest that dietary deficiencies other than Vitamin A could also influence night vision proficiency.

Hecht and Mandelbaum (24) reported another study of 17 young men who were subjected to a deficient diet. Fourteen of the 17 subjects showed an immediate reduction in both cone and rod cell sensitivity. Partial recovery occurred immediately after a single dose of Vitamin A, but the recovery was never complete and was always temporary until normal diet was restored. It was interesting to discover that treatment by vitamins other than Vitamin A gave negative results.

McFarland, Graybiel, et al. (30) were able to show that night vision sensitivity was reduced in subjects with Vitamin A deficiency. After large doses of Vitamin A, the general trend was toward recovery of normal dark adaptation thresholds.

## INFLUENCE OF COLORED FILTERS ON VISUAL PROFICIENCY

Between 1950 and 1955 more than 5 million automobiles have been equipped with heat-absorbing tinted windshield glass. By eliminating more than 50 percent of the radiant solar energy in the infrared part of the spectrum the comfort of occupants of automobiles may be somewhat increased, but at the same time the loss of transmissiveness reduces visibility, thus creating a potential safety hazard.

The light transmission of certain tinted windshields is reduced by approximately 30 percent, the limit permissible according to the American Standard Safety Code (3). While a 30 percent loss in light transmission does not influence visibility adversely at photopic luminance levels, the reduction is a matter of more serious consequences at mesopic and scoptopic luminance levels. In an attempt to clarify this problem the distance at which low contrast targets can be detected was determined in practical situations by Heath and Finch (19), using as targets such objects as road signs, posts, boxes, dirt piles, of varying reflectance. Roper (44) exhibited against the glare of oncoming headlights 15-inch square panels of low reflectance. Doane and

Rassweiler[1] (13) used targets simulating pedestrians distributed along both sides of the road, having a reflectance of 7 percent on one side, and 3 to 3.5 percent on the other. Since a number of not easily controllable factors are involved in tests of this type, differences in results are readily to be expected. Roper found 6 percent, Doane and Rassweiler, 3 percent, but Heath and Finch as much as 22 percent loss in visibility distance. Despite these differences the net conclusion of the investigators is that the losses in night visibility are not serious and are compensated for by the beneficial effects of glare reduction and heat absorption during daytime driving.

Clinical tests conducted by Miles (38) have shown that all tinted filters—light yellow, pink, and greenish-blue windshield glass—reduce visual acuity at mesopic luminance levels, and that tinted windshield glass combined with pink ophthalmic lenses is particularly disadvantageous, reducing visual acuity to 20/60. At luminance levels involved in night driving, the resolving power of the eyes is greatly reduced. Thus, a pair of targets which appear distinctly separate at 100 ft in unrestricted vision when seen through a clear windshield must be brought to a distance of 25 ft for distinction when they are viewed through a tinted windshield.

In 1954 in laboratory tests Blackwell (8) found a 23 percent loss in detection distance when targets were viewed through tinted windshield glass. As distance for detection without tinted filters became smaller, owing to a reduction of target size or luminance level, the percentage loss in detection distance increased rapidly with the tinted filter. From these findings Blackwell concluded that the loss in visual detection resulting from the use of filters at low luminance levels is so great that such filters are scarcely to be recommended unless drivers reduce vehicular speed accordingly. However, vehicle operators are not usually aware of the degree of reduction of visibility induced by tinted windshields.

In 1955 Haber (15) analyzed the effect of tinted windshield glass upon visibility theoretically. According to his findings visibility distance is reduced 9 to 15 percent at distances greater than 200 ft when targets are viewed through a tinted windshield. If, however, the contrast between target and background is low, so that detection through a clear windshield is possible only at a short distance, the percentage loss in visibility may be as high as 35 to 45 percent with a tinted windshield.

In 1956 McFarland and Wolf (37) conducted a series of related experiments designed to test in the laboratory the influence of tinted windshield glass upon, (a) dark adaptation, (b) recovery from light shock, (c) visual acuity, (d) depth perception, and (e) glare. And McFarland, Domey, Warren, and Ward conducted an experimental study of the influence of age and tinted windshield glass on dark adaptation (36).

Tinted windshields consist of a bluish-green plastic filter material laminated between two sheets of safety glass. The thickness of each glass pane is ⅛ in. The lower three-quarters of a windshield are uniform in density but the upper quarter represents a darker band increasing in density toward the top edge. Since only the honogeneous part is in the path of vision in looking at objects at eye level or below, the present studies were made only with glass filters cut from the midsection of the homogeneous part of the windshield.

The spectral transmission curves for two kinds of windshield glass were first determined. Both types transmit similar spectral ranges. The total transmission of A is greater than that of B. The transmission maximum for A is found near 500 millimicrons, for B near 480 millimicrons. B has a relatively lower transmission at both ends of the spectrum than A. By holding an A and a B filter side by side, the higher density and more bluish color of B can easily be noticed. Only filters of type A windshield glass were used in the experiments to be described here. Transmission measurements of

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[1] The unusually low value obtained by Doane and Rassweiler may be attributed to several conditions of the experiment. (1) data from several subjects were eliminated, (2) the sample of 6 subjects was small, (3) subjects were familiar with the track, (4) age was not controlled, (5) subjects repeated the test many times, (6) the several targets were fixed and not randomized from trial to trial, and (7) apparently any possible learning effects were not accounted for in the data.

various samples of A-glass with a Macbeth illuminometer yielded values between 65 and 69 percent.

Since tinted windshield glass can by no means be regarded as a "neutral" filter it seemed desirable to make comparisons with other filters having different spectral characteristics but approximately the same amount of transmission. Such filters are Cruxite B which has a brownish tint, and a transmission of 72 percent, and Noviol C which is deep yellow and has a visual transmission factor comparable to that of the other filters, if two sheets of filter glass are combined.

In the McFarland, Domey, Warren, and Ward studies, the dark adaptation process of 240 subjects ranging from 16 to 89 years of age was measured. (29) Each subject was seated and then his left eye was covered with a patch, and the retina of the right eye was bleached for three minutes by exposure to a standard light source of 1, 600 ml. The fixation point was 7 deg left of center and violet light was used for testing. Immediately upon termination of this process the first response to the adaptometer stimulus test light was obtained. After the first reading, taken within the first 40 sec after exposure to the bleaching light, beginning with the first observation, one observation was taken every min for 10 min, then every two min for the next 6 min, every three min for the following 24 min, and finally every min for the last 10 min, 50 min in all.

At the 41st min the first glass filter obtained from an ordinary windshield was inserted between the viewer and the test light. The transmission factor of this glass was about 90 percent. On the 46th min a second filter cut from the middle section of a popular tinted (green) windshield was substituted for the clear glass filter. The transmission factor of this glass was about 73 percent. Therefore, the first filter was not used until the 41st min of adaptation, and the second was not used until the 46th min of adaptation. Five observations were made with clear glass, and five observations were made with tinted glass. All observations were taken without an artificial pupil and when vision was uncorrected.

In addition to the dark adaptation data, a standard eye examination was administered to 178 of the 240 subjects. More than half of the subjects in each age group was examined, thus assuring a fair sample of the efficiency of vision of persons participating in this experiment. Because the curves for 13 subjects were highly distorted, they were omitted from the statistical analysis.

The mathematical treatment was as follows:

$$y = a\,e^{-bt} + c\ ,$$

was fitted to the cone curve, and another of the same form was fitted to the rod curve. The parameters for the cone curve were called a, b, and c, and for the rod curve a', b', and c', so that c is the asymptote of the rod curve and estimates the ultimate adaptation that should be attained at the end of an indefinitely long time. Also, a was equal to the differences between the first obtained value and c, and b was the drop rate.

The method of residuals (35) was used to fit the curves by least squares. The determination of the "cutting point" between the cone curve and the rod curve was determined by least squares also. That is, the pair of curves for any individual was fitted with, say, the first five points on the cone curve, and the remaining 15 on the rod curve. The sum of the 20 squared discrepancies was computed. Then the first six points were assigned to the cone curve, and the remaining 14 to the rod curve, and the least squares parameters were again determined, and the sum of the 20 squared discrepancies from this second fitting was compared with the earlier sum of 20 squared discrepancies. The pair of curves finally accepted as the "best fit" was the pair showing, among all pairs, the least sum of 20 squared discrepancies of the original data from the fitted curves. The details of the procedure are to be given in a separate publication (24).

Table 2 shows the degree to which Age, a, b, c, and c' were correlated as independent pairs and as a multiple correlation (See page 28).

It can readily be seen that the asymptote of the cone curve, c', was correlated with Age, and that of all the variables, Age proved the most influential.

The influence of tinted glass upon dark adaptation is represented by the terrace-like rises at the ends of the curve. The first rise occurred when the subjects were exposed to ordinary windshield glass used as a filter between the test light source and the viewer.

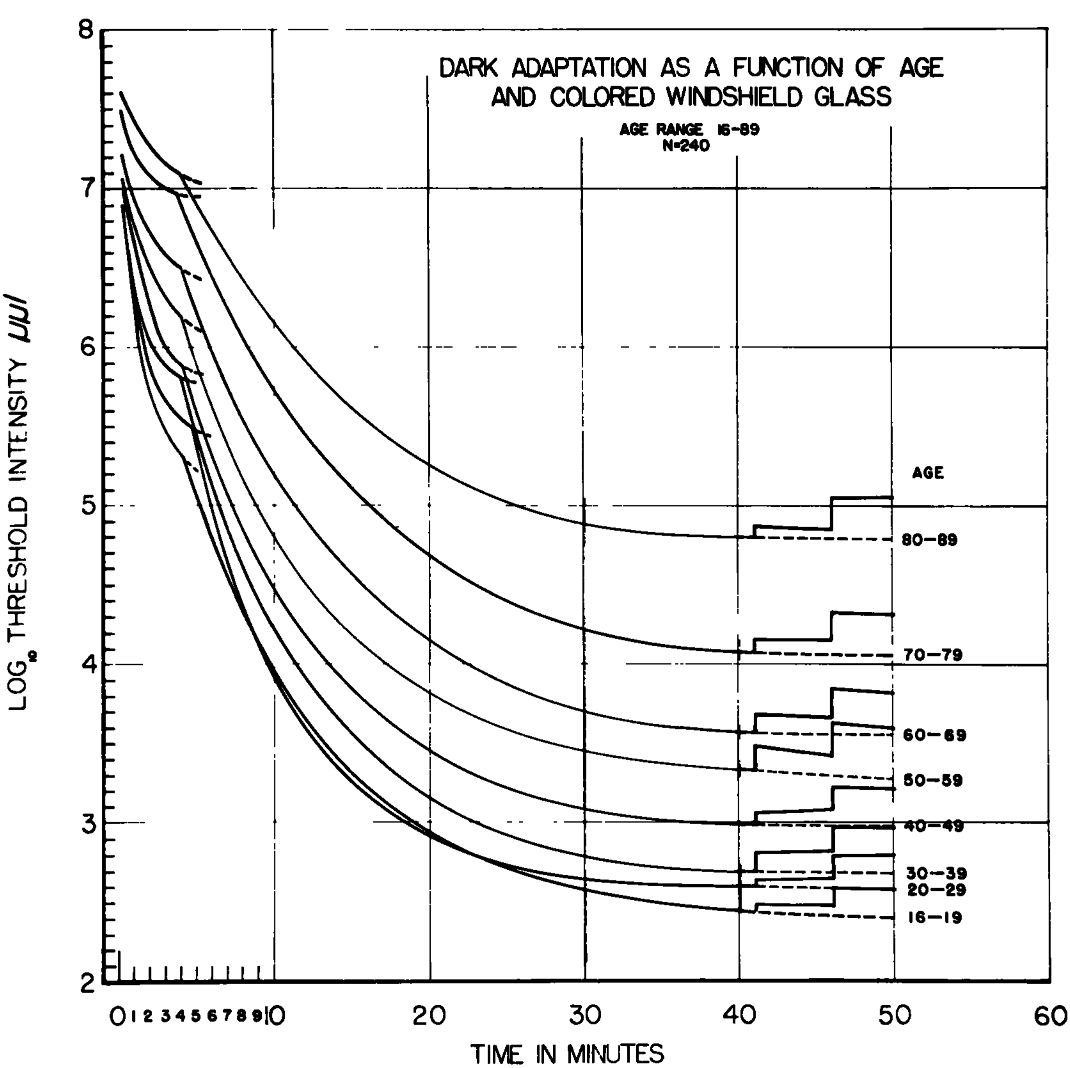


Figure 1.

The second rise occurred when tinted windshield glass was then substituted for clear windshield glass. It can readily be seen that the viewer demanded more light before he could see the test patch in both instances. His demand was greater after the introduction of the tinted glass.

There is a suggestion that the tinted windshield glass appears to influence the dark adaptation level more adversely for the aged than for the younger subjects. Columns D and G-I in Table 3 suggest this relationship.

Study of Figure 1 will show that with tinted windshield glass the final level of dark adaptation for the group aged 50-59 is not much better than the level of adaptation at the 12th min for teen-aged subjects, obviously before they have reached their final level of adaptation. Another way of putting the same thing would be to say that the increase of the 50-59 age group dark adaptation threshold induced by tinted windshield glass functionally equates them on the average with the group of people who fall in the 60-69 age group. Thus, the effect is to increase the functional "night vision" age of this group by about 10 years on the average.

If the 80-89 year old group is studied, tinted windshield glass functionally regressed the visual efficiency of this group back to the level expected at about the 25th min or

TABLE 2

CORRELATION - DARK ADAPTATION, Age, a, b, c, c'.[1]

| | Age | a | b | c | c' |
|---|---|---|---|---|---|
| Age | 1.000 | 0.475 | 0.026 | 0.549 | 0.752 |
| a | | 1.000 | 0.0390 | -0.735 | -0.299 |
| b | | | 1.000 | 0.490 | 0.044 |
| c | | | | 1.000 | 0.402 |
| c' | | | | | 1.000 |
| M | 50.237 | 1.963 | 0.662 | 5.620 | 3.139 |
| S.D. | 22.899 | 1.352 | 0.475 | 1.293 | 3.139 |
| beta | 0.764 | 0.139 | 0.030 | 0.099 | ---- |

N—There were 227 subjects.[2]

Multiple R 0.756

Note: All r values underlined are significantly different from zero.

[1] These values were derived by P. J. Rulon, Director, Educational Research Corporation, Cambridge, Massachusetts.

[2] Because of extreme visual pathology, 13 Ss were omitted from the original sample of 240 Ss, hence N equal to 227.

TABLE 3

NIGHT-VISION WITHOUT FILTER AND WITH CLEAR AND TINTED WINDSHIELD GLASS AS A FUNCTION OF AGE

| | B | B | H | D | I | F |
|---|---|---|---|---|---|---|
| Age | $Log_{10}$ uul without filter 40th Minute | (H-G) d | $Log_{10}$ uul With Clear Windshield Glass Average 41st-45th Minute | (I-H) d | $Log_{10}$ uul With Tinted Windshield Glass 46th-50th Minute | (G-I) d |
| 16-19 | 2.427 | 0.019 | 2.446 | 0.125 | 2.571 | 0.144 |
| 20-29 | 2.602 | 0.030 | 2.632 | 0.146 | 2.777 | 0.176 |
| 30-39 | 2.694 | 0.095 | 2.789 | 0.163 | 2.952 | 0.258 |
| 40-49 | 3.016 | 0.027 | 3.043 | 0.161 | 3.204 | 0.188 |
| 50-59 | 3.346 | 0.062 | 3.408 | 0.192 | 3.600 | 0.254 |
| 60-69 | 3.642 | 0.011 | 3.653 | 0.163 | 3.813 | 0.174 |
| 70-79 | 4.104 | 0.038 | 4.142 | 0.164 | 4.306 | 0.202 |
| 80-89 | 4.806 | 0.041 | 4.847 | 0.183 | 5.030 | 0.224 |

The rise of the differences in Column D suggests that tinted glass decreases the dark adaptation sensitivity of older subjects to a slightly larger extent than it does for younger subjects. The greater the $\log_{10}$ value the less efficient the vision.

before they have reached even their poor final level of adaptation. But this group is visually so much more inefficient than any of the younger groups that any reduction of illumination should be avoided. With tinted windshield glass this group resembles teenagers at about the 5th-6th minute of adaptation, precisely at the cone-rod cell junction, or in the mesopic range, one of the most inefficient points on the dark adaptation curve. The aged must also cope with slower rates of adaptation when even their already inefficient levels of adjustment cannot be stabilized in night driving because of the exposure to intermittent headlight glare. It is precisely when continuous adjustment is necessary that rapid rates of adjustment are most necessary, and slow rates of adjustment most disadvantageous.

In studies of the effect of tinted windshield glass on dark adaptation, recovery from or adaptation to light shock, visual acuity, depth perception, and visibility in the presence of glare, it has been shown that a reduction of visual function occurs with a tinted windshield in proportion to the absorption of radiant energy. When filters of approximately the same density but with different transmission characteristics were used, the reduction in visual efficiency was the same as with tinted windshield glass, indicating that it is rather the loss of luminance than the spectral selectivity which was responsible for reduction in visual function. In visual acuity, stereopsis, and glare tests a balancing of the loss in radiant energy might have been expected on the basis of limited spectral transmission, whereby a reduction of scatter of light and an enhancement of visibility might be achieved. This is not found to be the case. Owing to the bluish-green tint of the windshield glass light scatter might be even greater than with other filters of equal density but higher transmission in the long-wave region of the spectrum. Tests with Noviol and Cruxite do not indicate that the color of the filter materially influences visual performance. Furthermore tests with a stigmatoscope and small spherical corrections do not indicate that chromatic aberration is a decisive factor in influencing the results with the tinted windshield glass.

Glare has to be regarded as an entoptic phenomenon, into which enter such factors as diffuse transmission of light through the iris and sclera; flares, produced by multiple reflections at the different refracting surfaces; specular reflection from the front surface of the retina; halation produced by reflection at the pigment epithelium, choroid and sclera; light reflection through the vitreous from one part of the retina to another; fluorescence of the lens; and scatter by the ocular media (26, 50, 14). Effects of glare seem to be somewhat mitigated by the exclusion of short wave radiation from the glare source. This might be in part a reason for claims that yellow, or amber filters are advantageous in coping with glare.

When a glare source is viewed while the ambient illumination is sufficiently high the ill effects of glare are not experienced in their full extent. The glare effect increases as the contrast between glare source and surround becomes greater. Also the glare effect is lessened with large sources by which a greater retinal area is stimulated, since glare is inversely proportional to the area of the source. For this reason it has been suggested that the size of headlights ought to be increased (38).

Another factor contributing to the annoyance of glare in automobile driving consists in the dispersion of light in the windshield. With an absolutely clear and homogeneous medium between the eyes and a glare source, the image of the glare source is sharp, and flares and halations are reduced. The surface film of small particles on the windshield undoubtedly adds to the unpleasant effects of glare. It would therefore seem desirable to develop and apply adequate means for the elimination of surface film and fogging of windshields.

Since the purpose of tinted windshields is twofold, namely (a) the screening of radiant heat, and (b) glare reduction, the essential question seems to be, whether a tinted windshield is the proper and the only possible solution to this complex problem. It seems questionable whether heat absorption by tinted glass is of any real value as long as dark colors of automobile bodies will absorb far more heat than that which is excluded by the heat-absorbing glass. It also should be remembered that the heat absorption of glass does not depend upon a dark light transmission reducing tint.

In the McFarland, Domey, and Warren experiment, the tinted windshield glass was not the same as in the McFarland and Wolf study. Although the brand was different the transmission factor was about the same.

Many other relationships could be pointed out, but these interpretations will serve to illustrate the effect of the experimental variables and their combination upon night vision or the dark adaptation function.

In not a single instance was it demonstrated that tinted windshield glass improved the visual efficiency of any subject. On the contrary, in every instance the data clearly demonstrated that a reduction of illumination was invariably associated with a reduction of visual efficiency. As the age of the viewer increased this reduction became more and more critical since it was apparent that no subject could afford to experience light loss, the older subjects least of all. And as age increased, the effect of tinted windshield glass became the equivalent of raising the functional "visual age" of the subject or regressing his efficiency far back in time on the curve of adaptation. If such glass is used, a lighter density for the tinted portion should be placed at the sitting eye level of the drivers.

## SUMMARY

1. Dark adaptation, recovery from light shock, visual acuity, depth perception and visibility under glare conditions were studied when the targets were seen through tinted windshield glass. The results were then compared with those obtained with filters, or with filters of different absorptive properties.

2. The tinted windshield glass used in these tests is an absorptive filter of light bluish-green tint with a transmission maximum near 500 millimicrons. The percentage transmission of this type of glass is approximately 70 to 73 percent.

3. Thresholds are about 0.15 log unit higher in dark adaptation tests, when tinted windshield glass is used in front of the test light as compared with the condition when no filter was used. The higher threshold corresponds to the loss in test field luminance produced by the filter.

4. After a light shock, recovery time is 1.2 to 1.4 times longer when the test target is shielded by tinted windshield glass than when no filter is in front of the target. The increase in recovery time is proportional to the loss in luminance.

5. Using Landolt rings of small size differences as targets visual acuity is less when a tinted windshield is placed between observer and target than when no filter is used. Besides the lower luminance, prismatic effects produced by two curved, heavy laminated sheets of glass are responsible for reduced visual acuity.

6. Depth perception tests with a Verhoeff stereoptor yield about 25 percent poorer results when a tinted windshield is in the path of vision than when no filter is involved.

7. When thresholds are determined at which targets at fixed angular distances from a glare source become visible, it is found that the ratios of glare luminance/ target luminance are the same, whether glare source and target screen are shielded by tinted windshield glass or are not shielded by an absorptive filter.

8. The results of these tests could not be interpreted as being favorable to the use of tinted windshields, insofar as visual efficiency at low levels of illumination is concerned.

9. Statistical analysis of a large sample ranging from 16 through 89 years of age indicates that age is the best known predictor of the eventual level of dark adaptation.

10. Age, the initial level of adaptation, and the asymptotes of the cone and rod curve are reliably statistically correlated.

11. The initial level of adaptation is negatively correlated with the asymptote of the asymptotes of the cone and rod curve, and the final level of adaptation, or the asymptote of the rod curve.

12. The drop time of the cone curve is positively correlated with the asymptote of the cone curve.

13. The asymptote of the cone curve and the final level of adaptation are reliably correlated.

## REFERENCES


1. "Accident Facts." National Safety Council, Chicago, Ill., 1945-1955 editions.

2. "Age and the Ability to See at Night." Res. Rep. No. 43, Traffic Engineering and Safety Dep., American Automobile Assn., Washington, D. C. (1953).

3. "American Standard Safety Code. Z., 26.1-1950." Am. Standards Assn. (1950).

4. Anon. "Road Lighting in the United States." Nature, 139 (3510): 241-242 (1937).

5. Birren, J. E., Bick, M. W., and Fox, C., "Age Change in the Light Threshold of the Dark Adapted Eye." Jour. Gerontol., 3(4): 267-271 (1948).

6. Birren, J. E., and Shock, N. W., "Age Changes in Rate and Level of Visual Dark Adaptation." Applied Physiol., 2(7): 407-411 (1950).

7. Birren, J. E., Casperson, R. C., and Botinick, J., "Age Changes in Pupil Size." Jour. Gerontol., 5(3): 216-221 (1950).

8. Blackwell, H. R., "Visual Detection at Low Luminance Through Optical Filters." HRB Bull. 89, p. 43 (1954).

9. Bouma, P. J., "The Definition of Brightness and Apparent Brightness and Their Importance in Road Lighting and Photometry." Philips Technical Rev., 1(5): 142-146 (1936).

10. Bouma, P. J., "Visual Acuity and Speed of Vision in Road Lighting." Philips Technical Rev., 1(7): 215-219 (1936).

11. Bouma, P. J., "Perception of the Roads when Visibility is Low." Philips Technical Rev., 9(5): 149-157 (1947).

12. Clark, B., Johnson, M. L., and Dreher, R. E., "The Effect of Sunlight on Dark Adaptation." Am. Jour. Ophth., 29(7): 829-836 (1946).

13. Doane, H., and Rassweiller, G. M., "Cooperative Road Test of Night Visibility through Heat Absorbing Glass." General Motors Corp. (1955).

14. Fry, G., "Evaluating Disabling Effects of Approaching Automobile Headlights." HRB Bull. 89, p. 38, (1954).

15. Haber, J., Jour. Opt. Soc. Am., 45: 413 (1955).

16. Haig, C., Hecht, S., and Patek, A. J., "Vitamin A and Rod-Cone Adaptation in Cirrhosis of the Liver." Science, 87(2267): 534-536 (1938).

17. Halperin, M. H., Niven, J. I., McFarland, R. A., and Roughton, F. J. W., "Variations in Visual Thresholds During Carbon Monoxide and Hypoxic Anoxia." Federation Proc., 6(1): 120 (1947).

18. Hammond, C. E., and Lee, R. H., "Criteria for Scoring Dark Adaptation Tests." Report #3 on Studies in Aviation Medicine, July 10, 1941, Research Section, Division of Industrial Hygiene, U. S. Public Health Service, Federal Security Agency, Bethesda, Maryland.

19. Heath, W. M., and Finch, D. M., "Effect of Tinted Windshields on Nighttime Visibility Distances." In, Effect of Tinted Windshields and Vehicle Headlights on Night Visibility, HRB Bul. 68, Washington, D. C., National Academy of Sciences—National Research Council, p. 1-15 (1953).

20. Hecht, S., "Rods, Cones, and the Chemical Basis of Vision." Physiol. Rev., 17, 239 (1937).

21. Hecht, S., and Mandelbaum, J., "Rod-Cone Dark Adaptation and Vitamin A." Science, 88(2279): 219-221 (1938).

22. Hecht, S., and Mandelbaum, J., "The Relation between Vitamin A and Dark Adaptation." J. A. M. A., 112(19): 1910-1916 (1939).

23. Hecht, S., and Mintz, E. U., "The Visibility of Single Lines at Various Illuminations and the Retinal Basis of Visual Resolution." Jour. Gen. Physiol., 22(5): 593-612 (1939).

24. Hecht, S., and Mandelbaum, J., "Dark Adaptation and Experimental Vitamin A Deficiency." Am. Jour. Physiol., 130(4): 651-664 (1940).

25. Hecht, S., and Hsia, Y., "Dark Adaptation Following Light Adaptation to Red and White Lights." Jour. Opt. Soc. Am., 35(4): 261-267 (1945).

26. Holladay, L. L., Jour. Opt. Soc. Am., 12, 271 (1926).

27. Lauer, A. R., "An Experimental Study of Glare Susceptibility." Am. Jour. Opt., 13(6): 200-207 (1936).

28. Luckiesh, M., and Moss, F. K., "Glare from Sodium Light." Tr. Illm. Engin. Soc., 30(8): 602-610 (1935).

29. McFarland, Ross A., Domey, Richard G., Warren, A. B., and Ward, D., "Dark Adaptation as a Function of Age." (To be published.)

30. McFarland, R. A., Graybiel, A., Liljencrantz, E., and Tuttle, A. D., "An Analysis of the Physiological and Psychological Characteristics of Two-Hundred Civil Airline Pilots." Jour. Aviation Med., 10: 2-52 (1939).

31. McFarland, R. A., Halperin, M. H., and Niven, J. I., "Visual Thresholds as an Index of Physiological Imbalance During Anoxia." Am. Jour. Physiol., 142 (3): 328-349 (1944).

32. McFarland, R. A., Roughton, F. J. W., Halperin, M. H., and Niven, J. I., "The Effects of Carbon Monoxide and Altitude on Visual Thresholds." Jour. Aviation Med., 15(6): 381-394 (1944).

33. McFarland, R. A., Halperin, M. H., and Niven, J. I., "Visual Thresholds as an Index of the Modification of the Effect of Anoxia by Glucose." Am. Jour. Physiol., 144(3): 379-388 (1945).

34. McFarland, R. A., Halperin, M. H., and Niven, J. I., "Visual Thresholds as an Index of Physiological Imbalance during Insulin Hypoglycemia." Am. Jour. Physiol., 145(3): 299-313 (1946).

35. McFarland, R. A., and Fisher, M. B., "Alterations in Dark Adaptation as a Function of Age." Jour. Gerontol., 10(4): 424-428 (1955).

36. McFarland, R. A., Domey, R. G., Warren, A. B., and Ward, D., "Dark Adaptation as a Function of Age and Tinted Windshield Glass." (To be published.)

37. McFarland, R. A., and Wolf, E., "The Influence of Tinted Windshield Glass upon Visual Acuity, Glare, Stereopsis, and Light Shock." (To be published.)

38. Miles, P. W., Arch. Ophthalm., 51, 15 (1954).

39. Murrah, J. H., "Atlanta Lighting Cuts Crime 50 Percent, Averts 1,700 Traffic Accidents: It Is First Big City To Be Lighted by Illumination Engineering Society Standards." Am. City, 67(9): 157 (1952).

40. Peckham, R. H., "Effect of Exposure to Sunlight on Night-Driving Visibility." In, Night Visibility, HRB Bull. 56, Wash. D. C., National Academy of Sciences—National Research Council, p. 17-24 (1952).

41. Pennsylvania Turnpike Joint Safety Research Group, Eckhardt, P. L., (eds.) Accident Causation., Swissvale, Pa., Westinghouse Air Brake Co., (Sept., 1954).

42. Pinson, E. A., "Dark Adaptation in Army Air Corps Personnel." War Department, Air Corps, Material Division, Experimental Engineering Section, Memorandum Report No. EXP-M-54-653-51, (August 28, 1941.)

43. Robertson, G. W., and Yudkin, J., "Effect of Age upon Dark Adaptation." Jour. Physiol., 103:1-8 (1944).

44. Roper, V. J., "Nighttime Seeing through Heat Absorbing Windshields." In, Effect of Tinted Windshields and Vehicle Headlighting on Night Visibility, HRB Bull. 68, p. 16-30 (1953).

45. Ryan, T. A., "Fatigue and Effort in Relation to Standards of Performance and Systems of Payment." Internat. Labour Rev., 65(1): 44-63 (1952).

46. Shrenk, L. J., "Effect of Light Changes on Traffic Accidents Shown in Detroit Lighting Report." Illum. Engin., 42(9): 890-892 (1947).

47. Seburn, T. J., "Street Lighting - Traffic Accidents - Crime." Illum. Engin., 482-483 (1951).

48. Simonson, E., Blankstein, S., and Carey, E. J., "Influence of Selected Spectral Distribution on the Glare Effect, Studied by Means of Dark Adaptation." Am. Jour. Ophthalm., 28(7): 712-724 (1945).

49. Smeed, R. J., "Some Factors Influencing the Road Behavior of Vehicle Drivers." Advancement of Science, 9(36): 395-404 (1953).

50. Stiles, W. S., Proc. Roy. Soc., B, 105, 131, 129.

51. Torkelson, H. P., Fisk, L. B., and Brown, C. W., "Some Results from the Use of a Glare Recovery Apparatus with College Students." Jour. Applied Psychol., 25(4): 447-457 (1941).

52. Wald, G., and Steven, D., "An Experiment in Human Vitamin A Deficiency." Proc. Nat. Acad. Sciences, 25(7): 344-349 (1939).

53. Wolf, E., "Effects of Exposure to Ultra-Violet Light on Human Dark Adaptation." Proc. Nat. Acad. Sciences, 32(8): 219-226 (1946).

54. Wolf, E., "Optical Glass and Eye Protection." Ophthal. Foundation, N. Y. (1951).

55. Wolf, E., and Zigler, M. J., Jour. Opt. Soc. Am., 40, 211, 1950: 130 (1951).

# Night Legibility Distances of Highway Signs

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● TRAFFIC SIGNS have always played a significant role in the convenience and safety of drivers on the highways. On limited-access facilities, which are now entering a period of great expansion, the motorist is forced to rely to a greater degree on signs. To perform its function effectively, a sign must have good legibility at night as well as in the daytime. The increased need for overhead signs and the need for larger letter sizes make new demands on reflectorized materials. The use of illuminated signs is increasing. There is need for data on the legibility of reflective materials in these applications, and for a comparison of their legibility to that of artificially illuminated signs. It is to this problem that this study addresses itself.

In previous studies, the night legibility of signs has been studied in the laboratory (1), and the photometrics of reflectorized materials on the highway have been outlined (4). When the results of these two studies are combined theoretically, it is possible to predict the distance at which signs can be read on the highway, given the type and size of lettering, the illumination conditions surrounding the sign, and laboratory photometric measurements of the reflective material. In this way design standards can be developed, and the performance of a new material can be evaluated without extensive field study.

However, it is important that the results of laboratory studies be checked in the field before they are used in practice. Therefore the purpose of the present study was to validate in the field both phases of the laboratory work.

Full evaluation of the theoretical considerations will require extensive analysis, and will be reported in a later paper. This paper presents the practical results which were obtained, and their implications for sign design and usage at the present time.

As in all previously reported studies, only "pure legibility" (the distance at which people can read a sign) was studied. Although such factors as glance legibility, target value, and attention value are important (2) they were outside the scope of this research. Only white or silver letters on a black background were investigated. The effect of color of background is a topic of importance because of effects color may have on target value or attention value of signs. However, previous studies (5, 6) have demonstrated that the effect of background color on "pure" legibility is small so long as the brightness contrast between letters and background is not reduced too much. The results of this study, therefore, would have been nearly the same if colored backgrounds had been used, providing that the colored backgrounds were not too high in brightness.

Three types of reflective material were studied in letter sizes of eight to eighteen inches. In addition to night observations on reflective materials, observations were made on a sign with four levels of artificial illumination. Daytime legibility distances were also recorded to provide a baseline for night legibility data.

## PROCEDURE

The experiment was conducted on a straight flat section of rural highway near the University of Virginia. Deviations in horizontal and vertical alignment were less than $\frac{7}{10}$ of a ft. An overhead sign was mounted near one end of the section, and a roadside sign near the other. Observers sat in the front seat beside the driver, and had no task but reading the signs. The car approached the test sign at about 15 mph. As soon as the observer could read the test sign he spoke the message word. When the sign was read correctly, a recorder seated in the back seat read the distance from a foot-odometer or from stakes at the side of the road.

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[1] The data for this research was collected while the author was with the Council of Highway Investigation and Research. The paper was completed while the author was employed by the Highway Traffic Safety Center at Michigan State University.


Figure 1. Overhead test sign.

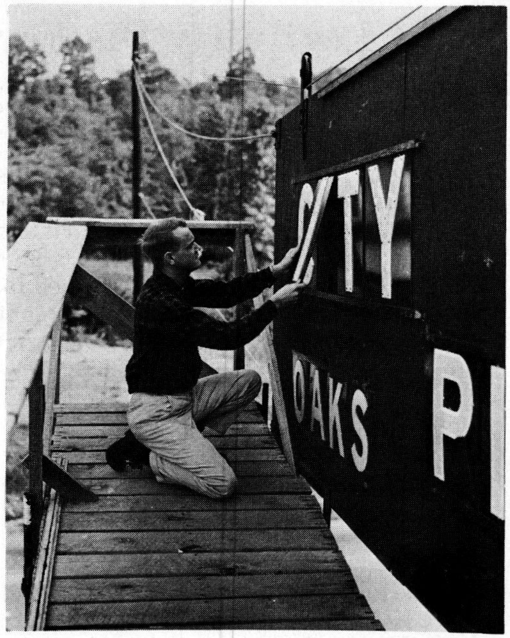


Figure 2. Placing letters on test sign.

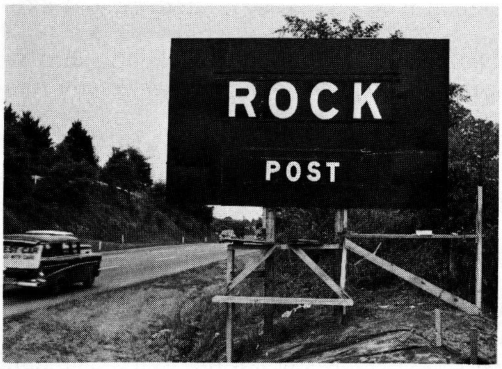


Figure 3. Roadside test sign.


Figure 4. Test car approaching sign.

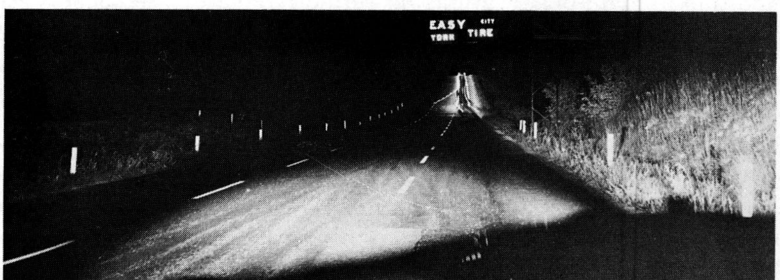


Figure 5. Driver's view of test sign at night.

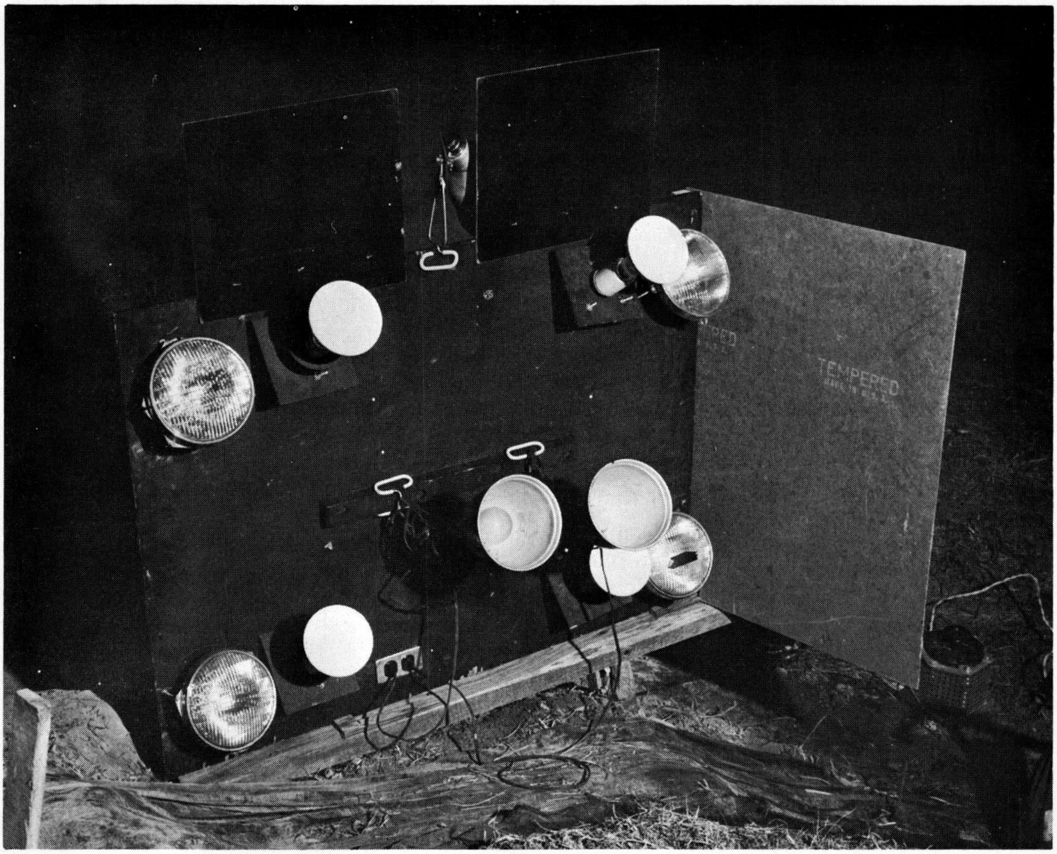


Figure 6. Bank of lamps for illuminated sign.

Test signs were viewed against a dark field at night, and observers had no glare from headlights of other cars. Near the center of the section of roadway, a restaurant was located on one side and a service station on the other. Although some glare was introduced by their lights, no better location was available.

Test Signs. Sign position should have no effect on the distance at which a sign is legible in the daytime, and should have no effect on the night legibility of an illuminated sign under the conditions studied. For reflective materials, however, since they depend upon illumination from headlamps, night legibility is very significantly affected by sign position. Both signs were positioned to be representative of sign positions on the Interstate System. The overhead sign was located over the travelled lane, with the center of the sign 20 ft above the pavement. The center of the roadside sign was 12 ft above the level of the pavement and 20 ft to the right of the pavement edge.

Figure 1 shows the overhead sign, which was mounted on pulleys on spanwires over the pavement. In order that message difficulty not affect results differentially, it was necessary that messages be changed after each test run. After each run, the sign was pulled over to the scaffold and a new set of messages was put in place. Figure 2 shows the letters being put in place. Each letter was mounted on hardboard with margins to give the proper spacing between letters. Figure 3 shows the roadside sign, upon which letters were mounted in the same way.

Test Car. The test car is shown in Figure 4, and Figure 5 shows the driver's view of the overhead sign at night. Typical G. E. No. 5040 headlamps were used with standard aiming. Voltage was controlled at the standard voltage for these lamps. Observations were made with both upper and lower beams.

Illuminated Sign. For the artificially illuminated sign four levels of illumination

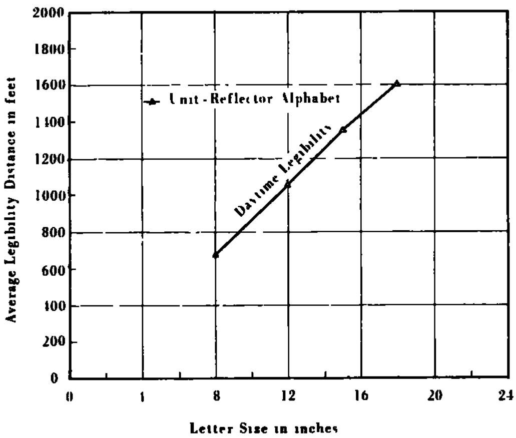


Figure 7. Daytime legibility distances.

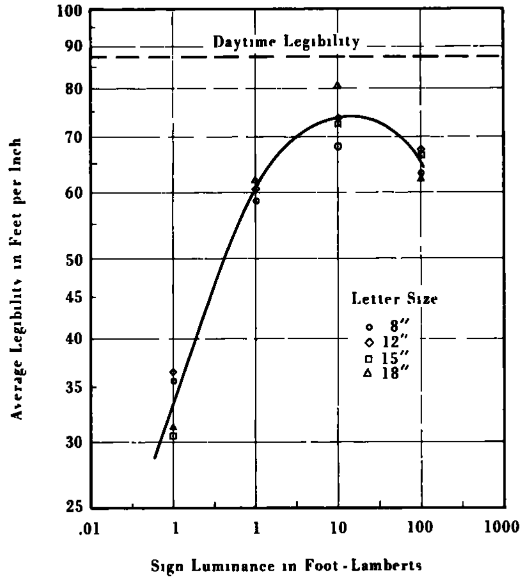


Figure 8. Legibility of artificially illuminated sign.

were used, yielding luminances of the letters of 0.1, 1, 10, and 100 ft-lamberts. It was found that conventional illumination fixtures would not yield such a wide range of levels of illumination, and their illumination was not sufficiently even for the purposes of this experiment. Therefore, the bank of tungsten lamps shown in Figure 6 was constructed. Since the effect of illumination would not be affected by sign position (and it was desired to save the overhead sign for use with reflective materials) the effect of sign illumination was studied with the roadside sign. Light from headlamps had negligible effect on the luminance of the white paper letters.

Reflective Materials. Three reflective materials were included in the experiment. These included the two materials which have been used most extensively on limited-access facilities, and a new material intended for such use. The materials were as follows:

1. Flat Sheeting - cut-out letters of a silver reflective sheeting consisting of glass spheres embedded beneath a flat outer surface.
2. Unit Reflectors - white metal letters in which round plastic reflector "buttons" are embedded.
3. Plastic-Covered Sheeting - a high-brightness silver beaded sheeting covered by a sheet of clear plastic which was sealed

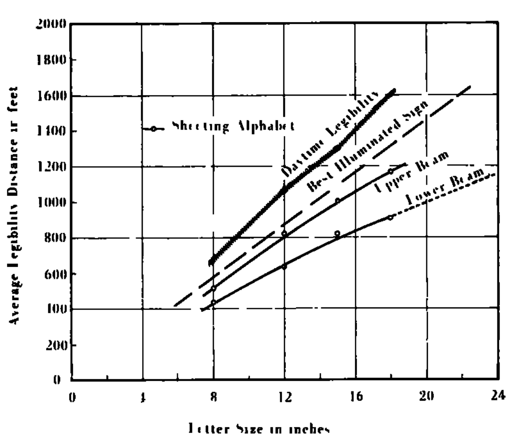


Figure 9. Legibility distances for flat sheeting on overhead sign.

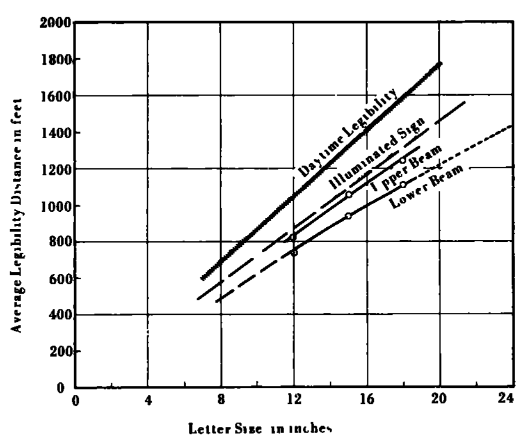


Figure 10. Legibility distances for plastic-covered sheeting on overhead sign.

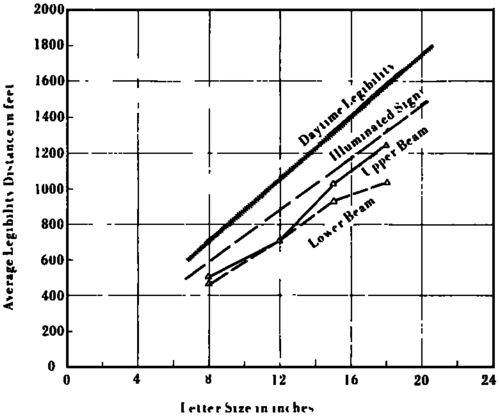


Figure 11. Legibility distances for unit-reflector letters on overhead sign.

to the sheeting by a means of a white plastic strip around the edge of the letter.

Alphabets. Each reflective material was used in the capital-letter alphabet recommended by the manufacturer. The flat sheeting material used an alphabet which was essentially the standard Series E, except that the stroke-width was 0, 20 in. per in. of letter height instead of 0.172 in. per in. of letter height. It is nearly identical to the alphabet previously studied by Forbes et al. (3). This same alphabet was used for the artificially-illuminated sign. The plastic-covered sheeting also used this same alphabet; however, the effective stroke width at night was 0. 14 in. per in. of letter height, because the plastic edging of these letters was not reflectorized. The alphabet of the unit-reflector letters was slightly narrower, but it also has a stroke-width of 0. 20 in. per in. of letter height.

It would have been desirable to have all materials identical in alphabet, so that all differences in results would be due to differences in reflective material. Although this was not possible, it was possible to equate the alphabets so that differences in alphabets would have negligible effect on results; this was done by modifying the recommended spacing between unit-reflector letters. The unit-reflector letters were slightly narrower, and the recommended spacing between letters was considerably less - resulting in about 10 percent less required sign space. The spacing between unit-reflector letters was increased so that the sign space required for the two alphabets would be approximately the same. In accordance with the manufacturer's recommendation, the additional spacing was added as a constant to each space between letters; ⅒ in. per in. of letter height was added to the recommended spacing between the unit-reflector letters. The manufacturer's recommended spacing for the sheeting letters was used without modification. Results to be presented later in this report showed that the desired result had been achieved—the daytime legibility of the two alphabets was almost identical.

Messages. Words to be used in messages were chosen so that a minimum of letters would be needed. In order that words could not be recognized by their length alone, all words were of the same length. Twelve messages of approximately equal legibility were used: FORK, TROY, ROCK, POST, PIKE, TIRE, CITY, LAST, EASY, CLAY, STAY, and OAKS. These messages were possible using only ten letters of the alphabet, ACEIKORSTY, plus letters which could be made by masking portions of these letters. The letters used accounted for 70 percent of the letters in a sample of 150 place names along Virginia's proposed Interstate routes.

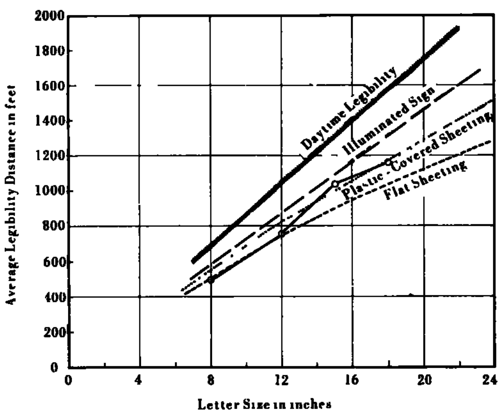


Figure 12. Unit-reflector letters on roadside sign with lower beams, and estimated curves for flat sheeting and plastic-covered sheeting.

Observers. The 48 test observers, 36 males and 12 females, ranged in age from 17 to 63, with an average age of 33. None were acquainted with the reflective materials used. Those who normally wore glasses when driving wore their glasses during the tests. Their far visual acuities with both eyes, measured by the Bausch and Lomb Ortho-Rater, ranged from 20/25 to 20/14 with an average acuity of 20/18.

Each observer was used for both day and night observations.

Design of Experiment. The experiment was designed to permit an accurate statistical analysis. Half the subjects made night observations first, and half made day observations first. Each subject viewed each combination of material, letter size, headlamp beam, etc. The order in which each subject viewed each material, sign position, headlamp beam, and message was determined by an incomplete block design.

## RESULTS

A total of 2,880 observations were obtained. Average legibility distances were computed using a log transformation to give proper weight to extreme observations. Since the car was travelling 15 mph., the car travelled some distance between the time the observer read the sign and the time that the recorder read the distance. If no correction were made, all legibility distances would be slightly too short. The combined reaction time in this case was estimated to be 0.7 sec, during which time the car travelled 15 ft. A correction of 15 ft was therefore added to all average legibility distances.

Daytime Legibility. Figure 7 shows the average legibility distance for each letter size in the daytime for the two alphabets. Since results were essentially the same for the overhead and roadside signs, the points shown are the average of both sign positions. It is clear that there was no significant difference between the alphabets when the spacing between unit reflector letters was augmented so that they require the same amount of sign space as the sheeting letters. For both alphabets, the average legibility distance was 88 ft per in. of letter height.

Illuminated Sign. Results for the artificially illuminated sign are shown in Figure 8. Results were plotted in a different form in order to illustrate the basic relationship between level of illumination and night legibility: when illumination is too low, legibility distance is low; as illumination is increased to an optimum value, the legibility distance reaches a maximum; when illumination is so high that the letters are too bright, legibility is less than the maximum. It is clear that the optimum luminance was in the neighborhood of 10 ft-lamberts. Similar results were found by Forbes and Holmes (2). A luminance level of about 10 ft-lamberts is obtained from many fluorescent fixtures now in use. It is clear that 100 ft-lamberts (such as is obtained with some internally illuminated signs) was too bright for this alphabet in the conditions studied.

However, the conditions of this experiment must be borne in mind. Observations were made in a dark rural area, without glare from headlights of oncoming cars. It is safe to predict that a much higher level of illumination will be required in urban areas in which the surrounding illumination is much higher, and where bright glare sources are in the field of view. There is need for legibility data collected under such urban conditions. Also, this experiment used white Series E letters, with stroke-width 0.20 letter height, on a dark background. Although results should be similar for any letters which have a stroke approximately equal to the enclosed dark space, quite different results would be obtained with a narrower stroke width. A discussion of the effect of stroke width on the required sign brightness can be found in a previous paper (1).

Figure 8 also illustrates the relation between daytime legibility and night legibility. The dashed line at the top of the figure shows daytime legibility results for comparison. Even with optimum illumination, night legibility distances were about 15 percent less than day legibility distances. Similar results were found by Forbes and Holmes (2).

Reflective Materials on Overhead Sign. Results for flat sheeting material on the overhead sign are shown in Figure 9. Smooth curves consistent with theory have been drawn through the points obtained from results for upper beams and for lower beams.

Daytime legibility results are shown for comparison. The dashed line in Figure 9 shows the results obtained from the illuminated sign with a luminance of ten ft-lamberts. This dashed line estimates the best night legibility that could be obtained with a sign with optimum illumination. A "perfect" reflective material could give results as high as this dashed line but could not exceed it. The dashed line, therefore, can be used in evaluating the results for reflective materials.

With upper headlamp beams, flat sheeting on the overhead sign could be read nearly as far as the best-illuminated sign. However, for lower headlamp beams, flat sheeting was significantly less than the "perfect" illuminated sign - from about 25 percent less for 8-in. letters to 30 percent less for 18-in. letters. The lower beam curve has been extrapolated to 24-in. letters. Although no observations were made with 24-in. letters, the extrapolation should not be seriously in error. It gave an estimate of 35 percent less than the best-illuminated sign.

Results for plastic-covered sheeting on the overhead sign are shown in Figure 10. The upper beam results were very close to the best possible as shown by the dashed line. (No points are shown for 8-in. letters because this material was not available in that size.) For lower beams, legibility distances were about 15 percent less than the best-illuminated sign. The extrapolation to 24-in. letters gives an estimate 20 percent below that for the best-illuminated sign.

Figure 11 shows the results obtained for unit-reflector letters on the overhead sign. For this material no smooth curves could be drawn, because there was no fixed relation between letter size and the reflectors used in the letters. Legibility distances for lower beam were 20 percent less than "perfect" for 8-in. and 12-in. letters, 16 percent less for 15-in. letters, and 22 percent less for 18-in. letters.

On the roadside sign, legibility observations were made with only one type of material, and with lower beams only. These results, for unit-reflector letters, are shown in Figure 12. Legibility distances on the roadside sign were considerably better - only 6 percent less than the "perfect" illuminated sign for 12-in. letters, and 12 percent less for 18-in. letters.

Although the other materials were not tested on the roadside sign, curves estimated from theory were added to Figure 12 for comparison. These curves show an increase over the results for the overhead sign, similar to the increase obtained for unit-reflector letters. This was in accordance with the common knowledge that reflective materials give better performance on roadside signs than on overhead signs. However, the difference between overhead and roadside signs should not be overemphasized. Note that for lower beams and letter sizes above 12 in., the curve for flat sheeting on the roadside sign (Figure 12) is not as high as the results for the two brighter materials on the overhead sign (Figures 10 and 11).

## DISCUSSION

A note of caution is needed regarding conclusions based on extrapolated curves and the theoretical curves of Figure 11. Although they are not believed to be seriously in error, conclusions based on small differences should be avoided. Also, differences between the best-illuminated sign and reflective materials may be slightly too large.

Use of the curves for design purposes would be seriously in error. They are based on observers with average vision riding slowly beside the driver, straining their eyes to read familiar messages. The data would be more meaningful if presented as the distance at which drivers with normal 20/20 vision can see the letters clearly. The data of Forbes et al. (3) makes possible such an estimate. Using a similar alphabet to the ones used in this study, observers with approximately 20/20 vision read scrambled letters at about 56 ft per in. of letter height. (Also, one minute of visual angle, the theoretical basis for 20/20 vision, corresponds to 57 ft per in. for these alphabets.) The average daytime legibility distance in this study was 88 ft per in. of letter height. Therefore, the letter sizes on the graph should be increased roughly 50 percent to be seen clearly by a driver with 20/20 vision. It may be helpful for the reader to renumber the horizontal axis of Figures 9-12 accordingly.

It should also be pointed out that the experiment was done under ideal conditions. All materials were new, clean, and dry. There was no rain or fog, and dew was not allowed to collect on the signs. No headlamps or luminaries caused glare in the observers' eyes, and the signs were viewed against a dark background. Further research is needed to determine the necessary allowances for these factors.

Results make possible the definite conclusion that in a dark rural area where no unfavorable conditions of alignment exist, overhead signs using reflective materials can give satisfactory performance. Results do not bear out the common conclusion that all overhead signs must be artificially illuminated and no roadside signs must be artificially illuminated. Results suggest that either of the brighter materials, when used on an overhead sign, can give legibility distances as high as the flat sheeting material on a roadside sign. It is suggested that consideration be given to the use of reflectorized overhead signs in rural areas where there are no unfavorable conditions of highway alignment or surrounding illumination; and that consideration be given to the use of illuminated roadside signs where unfavorable conditions exist.

## ACKNOWLEDGMENTS

The work reported in this paper was part of a study of highway signs sponsored jointly by the Virginia Department of Highways and the Bureau of Public Roads.

Grateful acknowledgment is made to the manufacturers of reflective materials who supplied the materials used in this study; to the persons who served as test observers; to C. E. Giannini, H. H. Newlon, Jr., David Marsee, David Cooke, John Knight, H. T. Craft, the Report Section, and many others of the staff of the Virginia Council of Highway Investigation and Research; to Arthur L. Straub whose previous direction of the highway sign studies made this further study possible; and to T. E. Shelburne for his continuing support of the studies. The author is also grateful to Gordon Sheehe, Director of the Highway Traffic Safety Center, and T. W. Forbes, Director of Research, for permitting the author the time needed to complete this study.

## REFERENCES

1. Allen, T. M. and Straub, A. L., "Highway Sign Brightness and Legibility." Highway Research Board Bulletin No. 127, pp. 1-13 (1955).
2. Forbes, T. W. and Holmes, R. S., "Legibility Distances of Highway Destination Signs in Relation to Letter Height, Letter Width, and Reflectorization." Proc. Hwy. Research Bd., Vol. 19, pp. 321-355 (1939).
3. Forbes, T. W., Moskowitz, K., and Morgan, G., "A Comparison of Lower Case and Capital Letters for Highway Signs." Proc. Hwy. Research Bd., Vol. 30, pp. 355-373 (1950).
4. Straub, A. L. and Allen, T. M., "Sign Brightness in Relation to Position, Distance, and Reflectorization." Hwy. Research Bd. Bulletin No. 146, pp. 13-44 (1956).
5. Anon. "Sign Legibility Study." Salem, Oregon: Oregon State Highway Commission (1954).
6. Unpublished report "Sign Tests—1955" of the Traffic Subcommittee (George F. Hagenauer, Chairman), Cook County Highway Department and Illinois Division of Highways (1956).

# Efforts to Improve Visibility in Fog

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●IN daytime fogs, most vehicle parking lights are less visible than the car itself. The lower beam of the newer type headlamp is inadequate. The upper beam, however, provides better forward visibility and therefore should be used.

Forward Lamps, Nighttime

It has been found (1) that headlamps should illuminate the minimum volume of fog between the driver and the road, and (2) that the angle between the headlamp beam axis and the light scattered back along the driver's line of sight should be one to produce low values of scattering. In Table 1, it can be noted that the most desirable angle is one in the region of 90 deg, that is having the headlamp beam at a right angle to the viewer's line of sight. (Only the angles from 90 deg to 180 deg are applicable to this situation


Figure 1. This is a fogless view of the scene shown in Figures 2 to 8. The road surface is 4 ft wide and 40 ft long, of rough textured hardboard sprayed with asphalt to simulate a black top road. The back of the truck is too large to this scale. It carries full size marker and turn indicators. The upper right and lower left markers are amber, the others red. The diagonal stripes are of beaded white paint scrubbed to give a traffic polished effect. The rectangular and cylindrical test objects in the foreground are painted dull black.

Figure 2. A luminaire of a type used in several toll roads is on in this picture. In this and the next two photographs the camera looks over a pair of low-mounted PAR-36 clear fog lamps. The common practice of showing lighted streets in the absence of headlamps seems unrealistic and increases the apparent value of silhouette seeing. The spotlight at the extreme right in this and several other pictures is part of the fog-regulating device.

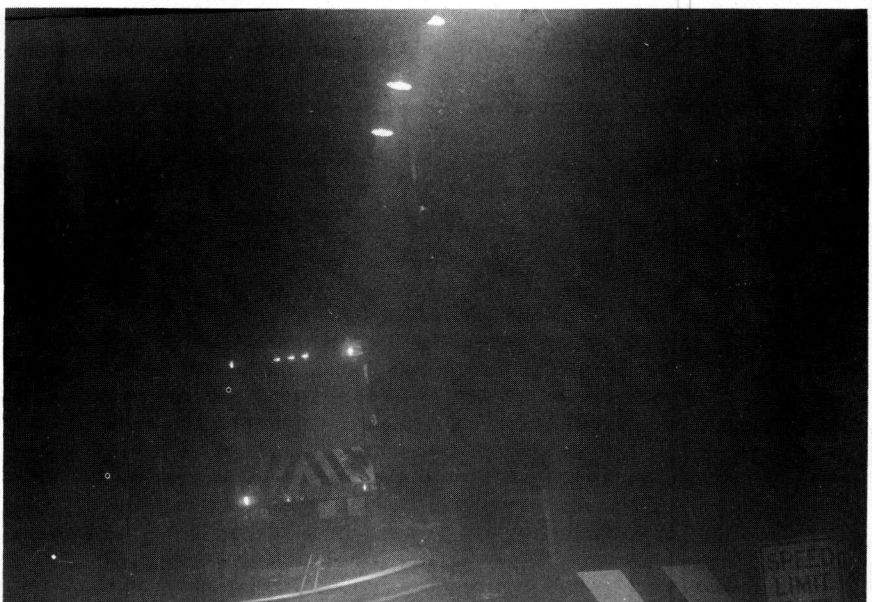


Figure 3. These PAR-38 spots mounted overhead, much closer together than standard spacing, light the road. The angles between line of sight and direction of light are those having minimum scatter and so reduce the veiling glare seen in Figure 2. In Figures 2 through 8, the fog density is held constant at five percent scattered per ft.


Figure 4. Here the road is lighted by low-mounted lamps to one side. The angles between light direction and sight lines are similar to those in Figure 3 and so small amounts of light are scattered toward the driver. In addition, the volume of illuminated fog between driver and road is less since the lamps have sharp upper cutoff. For this scale, 40-watt PAR-46 fog lamps were used.

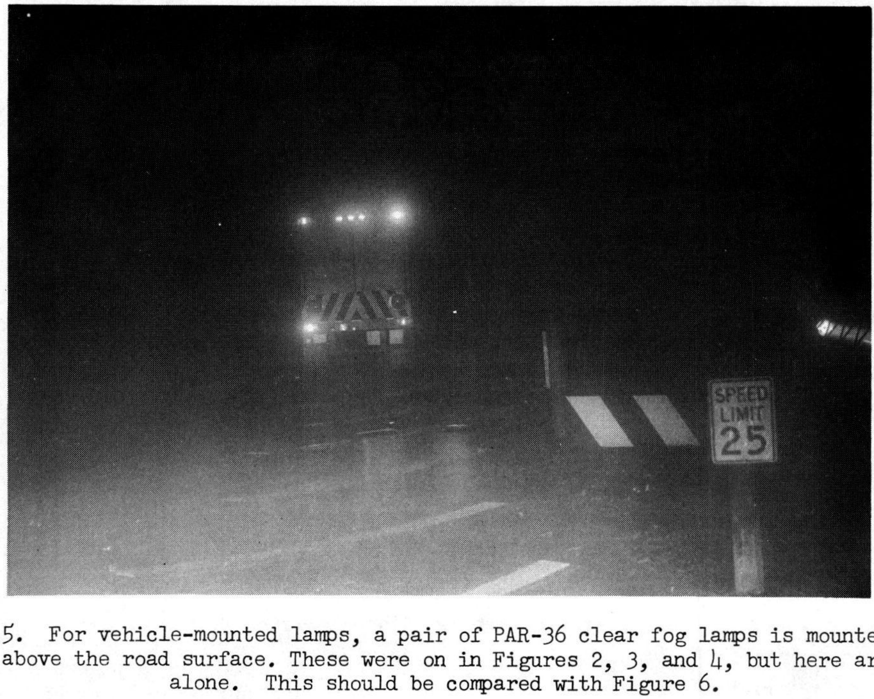


Figure 5. For vehicle-mounted lamps, a pair of PAR-36 clear fog lamps is mounted a few inches above the road surface. These were on in Figures 2, 3, and 4, but here are shown alone. This should be compared with Figure 6.


Figure 6. The lights used here, a pair of PAR-36 30-watt fog lamps, are the same as Figure 5 except that they have been raised to where the angles between light beams and camera axis correspond to those between head lamps and driver's line of sight in modern passenger cars.


Figure 7. A 100-watt PAR-46 spot covered with a polarizing filter of about 40 percent transmittance is used alone here. This is equivalent to an unfiltered 40-watt except that the filter reduced the 140-deg back scatter (rainbow) which is strongly polarized.


Figure 8. This differs from Figure 7 in that a crossed polarizing filter was before the lens. The exposure was increased to be sure of recording all low brightness areas. The back scatter from the beam is reduced to about 0.01 of that in Figure 7. The two squares at the lower right of the truck are retro-reflective sheets. On each side of the license are plastic prismatic reflectors.

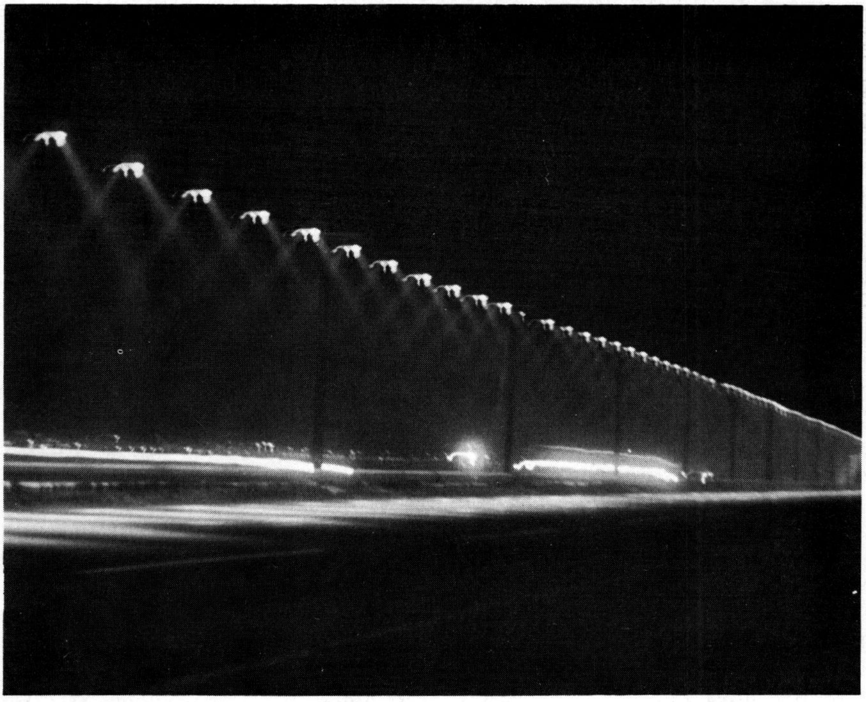

Figure 9. Overhead lights installed on the New Jersey Turnpike East of the Newark Airport. These 300 w., narrow beam spots are mounted 26 ft above the road and spaced 15 ft apart. They illuminate only one lane in each direction.

Figure 10. Low mounted fluorescents installed on the New Jersey Turnpike. These are 8 ft, 200 w. lamps, 18 ft on centers, mounted just above the guardrails. The reflectors direct the light below the horizontal. Louvres are used to reduce the component toward oncoming traffic.

since the headlamp beam is directed away from the viewer. ) While 90 deg cannot be achieved, the larger angles of 140 deg and near to 180 deg should be avoided.

The arrangement which most nearly satisfies both of the above requirements has the headlamps placed as low as possible on the vehicle and projecting light in a thin layer close to and parallel to the road surface (Fig. 4). This results in low brightness of pavement but high brightness of objects on or beside it.

A polarized spot lamp and cross polarized viewer is the most effective fog light system developed so far, although polarized light penetrates fog to no greater extent than unpolarized light. Polarized light which is scattered back from fog is not depolarized but is blocked when seen through a viewing filter polarized at 90 deg to the lamp filter, thus removing much of the veiling glare normally present. Light striking opaque objects lacking metallic lustre is partially depolarized and the object therefore, can be seen through the filter. Self luminous objects, such as tail and signal lights and traffic signals, as well as opaque objects, are not obscured by the filter. Restrictions in the application must be observed for satisfactory performance of a polarized fog light system.

1. The plane of polarization of the filters used for polarizing and viewing must be either parallel or perpendicular to the plane defined by the lamp's centerline or beam axis and the driver's eyes, the polarizor one way, the viewer the other way.

2. The beam spread must be such that if the light rays were projected back through the lamp, they would meet at a point on the lamp's axis defined by its intersection with a perpendicular line in the plane of the driver's eyes. If a broader beam is needed, it must be produced by more than one lamp arranged so that all meet this requirement.

3. This system will give visibility to opaque objects which depolarize the light, beaded painted pavement markings, plastic reflectors such as those used to delineate turnpikes and those on cars and trucks, and some forms of reflective sheeting, but not to the red tape commonly used on rear bumpers.

4. This system will obscure the scatter light produced by an oncoming vehicle similarly equipped. It will also obscure the headlamps and possibly a visual warning of the car's presence. If the polarizing filters are oriented at 45 deg from the vertical, the polarized headlamp of the oncoming car will be visible and give warning, but the scattered light will also be visible, producing glare. So, since the scatter light is not desirable, at least one marker lamp would be needed for visual warning.

5. Since the polarizing filter transmits only about 40 percent of the visible light, a 40-watt PAR-46 compares poorly in road illumination with a pair of sealed-beam headlamps of 40 watts each, on lower beam; therefore, more powerful lamps, such as 100-watt spots, will be needed.

TABLE 1

INTENSITY OF SCATTERED LIGHT, PER UNIT OF FLUX INCIDENT, PER FOOT OF BEAM PATH LENGTH

| Angle between incident light and scattered light in the direction of view | Unpolarized light | Polarized light viewed through crossed filters |
|---|---|---|
| deg | | |
| 20 | $4400 \times 10^{-4}$ $ft^{-1}$ | $19 \times 10^{-4}$ $ft^{-1}$ |
| 30 | 2900 | 13 |
| 40 | 1500 | 9 |
| 50 | 710 | 6.3 |
| 60 | 400 | 4.2 |
| 70 | 200 | 3.4 |
| 80 | 100 | 2.7 |
| 90 | 76 | 2.5 |
| 100 | 57 | 2.6 |
| 110 | 54 | 3.2 |
| 120 | 63 | 4.3 |
| 130 | 87 | 6.3 |
| 140 | 160 | 10 |
| 150 | 180 | 12.5 |
| 160 | 180 | 16 |

From graphs drawn by the Polar Nephelometer of the Vision Research Laboratory, University of Michigan.

6. With these high-power lamps, and where dense fogs require speeds of less than 20 mph, precautions are necessary to prevent overheating of the filters. The test installations have blower cooled filters.

To define a vehicle's position, two lamps are needed. Two lamps can also supply light at wider angles than one. Two 30-watt, PAR-36 lamps hung from below and behind the front bumper do this adequately. Both spot and fog lights have been used, and each has advantages.

## Rear Lamps

For use in daytime and in both day or night fog, a higher brightness lamp, which may be smaller, is needed to contrast with the high brightness of daytime fog, or, at night, with the fog illuminated by scattered light from vehicles and street lamps. At present, in day fog, the average tail lamp is useless except on very light colored cars.

The turn indicators on most passenger cars and the more recent truck signals are more visible than the present taillights. On turnpikes, these could be operated on left turn without ambiguity as no left turns are permitted on most toll roads.

A preferred arrangement is that of providing a switch so that turn indicators can be operated in front or rear pairs as well as right and left. Turn signals only should be used as markers on trucks and on those cars which have separate lamps for turning and for braking. To do so where the same lamps are used for both functions would leave the driver with no braking signal.

Higher mounting of rear lamps reduces the veiling effect of fog lighted by the headlamps or fog lights of the following car, and thus increases the nighttime visibility. The contrast of rear lamps in daytime can be increased by adding a dark surround. A lamp mounted outboard seems to stay cleaner than one flush mounted but suffers from higher background brightness.

The following list of attributes of a lighting system suitable for satisfactory performance in fog is offered.

1. The volume of illuminated fog between the driver and the road should be small.

2. The light which must traverse this volume of fog should do it at angles with the driver's vision which produce the minimum light scattering.

3. Direct glare sources should be minimized for fog as well as clearer atmospheres.

4. Except for haze having particles much smaller than fog droplets, color seems not to be a factor in scattering. But some colors, such as that from clear mercury vapor lamps, afford higher color contrast with red and amber signal lamps but seem to cause more peripheral haze.

## REFERENCES

1. Literature Search and Evaluation of the Physics of Fog: Stanford Research Institute Report No. 1 (February 16, 1953).

2. Leipper, Dale F.: Fog Bibliography, Scripps Institution of Oceanography Contract N 6041-211 Fog Project Report No. 1, 14 p. (1947).

3. Meteorological Abstracts and Bibliography, Vol. 6, American Meteorological Society, Boston (1955).

4. Middleton, W. E. K.: Vision Through the Atmosphere, University of Toronto Press (1952).

# Aiming for Better Headlighting

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● RECOGNIZING the complexity of the night driving situation, and realizing the problem of evaluating some very pertinent factors that are difficult to include in laboratory or stationary testing, in the early 1930's it was decided to conduct dynamic tests using observer-drivers.

Such dynamic testing automatically includes such factors as the time it takes to see, or one might say the lack of time for seeing under driving conditions, the general environment of the driving condition, and the actual physical effort required in the act of driving.

Over the years, instrumentation was developed to permit the taking of a large number of individual observations over a short period of time, under controlled test conditions. The arrangement used most frequently involves the use of a straight, level, two-lane highway with a useful test stretch of one mile in length. Obstacles were placed at both edges of the travelled road, in known positions. Two opposing cars were placed at each end of the one-mile stretch, at fixed starting points. Each car was equipped with a tape recorder, geared to the transmission. Upon signal, the observer-drivers start, accelerate uniformly to a predetermined speed, and hold that speed for the entire test run. A pen on the tape recorder draws a continuous straight line on the tape. This pen is connected through a circuit to the horn ring. When the observer-driver perceives an obstacle (he watches for those on his right side of the road only), he touches the horn ring which effects a pip in the line on the tape. Since the obstacle positions

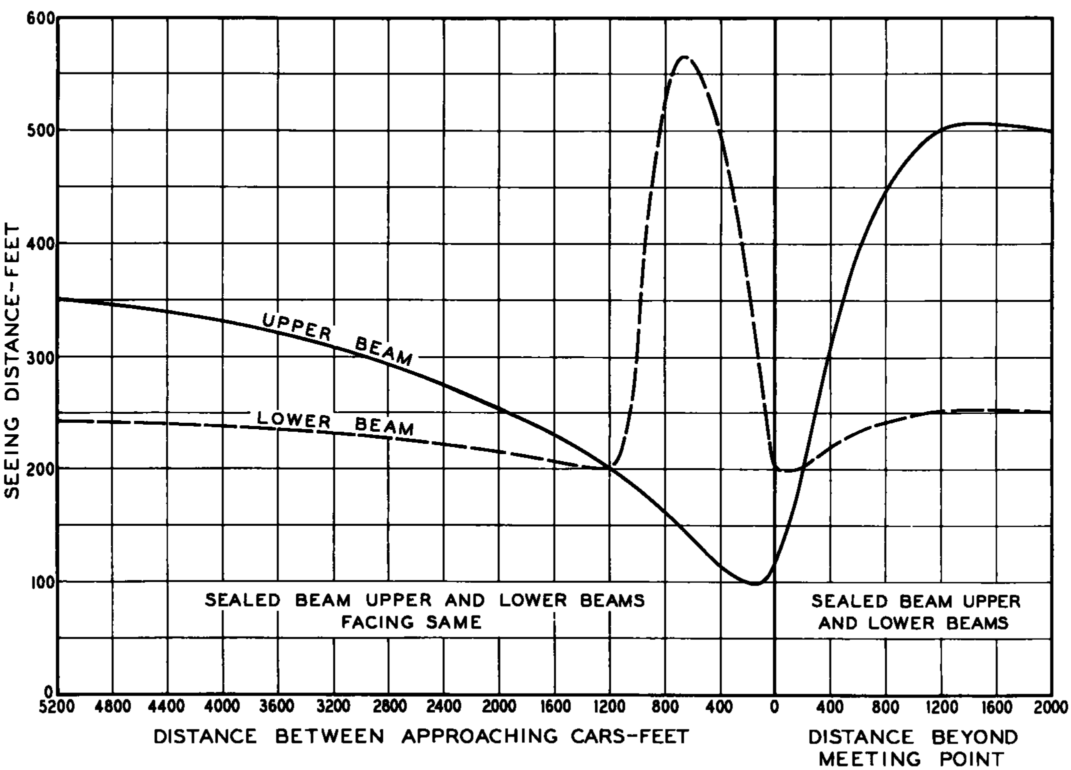


Figure 1. Typical seeing distance curves as two cars approach and pass obstacle - man-size dummy in dark clothing at right edge of road, speed 40 mph.

are known and fixed, their positions may also be plotted on the tape. A dozen or more individual observations may be obtained with each observer for each one-mile test run. This permits the plotting of a seeing distance curve with seeing distance as the ordinate and distances between cars as the abscissa.

The two cars pass at the center point and then the seeing distance values become "clear road" values, with no opposing glare.

Figure 1 shows the results of a series of observations (1) made using the original type sealed beam headlamps, not the new improved variety which appeared on 1956 cars nor the dual-unit type appearing on some 1957 and most 1958 cars.

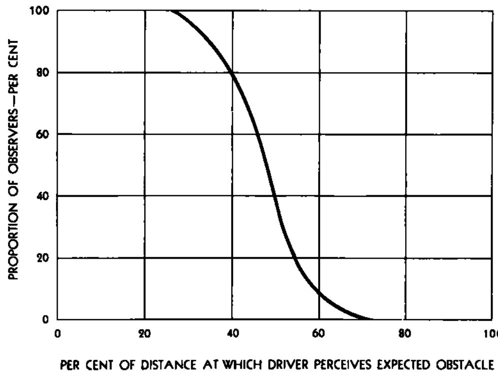


Figure 2. Distance at which driver perceives unexpected obstacle.

The solid curve is for the upper beam, facing the same. The dashed curve is for the lower beam, facing the same. The point where the two curves cross (at 1, 200 ft) represents the optimum distance for depressing the beams.

The sharply rising portion of the lower beam curve (after the two cars approach from 1, 200 ft apart) represents silhouette seeing. That is, for this portion of the curve, the obstacles were seen as dark obstacles against a lighted background.

A dynamic test of this kind is still not fully representative of a typical driving situation. The observer-drivers were knowingly engaged in a test, and therefore they were paying more attention than would the normal driver. They know that there are obstacles ahead, and they are alert to the situation.

It is necessary to know what attention factor should be applied to these data to obtain seeing distance values which would be more typical of normal driving situations.

An I. E. S. paper presented in 1937 (2) described a dynamic test procedure to establish this attention factor, and presented data obtained with a number of observer-drivers. The objective was to use observer-drivers who were unaware of the fact that they were participating in a seeing distance test. This was accomplished by having each drive a test car with the stated objective of criticising the beam pattern. On the return part of the trip, he was directed to a test stretch of roadway in which an obstacle was placed in the center of his lane of travel. Incidentally, the obstacle was attached to a rope, the other end of which was held by a person hiding in the ditch at the side of the road, just in case it would be necessary to avoid physical contact of the obstacle and the car.

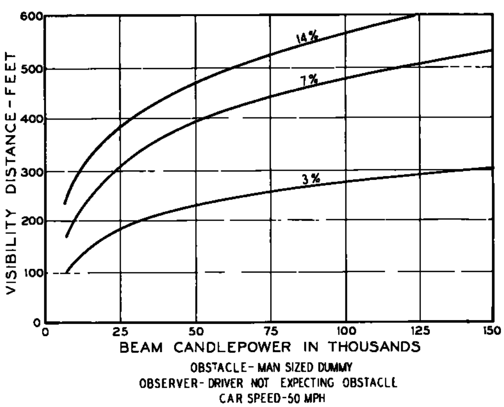


Figure 3. Seeing distance as affected by reflection factor of obstacle.

Upon perception of the obstacle, the driver's reaction was invariably to release pressure on the accelerator. Enough light was provided under the dash so that an engineer sitting beside the driver could observe the instant when the pressure on the accelerator was released, and press a button which actuated a wheel revolution counter. The counter was stopped upon reaching the obstacle. The driver was then informed that this was the real reason for the test trip, and was asked to repeat the test, knowing that the obstacle was there.

Figure 2 shows the distribution of these observations. On the average, the unexpected obstacle was seen just half as far away as the expected obstacle, for the situation of clear road driving.

No test has been devised to determine

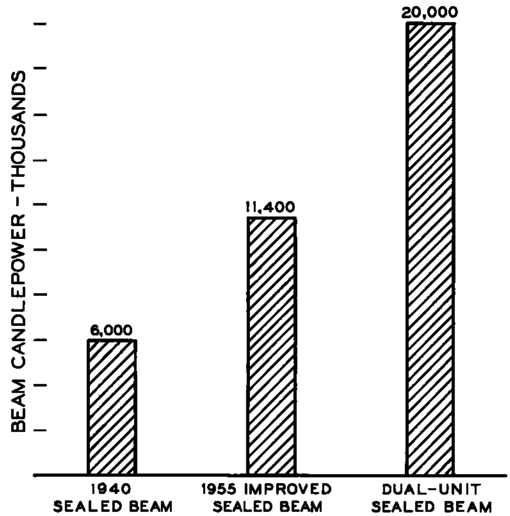


Figure 4. Relative beam candlepower directed 300 ft ahead at right side of road by lower beam.

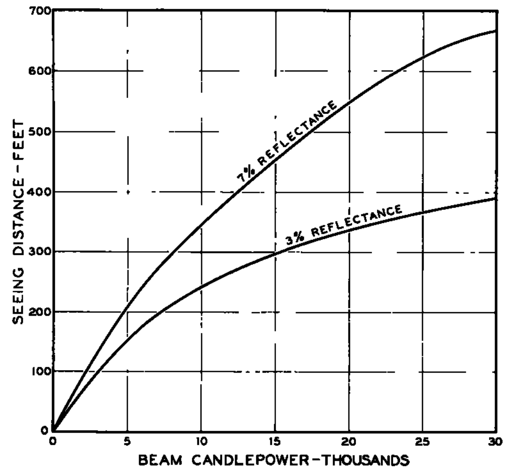


Figure 5. Relation of beam candlepower and seeing distance alert driver - speed 50 mph, no opposing glare.

the attention factor for the situation of meeting other cars. However, it is reasonable to assume that under this condition, one is paying somewhat more attention to one's own lane of travel, and therefore the attention factor is higher than 0. 5, although certainly lower than 1, perhaps about 0. 7 or 0. 8.

Having the attention factor, it becomes relatively easy to obtain a large number of observations with observers knowingly engaged in a test, and establish a relation between beam candlepower values and seeing distance, for clear road driving. Figure 3 shows the relationship of beam candlepower and seeing distance for obstacles of three different reflection factors: 3 percent, which is black; 7 percent, medium gray; and 14 percent, light gray. In this case the car speed was 50 mph and the 50 percent attention factor was applied (2).

Any present-day discussion of headlighting would be incomplete without emphasis of the importance of proper headlamp aiming.

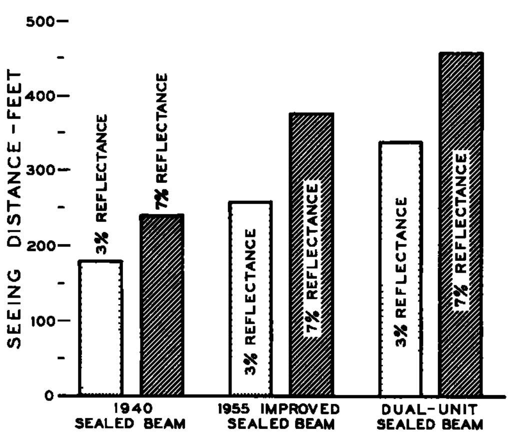


Figure 6. Relative seeing distance capability in direction of area on road 300 ft ahead at right-hand side. Lower beams - alert driver, speed 50 mph - no opposing glare.

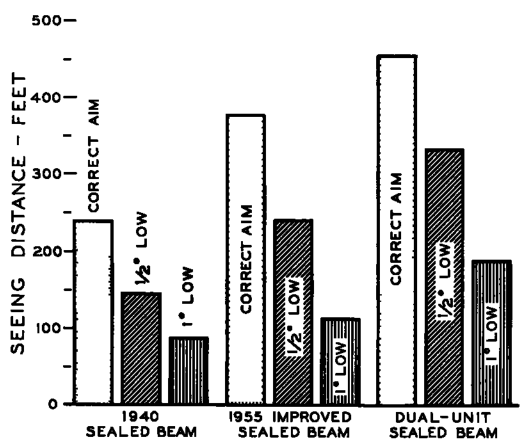


Figure 7. Effect of misaim (low) on seeing distance. Lower beams - alert driver, speed 50 mph - obstacle reflectance 7 percent, no opposing glare.

The specifications of the Society of Automotive Engineers call for minimum and maximum values at various specification points covering both upper and lower beams. One important seeing specification point in the lower beam should be considered. This is a point ½ deg below the horizontal at the level of the headlamp centers, and 2 deg right of the vertical, or right of straight ahead. For average headlamp mounting height, this is a point at the right edge of a two-lane road, 300 ft ahead. It is apparent that this is an important seeing distance specification point in the lower beam. Figure 4 shows the beam candlepower values directed at this point by a pair of lower beams of the 1940 sealed beam variety, the 1955 improved sealed beam, and the 1957 dual-unit sealed beam, all properly aimed.

Figure 5, taken from previous data, shows what these candlepower values mean in terms of seeing distance, with no opposing glare and considering an alert driver—that is, no attention factor applied. The lower curve is for an obstacle of 3 percent reflectance; the upper curve, for an obstacle of 7 percent reflectance. Now combine these data to obtain the charted information in Figure 6—that is, the relative seeing distance capability in a direction of an area on the road 300 ft ahead at the right-hand side with the lower beams, considering an alert driver proceeding at a speed of 50 mph and with no opposing glare. It should be emphasized that these data represent seeing distance capability. It is what may be achieved with the concentrated attention of an alert driver with good eyesight.

It is obvious that the manufacturers have made two improvements recently: with the improved sealed beam lamps installed on 1956 cars, and in the dual-unit system.

However, this is for the condition of perfect aim of the headlamps. What happens when they are misaimed low? Figure 7 shows the more favorable condition of the obstacle of 7 percent reflectance. The left bar for each system shows the seeing distance capability at the point 300 ft ahead with correct aim, the 1940 sealed beam, the 1955 improved sealed beam, and the 1958 dual-unit system.

The center bar shows the seeing distance capability at this same point with the headlamps misaimed ½ deg low, and the right-hand bar for the situation of misaim 1 deg low. Also, this is for the condition of no opposing glare. It can be appreciated from this, that with misaimed headlamps, in normal traffic, and an inattentive driver who may be fatigued after hours of driving, the seeing situation can indeed be serious.

Experience shows that the average headlamps are misaimed by at least ½ deg, oftentimes more. So without spending any money on equipment, the average driver can obtain a considerable increase in seeing distance by simply having his headlamps aimed exactly right.

All sealed beam headlamps are now manufactured with three aiming pads on the front surface of the lens. The front surfaces of these pads are correctly aligned with respect to the aim of the beam. Hence this permits the use of simple, inexpensive mechanical aimers to seat on the front surfaces of these pads and to align the lamps correctly without the need for a darkened area, and hardly more space than that for the car itself.

If the proper attention to headlamp aiming were "sold" to the public and to the service trade, the manufacturers could provide further improvement in headlighting performance, with still more light directed along the right side of the road from the lower beam.

## REFERENCES

1. "Seeing Against Headlamp Glare," Illuminating Engineering, Vol. XLVII, No. 3 (March 1952).

2. "Seeing with Motor Car Headlamps," I. E. S. Transactions, Vol. XXXIII, No. 5 (May 1938).

# Relation Between Scotopic Vision as Measured by The Night Sight Meter, Daylight Vision and Age

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●THE HIGH frequency of nighttime traffic accidents and the frequent complaints about glare blindness calls attention to a very important phase of highway safety investigation. Up-to-date this phase has received only meager attention by students of highway safety.

There are several aspects to the night vision problem and it might be well to consider them in order. The hypothesis to be investigated may be stated as a question, "What relationship exists between vision measured in daylight and vision measured in very low illumination?"

The Night Sight Meter is an instrument designed to give three types of scores on phases of night vision which are commonly mentioned as important to motorists travelling the highway at night. The visual measurements for daylight vision were made with the regular Sight Screener made by the American Optical Company.

## PLAN OF THE EXPERIMENT AND PROCEDURE

A set of instruments was installed in a booth at the Iowa State Fair and persons visiting the Fair were invited to serve as subjects. The instrumentation was screened off in the booth and was manned by trained examiners, one on each specific test. Each subject was read standard operating directions and then taken through the series of tests. They were requested to complete the series but for different reasons about one-fourth of the records were incomplete and could not be used. Of over 450 persons starting the tests only 288 had completed records.

The data were carefully analyzed, coded and put on IBM cards. Intercorrelations were run between age, miles driven, vision in low light, glare vision, glare recovery time and daylight vision as measured by the Sight Screener. The latter measurement was used as the criterion.

## ASPECTS OF NIGHT VISION

First, there is the problem of night seeing efficiency in the absence of glare. Some persons see very well at night considering the amount of illumination available while others see very poorly. The first problem concerns the relationship between seeing in very low illumination and seeing in high illumination. By very low illumination we refer to levels of light less than $\frac{1}{10}$ ft candles, whereas levels of illumination of 10 ft candles and above as used for visual examinations, are arbitrarily referred to as high level or daylight vision.

The second score of interest was that of the ability to see against glare as determined by a second measurement on the Night Sight Meter. This is done by using the same low illuminated letters as the fundamental stimuli, at the same time introducing a glare light beam source thrown into the subject's eye. This materially raises the threshold for seeing and establishes a second score.

A third phenomenon is that of temporary blindness when a motorist meets a bright light. Is this related to the other two phenomena and what interrelationship exists with vision, age, and driving performance? To obtain a reasonable sampling of measurements the instrumentation was set up as described and all measurements on common subjects were obtained. From these scores intercorrelations were computed to determine the relationships desired.

Age was used along with the total mileage driven to determine whether these variables might influence results obtained. It is known that older persons are more affected by glare.

## RESULTS OBTAINED

The booth was kept open for 10 days and about 400 subjects taken through. Of the

288 complete records six variables on vision were intercorrelated and the results are shown in Tables 1 and 2. Table 2 shows the means and standard deviations with the exception of mileage which turned out exceptionally high, being nearly double the mean. This would indicate that estimates on mileage differ widely and are perhaps not reliable.

TABLE 1

CORRELATIONS N = 288

| 1<br>Age | 2<br>Total Miles Driven | 3<br>Dim Light | 4<br>Glare | 5<br>Glare Recovery Time | 6<br>Vision Sight Screener |
|---|---|---|---|---|---|
| 1 | +.4495 | +.1270 | +.0714 | +.2070 | -.2373 |
| 2 | ---- | -.0423 | +.0076 | +.0928 | -.1553 |
| 3 | | ---- | +.3921 | +.1238 | -.0579[a] |
| 4 | | | ---- | +.1758 | -.1151[a] |
| 5 | | | | ---- | -.0579[b] |

$R_{6\,.\,12345} = .2632$

[a] Less acuity, more light needed.
[b] Less acuity, longer to recover.

As expected those older had travelled more miles. They had slightly poorer vision as measured by the Sight Screener. The average was somewhat less than 20/20 vision, being about 6.8 in Sight Screener units. The correlation of -0.24 indicates poorer vision for the older group. There was a slight negative correlation between scotopic and photopic vision as noted. The relationship is quite low. Glare recovery time also correlated negatively with daylight vision. Considering the nature of the scores this means that one with poor vision takes longer to recover from glare. The other correlations indicate relative independence of each of the separate Night Sight Meter measurements. The mileage relationships shown are probably due to the effect of age, experience being a doubtful factor.

A multiple R of 0.26 with daylight vision reflects mostly the effect of age on vision. A moderate correlation of +0.21 shows older persons have a slightly longer glare recovery time.

There was only a slight negative relationship between night vision and daylight vision scores as taken. This is mostly noticeable for glare recovery time.

The nature of the subjects used is shown quite well by the table of means.

TABLE 2

ALL SUBJECTS

| Variable | Mean | S.D. |
|---|---|---|
| Age | 23.90 | 9.40 |
| Total miles driven | 81,319.00 | ----[a] |
| Sight Screener | 6.80 | .84 |
| Night or dim vision score | 23.80 | 4.63 |
| Glare vision score | 51.98 | 14.30 |
| Glare recovery time | 2.70 | .78 |

[a] Very large, not inserted.

## CONCLUSION

Within the scope of this investigation and considering the various limitations the following tentative conclusions may be stated:

1. Night vision is different from daylight vision and should be measured separately.
2. The scores on the Night Sight Meter are relatively independent. All should be

taken to get a measure of one's vision for driving.

3. Age shows greatest effect on glare recovery of the variables considered.

4. Considering the direction of scores, one with good vision sees slightly better at night, but the two measurements overlap only slightly.

5. To secure an adequate appraisal of a driver's vision one should have both daylight and night vision scores.

6. The following tables of norms do not indicate sex differences of substantial magnitude.

## *Appendix — Norms*

TABLE A

NIGHT SIGHT METER

| Dim Light Scores | Women Frequency | Women Cumulative Frequency | Men Frequency | Men Cumulative Frequency | Men and Women Frequency | Men and Women Cumulative Frequency |
|---|---|---|---|---|---|---|
| 36-37 | 2 | 87 | 8 | 290 | 10 | 377 |
| 34-35 | 3 | 85 | 7 | 282 | 10 | 367 |
| 32-33 | 4 | 82 | 11 | 275 | 15 | 357 |
| 30-31 | 6 | 78 | 17 | 264 | 23 | 342 |
| 28-29 | 3 | 72 | 30 | 247 | 33 | 319 |
| 26-27 | 10 | 69 | 30 | 217 | 40 | 286 |
| 24-25 | 17 | 59 | 46 | 187 | 63 | 246 |
| 22-23 | 21 | 42 | 47 | 141 | 68 | 183 |
| 20-21 | 14 | 21 | 47 | 94 | 61 | 115 |
| 18-19 | 4 | 7 | 25 | 47 | 29 | 54 |
| 16-17 | 3 | 3 | 22 | 22 | 25 | 25 |
| | N = 87 | My = 24. 592 | N = 290 | My = 24. 252 | N = 377 | My = 24. 330 |

TABLE B

NIGHT SIGHT METER

| Glare Scores | Women Frequency | Women Cumulative Frequency | Men Frequency | Men Cumulative Frequency | Men and Women Frequency | Men and Women Cumulative Frequency |
|---|---|---|---|---|---|---|
| 91-96 | 6 | 87 | 17 | 290 | 23 | 377 |
| 85-90 | 1 | 81 | 3 | 273 | 4 | 354 |
| 79-84 | 2 | 80 | 4 | 270 | 6 | 350 |
| 73-78 | 1 | 78 | 7 | 266 | 8 | 344 |
| 67-72 | 8 | 77 | 13 | 259 | 21 | 336 |
| 61-66 | 10 | 69 | 32 | 246 | 42 | 315 |
| 55-60 | 10 | 59 | 60 | 214 | 70 | 273 |
| 49-54 | 17 | 49 | 48 | 154 | 65 | 203 |
| 43-48 | 19 | 32 | 41 | 106 | 60 | 138 |
| 37-42 | 9 | 13 | 32 | 65 | 41 | 78 |
| 31-36 | 1 | 4 | 22 | 33 | 23 | 37 |
| 25-30 | 3 | 3 | 11 | 11 | 14 | 14 |
| | N = 87 | My = 55. 916 | N = 290 | My = 54. 254 | N = 377 | My = 54. 638 |

TABLE C

NIGHT SIGHT METER

| Recovery Time | Women | | Men | | Men and Women | |
|---|---|---|---|---|---|---|
| | Frequency- | Cumulative Frequency | Frequency- | Cumulative Frequency | Frequency- | Cumulative Frequency |
| 4.0-4.2 | 3 | 87 | 13 | 290 | 16 | 377 |
| 3.7-3.9 | 1 | 84 | 11 | 277 | 12 | 361 |
| 3.4-3.6 | 0 | 83 | 7 | 266 | 7 | 349 |
| 3.1-3.3 | 10 | 83 | 10 | 259 | 20 | 342 |
| 2.8-3.0 | 7 | 73 | 20 | 249 | 27 | 322 |
| 2.5-2.7 | 11 | 66 | 29 | 229 | 40 | 295 |
| 2.2-2.4 | 6 | 55 | 36 | 200 | 42 | 255 |
| 1.9-2.1 | 12 | 49 | 36 | 164 | 48 | 213 |
| 1.6-1.8 | 18 | 37 | 63 | 128 | 81 | 165 |
| 1.3-1.5 | 14 | 19 | 39 | 65 | 53 | 84 |
| 1.0-1.2 | 5 | 5 | 26 | 26 | 31 | 31 |
| | N = 87 | My = 2.190 | N = 290 | My = 2.173 | N = 377 | My = 2.177 |

ACKNOWLEDGMENT

This study was carried out in cooperation with the American Automobile Association.

# Vision at Levels of Night Road Illumination

## *III. Literature 1956–57*

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● BAD VISION is believed by the Association of Optical Practitioners to be a contributing factor in at least 10 percent of road accidents in Britain (4). Lighting of roads lessened accidents by a factor of ten in Indiana (7) and an accident rate in Chicago of 17.9 per million miles of travel with 0.144 ftc reduced to 9.5 with lighting of 0.88 ftc (50). Figures of merit of roadway lighting are summarized and discussed by Rex (41). Hofstetter (25) considers visual driving problems of glare, poor visibility in dim light, central acuity, peripheral vision, diplopia, judgement of direction and depth, adaptation to fixational changes of distance and the ability to recognize objects seen. Savin, Weston and Grime (44) present an excellent summary of the seeing ability of the driver and the illumination of the roads. Forbes and Katz (18) summarize many data on seeing and discuss their application to highways.

Bryan (8) and Hervey (24) report on the work that the American Optometric Association's Vision Committee is doing toward finding out the actual abilities of auto drivers. The preliminary report indicates that about 22 percent of the people tested were deficient in acuity and in depth vision, about 29 percent have inadequate muscular balance (lateral and vertical phorias), 7½ percent are deficient in color vision, 10 percent have reduced fields, and 5 percent have inadequate glare resistance. Of this group, 22 percent had reportable accidents.

The brightness of mercury lamps appears greater than the photometric brightness, with respect to sodium lamps, as the mercury luminance had to be reduced to ⅓ of that of sodium before observers judged them equally bright. Preferences for sodium light Ferguson and Stevens (16) state are due more to the characteristics of the luminaire than to less glare.

Hopkinson (26) developed a scale of apparent brightness for a 2 deg patch on a 120 deg field which shows the sensation of brightness (M) follows the physical luminance (L) according to the equation $M = kL^{0.3}$. The exponent varies with the adapting field and the surround has some effect on appearance, e.g. two luminances, one twice the other, appear at high intensity, to be about this difference, but seen in a dark surround they appear nearer to ten to one in brightness. Nolan (35) gives equations relating luminous energy, target size and duration for foveal stimuli. Stevens (47) reviews work on scales of brightness with reference to luminance.

The brightness of an object is related to and derives in part from its photometric luminance, for aside from dark adaptation, brightness is determined by the light reaching a given area of the retina and this in turn depends upon the part of the light illuminating the object which is reflected to the eye and the size of the pupil. Thus, it is evident that luminance and brightness although related are not the same, and it is the latter which triggers the driver. Someday equations will completely relate the illuminance and reflectance of the lighting engineer with the brightness of the various elements of the visual image as perceived by the retina and brain. In the meantime it behooves us to recognize the physical, biological and psychological aspects of vision, our ignorance in each field, and plan efficient experiments to obtain enough information to solve the motorist's vision problem at night. Forbes and Katz (18) also point the way here.

Aguilar and Stiles (1) conclude that at a field intensity of 100 scotopic Trolands the sensitivity of the rod mechanism to stimulus differences begins to fall off rapidly and that at about 2,000 to 5,000 Trolands the rod mechanism becomes saturated and is no longer capable of responding to an increase in stimulus.

Jayle and his associates (29-31) have investigated 1,600 young air recruits by a motion picture technic to learn at what level a screen appears lighted, the threshold for differences in luminance on the screen, for form differences and for recognition of the form seen. The latter, identification threshold (0.0058 to 0.058 ft-L) just falls in the lower range of highway luminances, and this method may provide another analytical technic. Another projection method for training night vision is described by Perdriel et al (38). The use of a tachistoscope is recommended (28) for testing driver's vision.

Actual levels of dark adaptation driving at night have been measured by Davey (10). On a dark road where the illumination varied from 0.7 to 0.2 ft-L, the adaptation level found was log $\bar{5}.79$ ft-L. In the city the level of adaptation was about log $\bar{4}.47$ ft-L and in the country it was about log $\bar{5}.17$ ft-L. From the dark adaptation curve of the subject Davey estimated that it would take about 5 min for adaptation from the city to the country lighting.

Measurements of acuity from the fovea to the periphery reported by Oliva and Aguilar (36) show visual acuity to decrease, the visual size of the retinal unit to increase and this decrease in vision is related to the distribution of the sensory units in the retina. Krauskopf (32) examined contrast thresholds during continuous seeing as the retinal image was moved by means of a mirror. Low frequency vibrations of 1, 2, and 5 cps of the retinal image were found beneficial to maintained vision, while higher frequencies of 10, 20, and 50 cps were, in the absence of normal image motion, detrimental to continuous vision. Vibration over 10 cps likewise decreased detection and resolution as shown by the graphs of Ercoles et al (15).

Finch (17) summarizes the factors involved in night visibility of roadway obstacles due to the form and shape of the obstacle and the lighting.

Sachsenweger (43) has reported that depth impressions are heightened for most people in twilight. Objects which are clearly seen to lie in different depths seem to lie in greated distances from each other in the dusk than in bright daylight. He believes that good muscle balance is important in twilight vision, because there is less stimulation outside of the macula for fusion and any night myopia present worsens the image. The various methods for estimating stereopsis are described by Anapolle (3) and he believes that all operators of moving vehicles should be tested for depth perception and stereoscopic vision.

Oliver and Lauer (37) have found that driving experience does not improve the ability to judge distance and speed. With poor visibility or poor vision the perceptual distance is shortened. Acuity and speed estimation are slightly, though not significantly, correlated; but acuity and distance perception were significantly correlated. Men were found slightly better than women in judging distance.

Davey (9) discusses visual acuity in driving based on information obtained from 40 drivers and a test course. Since vision is better out of doors than indoors it is recommended that the acuity measurements for drivers in England should be made out of doors. High acuity was not required for driving along a winding course. Visual acuity and perception time are correlated. The sharper the retinal image, the quicker it was perceived. Good acuity is helpful in seeing bus numbers, to know where they are going and in seeing via the rear view mirror. Such clues evade a person with poor vision and Davey writes: "Whether this makes him more dangerous will depend to a large extent on whether he is aware of his limitations and drives accordingly. He may, however, unwittingly balk other road users by slowing to read a road sign which is clearly visible to others and by failing to position early in the correct traffic stream in preparation for a required maneuver." Davey (11) found also that a small amount of veiling glare from slight scratches in goggles reduced the speed of speed driving, because with unscratched goggles he was able to make the same speed in the afternoon as on a gray morning, with no glare from the sun.

Mansini (34) discusses the new signs, some color coded, placed on the main highways in Rhode Island. Birren (6) reports on day and night visibility of markers. The best seeing of signs at night is about 88 percent of that during the day and he recommends white on a green background for easy visibility. Straub and Allen (48) give measurements of sign brightness with relation to position, distance and reflectorization.

Seeing involves dynamic factors not found in a camera and blurred photographs taken from a motor vehicle should not, in the writer's opinion, be used to explain vision (23) because the blur is controlled entirely by the photographer.

Danielson (13, 14) investigated the relationships of the fields of vision to safety in driving, summarizes much of the known information and adds a new measurement of his own. His results indicate that it is more important to see well in the central area than to have large areas of peripheral vision, because the peripheral vision is less useful. He was able to drive with greater comfort at high speeds when his peripheral visual fields were blocked out, but the corresponding experiment of blocking out the central fields of vision was a dangerous handicap. Danielson also discusses accidents and his recommendations deserve consideration and application.

Hopkinson (27) examined glare discomfort and pupil diameter. The pupil diameter is reported to be governed by the illumination received at the eye rather than relating directly to the discomfort sensation. More concentrated glare produced greater pupil contraction, and with intolerable glare the pupil contraction relaxes irregularly every few seconds. This instability may be an emotional reaction to the severe discomfort. At night driving luminances, the retina is not stimulated beyond its adapting ability, but the conditions producing dark adaptation are not compatible with a brief glare stimulus. The sensation of discomfort may be partly associated with opposing action of sphincter and dialator muscles due to contradictory indications from highly stimulated parts of the retina and areas of low stimulus (surround), or it may be of emotional origin. Such investigation should cast some light on the problem of successive glare in passing a number of cars.

Measurement of stray light by Boynton and his associates (12) in enucleated eyes shows a rapid falling off of the light as the glare angle increases; about 40 percent at one deg and 4 percent at two deg.

Psychiatric disorders can influence night vision. Granger (19-21) reports slightly lower thresholds for people in anxiety states, while hysterics dark adapt more slowly and their thresholds are significantly higher.

Swartout (49) has reviewed the general refractive problems of the aged and believes that for night driving increased glare sensitivity is the most serious disadvantage of age. Sheridan (45) thinks that the greatest gain in night driving vision would come if more elderly people could be convinced of the necessity of wearing their distance correction when driving.

McFarland and Fisher (33) report that dark adaptation is slower for ages 20 to 29 and 50 to 59 than for ages between these, or at greater ages. They note that "Serious questions of safety may be raised if the amount of available light is further reduced for older persons through the use of tinted windshields or colored glasses." Their measurements suggest that for each 13 years of age the light would need to be doubled to be seen just by the fully adapted eye. This is an important problem because, on the road, lighting cannot be so doubled and the older people are correspondingly handicapped. Guth (22) also has shown the need for increased illumination for equal seeing by older people. While his measurements were made at higher intensity levels than found in night driving, it is likely that the need will be at least as great for night driving vision.

According to Allen (2) the change in lens shape during accommodation is faster in youth than at maturity. Contraction of the lens is considerably slower than relaxation of the lens, but no relation was found between lens viscosity and a high accommodation-convergence accommodation ratio.

Commenting further on the glare from scratched goggles (mentioned above) Davey (11) states: "Ever since this experience I have been convinced that one of the primary reasons why a driver becomes slower with the years is that keenness of his eyesight diminishes and that, as a probable consequence of this, so does his judgment of distance."

The problems of driver licensing and re-examination have received further discussion. One set of recommendations was proposed at a symposium at New York University (5). Medical examinations are recommended and a number of medical conditions that should preclude a driving license are stated.

Porter (31) recommended that drivers be re-examined every five years to 80 and then yearly after age 80. A simple and comprehensive test chart is reported under development in New South Wales (46). The visibility measurements of Prince (40) should aid in obtaining better alphabets for charts and signs. The American Optometric Association's Driving Committee also recommends periodic re-examinations, a thorough visual examination for accident repeaters, more use of vision specialists as consultants to government, state, and other traffic boards, and that minimum standards be set up for acuity, glare resistance, adaptation to low luminance, distance judgment, width of field, and color vision (8, 24).

## REFERENCES


1. Aguilar, M., and Stiles, W. S., "Saturation of the Rod Mechanism of the Retina at High Levels of Stimulation." Optica Acta 1:59-65, (1954).
2. Allen, M. J., "The Influence of Age on the Speed of Accommodation." Am. J. Optom. 33:201-208, (1956).
3. Anapolle, L., "An Evaluation of Stereopsis Tests." Am. J. Optom. 34:310-319, (1957).
4. Anon., "Vision and Road Safety." Optician 133:523, (1957).
5. Anon. "Recommendations for Driver Licensing and Reexamination." Highway Res. Absts. 27(2):38, (1957).
6. Birren, F., "Safety on the Highway." Am. J. Ophth. 43:265-270, (1957).
7. Blythe, J. B., "Highway Lighting and Accidents in Indiana." HRB Bull. 146:1-7, (1957).
8. Bryan, W. E., "Research in Vision and Traffic Safety." J. Am. Optom. Assoc., 29:169-172, (1957).
9. Davey, J. B., "The Effect of Visual Acuity on Driving Ability." Brit. J. Physiol. Opt., 13:62-78, (1956).
10. ________ and Sheridan, M., "Levels of Dark Adaptation when Driving at Night." Brit. J. Physiol. Opt., 14:183-189, (1957).
11. ________ "Visual Acuity and Driving Ability." Optician 134:204, (1957).
12. DeMott, D. W., and Boynton, R. M., "Retinal Distribution of Entopic Stay Light." J. Opt. Soc. Am., 48:13-22, (1958).
13. Danielson, R. W., "The Relation of Fields of Vision to Safety in Driving." Tr. Am. Ophth. Soc. 54:369-416, (1957).
14. ________ "The Relationship of Fields of Vision to Safety in Driving." Am. J. Ophth., 44:657-680, (1957).
15. Ercoles, A. M., Fiorentini, A., and G. Toraldo di Francia, "Visual Experiments with a Vibrating Test Object." Optica Acta 3:40-46, (1956).
16. Ferguson, H. M., and Stevens, W. R., "Relative Brightness of Colored Light Sources." Tr. Illum. Eng. Soc., Lond. 21:227-247, (1956). From HRB Absts. 27(10):5 (1957).
17. Finch, D. M., "Some Factors Influencing the Night Visibility of Roadway Obstacles." IES Preprint No. 27. 11 pp. (1956). Abstract, Illum. Eng. 51:619, (1956).
18. Forbes, T. W., and Katz, M. S., "Summary of Human Engineering Research Data and Principles Related to Highway Design and Traffic Engineering Problems." Am. Inst. Res., Pittsburgh. Mimeogr. (1957).
19. Granger, G. W., "Dark Adaptation in Anxiety States and Hysterics." Brit. J. Physiol. Opt. 13:235-241, (1956).
20. ________ "Night Vision and Psychiatric Disorders." J. Ment. Sci. 103:48-79, (1957).
21. ________ "Effect of Psychiatric Disorder on Visual Thresholds." Science 125:500-501, (1957).
22. Guth, S. K., "Effects of Age on Visibility." Am. J. Optom. 34:463-477, (1957).
23. Harman, P., "Motorists' Vision: A Neglected Area in Research." Optician 134:13-15, (1957). From Opt. J. Review of June 15, 1957.
24. Hervey, W., "Vision for Driving." Optom. Weekly 48:1845-1847, (1957).
25. Hofstetter, H. W., Industrial Vision. Chilton Co., Philadelphia, 189 pp. (1956).
26. Hopkinson, R. G., "Light Energy and Brightness Sensation." Nature 178:1065-1066, (1956).
27. ________ "Glare Discomfort and Pupil Diameter." J. Opt. Soc. Am. 46:649-656, (1956).
28. Izard, A., and Jardillier, P., "Etudes sur un nouveau test de perception: le 'tachistoscope'." Arch. Mal. Profes. Par. 18:59-61 (1957).

29. Jayle, G. E., et al. "Importance du niveau intellectuel sur les seuils psycho-sensoriels en vision nocturne." Med. aeronaut. 10:247-254, (1955).

30. __________ et al. "Principes et resultats de l'exploration cinematographique de la vision nocturne." Bull. Soc. Fr. Ophth. 67:508-522, (1954).

31. __________ et al., "Exploration de la vision nocturne chez les daltonians." Med. aeronaut. 11:21-28, (1956).

32. Krauskopf, J., "The Effects of Retinal Image Motion on Contrast Thresholds." Rept. 221. Army Med. Res. Lab., Fort Knox, Ky. 33 pp. (1955).

33. McFarland, R. A., and Fisher, M. B., "Alterations of Dark Adaptation as a Function of Age." J. Geront. 10:424-428, (1955).

34. Mancini, P. S., "Traffic Engineering and Planning at a High Level in State Government." Traffic Quart. 10:564-574, (1956).

35. Nolan, G. F., "On the Functional Relation between Luminous Energy, Target Size, and Duration for Foveal Stimuli." J. Opt. Soc. Am. 47:394-397, (1957).

36. Oliva, J. and Aguilar, M., "Distribution des unites sensorielles dans l'extrafovea." Optica Acta 3:36-39, (1956).

37. Oliver, R. J., and A. R. Lauer. "Correlation of Speed and Distance Judgment with Visual Acuity." Am. J. Optom. 33:263-265, (1956).

38. Perdriel, G., Colin, J., and Brice, R. "Un nouvel appareil d'entrainement a la vision du nuit." Med. aeronaut. 10:507-512, (1955).

39. Porter, E. L. "The Case for Periodic Driver Re-examination on the Basis of Visual Acuity." N. E. J. Optom. 8(1):3-5, (1957).

40. Prince, J. H. "Experiments Related to the Need for More Than One Letter Style in Refraction and Screening Tests." Brit. J. Physiol. Opt. 13:98-101, (1956).

41. Rex, C. H. "Principles and Figures of Merit for Roadway Lighting as an Aid to Night Motor Vehicle Transportation." HRB Bull. 146:67-82, (1957).

42. Richards, O. W. "Vision at Levels of Night Road Illumination II." HRB Bull. 146:58-66, (1957).

43. Sachsenweger, R. "Stereoscopic Acuity in Twilight." Optician 131:475-481, (1956) Cond. from Arch. Ophth. 155:496-517, (1954).

44. Savin, L. H., Weston, H. C., and Grime, G. "Discussion on the Visual Problems of Night Driving." Proc. Roy. Soc. Med. 50:173-184, (1957).

45. Sheridan, M. "Road Accidents 1955: Some Ophthalmic Implications." Optician 132:419-422, (1956).

46. Simon, V. C. "The Visual Component in Road Safety." Optician 133:590, (1957).

47. Stevens, S. S. "On the Psychophysical Law." Psych. Rev. 64:153-181, (1957).

48. Straub, A. L., and Allen, T. M. "Sign Brightness in Relation to Position, Distance and Reflectorization." HRB Bull. 146:13-44, (1957).

49. Swartwout, J. B. "Refractive Problems of the Aged." Canad. J. Optom. 19(1): 14-17, (1956).

50. Wyatt, F. D., and Lozano, E. "Effect of Street Lighting on Night Traffic Accident Rate." HRB Bull. 146:51-55, (1957).

# Comparison of Driver Behavior on Lighted and Unlighted Highways[1]

O. K. NORMANN, Deputy Assistant Commissioner for Research,
Bureau of Public Roads

● DURING the fall of 1957 the Bureau of Public Roads in cooperation with the Illinois and Michigan State Highway Departments, the Cook County and Wayne County Highway Departments, and the city of Detroit, Department of Streets and Traffic, conducted driver behavior studies at a number of locations on freeways in the Chicago and Detroit areas. Some of these were lighted and others unlighted. Driver behavior at night on the lighted and unlighted sections will be compared with the daytime behavior. It will be several months before the results of these studies are available.

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[1] Abstract of an informal discussion of studies recently initiated by the Bureau of Public Roads.

# Lighting the Connecticut Turnpike[1]

ERNEST T. PERKINS, Assistant Chief Engineer,
Connecticut State Highway Department

● THE frequency of interchanges, service areas and barrier toll stations on the westerly 54 miles of the Connecticut Turnpike, together with high volumes of mixed traffic, indicated the need for continuous highway illumination. Forty-seven miles of mercury vapor and 7 miles of fluorescent lighting will be used. East of Branford, lighting will be provided only for toll plazas, approaches to service areas and selected interchanges.

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[1] An abstract of the informal paper presented at the 37th Annual Meeting, HRB.

# Field Test of Roadway Lighting[1]

EDMUND R. RICKER, Traffic Engineer,
New Jersey Turnpike Authority

●THE NEW JERSEY Turnpike Authority has followed with great interest the research performed on fog lighting at Pennsylvania State University and the University of Michigan, the results of which have been described by other speakers. Following the demonstration of the practical results of this research at Boalsburg, Pennsylvania, last summer, the Authority initiated the installation of a half-mile test section of this type of lighting on the Turnpike in one of the most serious fog areas. After numerous delays a contract was awarded and the work is now nearing completion.

The principal installation on the Turnpike consists of about two thousand feet of overhead mounted spot lights aimed so as to project the beam nearly vertically and at right angles to the driver's line of sight. The lamps used are 300 watt PAR 56 aimed so as to cover the inner lane of the roadway next to the median. On the northbound lane the beam pattern is 20 deg transverse to the roadway and 15 deg along the roadway; the southbound lane beam pattern is 20 deg transverse to the roadway and 35 deg along it. The lamps are suspended at 15 ft intervals along a catenary system attached to wooden poles and mounted 26 ft above the pavement surface.

The second part of the installation consists of about 500 ft of low mounted fluorescent units. VHO type lamps are used with a parabolic reflector mounted so that light is projected horizontally and below the level of the driver's eyes. The units are aimed alternately at the northbound and southbound lanes at intervals of about 20 ft. The entire installation is protected by guardrail.

When the installation of these units is completed, tests will be conducted in conjunction with the Civil Aeronautics Administration to determine if there is possible adverse affects on the approach lighting system for the Newark Airport, which lies immediately adjacent. If these tests are successful, additional tests will be conducted under low visibility conditions. The entire project is being coordinated with the Illuminating Engineering Society and the representatives of the colleges who performed the basic research. Power supply and switching arrangements are made as flexible as possible to test different light patterns and to allow the installation of other types of lighting fixtures which may seem worthy of investigation.

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[1] Summary of Remarks before Night Visibility Committee, Highway Research Board.

HRB:OR-186

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Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.