# PUPILLARY RESPONSE VISIBILITY METER: FUNCTION, OPERATION AND APPLICATION

by

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Approved by:

Corwin A Bennett
Major Professor

To

My beloved family and loved ones

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# INTRODUCTION

Ability to see objects through the atmosphere, underwater or in space is limited by the availability of light, its distribution on the object of regard and its background, the reflective properties of the object of regard and its background, the transmission characteristics of the intervening media, the properties of any magnifying or filtering optical devices employed and the characteristics of the human visual system (Duntley, Gordon, Taylor, White, Boileau, Tyler, Austin and Harris, 1964).

For many years researchers have striven to find answers to several questions relating to the characteristics of visual systems, questions like: Can some particular object be seen? How far can it seen? How rapidly can it move and yet be visible? How dim can the illumination become before the object is lost to view? Is magnification necessary to make the object visible? What is the optimum procedure for visual search? What is the probability of success in sighting an object searched for? Under what circumstances can it be recognized? Is identification possible? How is visual performance affected by fatigue, discomfort, distraction, apprehension, motivation, etc..? This field of research was referred to as visibilty research and regarded as a professional speciality within optics (Duntley, et al., 1964).

There have been several interpretations of the word "visibility" and a general lack of consensus regarding its definition was the result (Bennett, 1931; Cottrell, 1951). It is, therefore, necessary to explain the use of the term visibility. In this research visibility will be used to denote the human capability to detect, recognize and identify objects by means of the human visual mechanism. Thus at different levels of visual performance, an object may be detected as a shapeless

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spot, recognized as an alphabet i.e. character, and, finally, identified as the letter "a". Another definition of visibility was expressed by Cottrell (1951). In his paper the term visibility was used to refer to that special quality of a seeing task which depended on a combination of the brightness contrast, the subtended angular size of the detail, the brightness of the background and the time of observation. If any one of the above factors were varied the visibility of the task would also be varied. Hence, visibility was frequently specified by determining the threshold of one or more of the factors mentioned and expressing the index of visibility as the reciprocal of the threshold; or to set up an arbitrary scale of visibilities based on a selected reference task considered to be at "unit visibility".

Feree and Rand (1931) pointed out that the three most important physical factors in the visibility of objects are size of visual angle of the detail to be discriminated, difference in co-efficients of reflection between the object of regard and background (contrast) and the intensity of illumination. Their findings could be summarized as follows: a) With a given co-efficient of reflection the visual or sensation difference is greater in the case of light objects on dark backgrounds than it is in the case of dark objects on light backgrounds, b) the sensation differences increase rapidly with increase of intensity of illumination, and c) the increase in sensation with increased illumination is more rapid for white objects on black backgrounds or light objects on dark backgrounds than it is for dark objects (black) on light (white) backgrounds. In their study, Feree and Rand rated visibility in terms of the visual angle subtended by the object at the eye and measured visibility by speed of vision (needed to see the object). They found that visibility as measured by speed of vision varies greatly with intensity of illumination and with relation of object to background and that visibilities as measured by speed are, in general, greater than visibilities rated in terms of visual angle. Table 1 illustrates a part of their findings. The first column gives the increase of one disc over the former in terms of the visual angle. Thus 2 and 1 would mean that the second disc presented to the observer was twice the size of the first. The second column is the ratio of the two discs and is the visibility rated in terms of the visual angle. Thus for a increase of visual angle 2 and 1 the ratio would be 2.0 and this is the visibility rated in terms of the increase in visual angle. The third column presents the ratio of the speeds of vision needed to see the discs under different levels of illumination.

An object is said to be visible if it is at a particular threshold of detection, recognition and identification. The object being viewed is said to be above threshold of visibility if its details can be easily recognized. The threshold value is that value of either luminance, speed or visual angle when the object being viewed is just visible. The "above thresholdness" of the object of interest is frequently referred to as "suprathresholdness". This suprathresholdness of an object has been used as an index of visibility.

The object being viewed will be called a "display". If a display is produced by an electronic imaging system such as a cathode ray computing terminal it will be called a "information display". The whole visual system will be referred to as "information transfer in a display-to observer system" (Clauer and Bates, 1970).

Generally, a display is above the observer's threshold and it is desirable to measure the display's visibility in terms of how much it is above threshold. Apart from the measure of visibility (recognition) of an object, a measure of the quality of an information display is required, particularly for displays produced by electronic imaging systems (Clauer and Bates, 1970).

Table 1

Visibility as Rated in Terms of Visual Angle and Measured by Speed of Vision (Feree and Rand, 1931)

| Visual angle in mins of arc | Ratio of visibility: visual angle scale | Ratio of visibility as measured by speed of vision Foot-candles of illumination | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1.25 | 2.5 | 5.0 | 7.5 | 10.0 | 15.0 | 20.0 | 30.0 |
| 2 and 1 | 2.0 | 5.27 | 4.55 | 5.00 | 5.58 | 5.90 | 5.63 | 5.20 | 4.60 |
| 4 and 2 | 2.0 | 2.55 | 2.78 | 2.30 | 2.04 | 1.82 | 1.57 | 1.51 | 1.49 |
| 2 and 1 | 2.0 | 5.27 | 4.55 | 5.00 | 5.58 | 5.90 | 5.63 | 5.20 | 4.60 |
| 3 and 2 | 1.5 | 1.77 | 1.87 | 1.73 | 1.52 | 1.40 | 1.26 | 1.24 | 1.23 |
| 4 and 3 | 1.33 | 1.44 | 1.43 | 1.34 | 1.34 | 1.29 | 1.24 | 1.22 | 1.21 |
| 5 and 4 | 1.25 | 1.33 | 1.29 | 1.26 | 1.25 | 1.22 | 1.21 | 1.20 | 1.20 |
| 2 and 1 | 2.0 | 5.27 | 4.55 | 5.0 | 5.58 | 5.90 | 5.63 | 5.20 | 4.60 |
| 3 and 1 | 3.0 | 9.30 | 8.50 | 8.65 | 8.45 | 8.27 | 7.13 | 6.40 | 5.65 |
| 4 and 1 | 4.0 | 13.40 | 12.10 | 11.50 | 11.70 | 10.70 | 8.84 | 7.83 | 6.90 |
| 5 and 1 | 5.0 | 17.80 | 15.70 | 14.50 | 14.20 | 13.00 | 10.70 | 9.40 | 8.20 |
| 3 and 2 | 1.50 | 1.77 | 1.87 | 1.73 | 1.52 | 1.40 | 1.26 | 1.24 | 1.23 |
| 4 and 2 | 2.0 | 2.55 | 2.60 | 2.30 | 2.04 | 1.82 | 1.57 | 1.51 | 1.49 |
| 5 and 2 | 2.50 | 3.38 | 3.46 | 2.90 | 2.55 | 2.20 | 1.90 | 1.82 | 1.79 |
| 4 and 3 | 1.33 | 1.44 | 1.43 | 1.34 | 1.34 | 1.29 | 1.24 | 1.22 | 1.21 |
| 5 and 3 | 1.67 | 1.91 | 1.84 | 1.68 | 1.68 | 1.58 | 1.50 | 1.48 | 1.46 |

The optical signal which reaches the observer's eyes after modification by the optics of the environment constitutes the raw material of visual discrimination. The visual performance capabilities of the observer will govern whether the available signal provides an adequate basis for the discrimination of interest (Duntley, et. al., 1964). A measure of this signal for an adequate basis for discrimination is desirable to measure the threshold of visibility.

This research describes a device built to measure visibility of electronic imaging displays such as CRTs'. Several instruments were devised to measure suprathresholdness of information, allowing the reduction of visibility to threshold and using a measure of this reduction as a measure of suprathresholdness. Principles of reduction such as contrast reduction, brightness reduction, total reduction and partial reduction were used. A brief discussion of each of these devices follows most of which are unavailable now.

Visibility Meters

Jones' Visibility Meter (Jones, 1920)

As early as 1918 Lyod A. Jones described a visibility meter which was used primarily to evaluate the visibilities of ships at sea and to check the adequateness of their camouflage as a protective measure from German submarines during WW1. Figure 1 illustrates the principle of operation of this visibility meter.

The meter consists of a veiling brightness source which could be moved either farther away or nearer the optical axis thereby decreasing or increasing the brightness of the diffusing glass. A partial mirror in the principle optical path transmits part of the light (incident flux) from the object being viewed and reflects part of the light from the veiling glare source. A neutral non-diffusing optical wedge was arranged to move across the path of the incident flux and linked to the veiling source so that the wedge was moved into the path (increasing reflectance) of the

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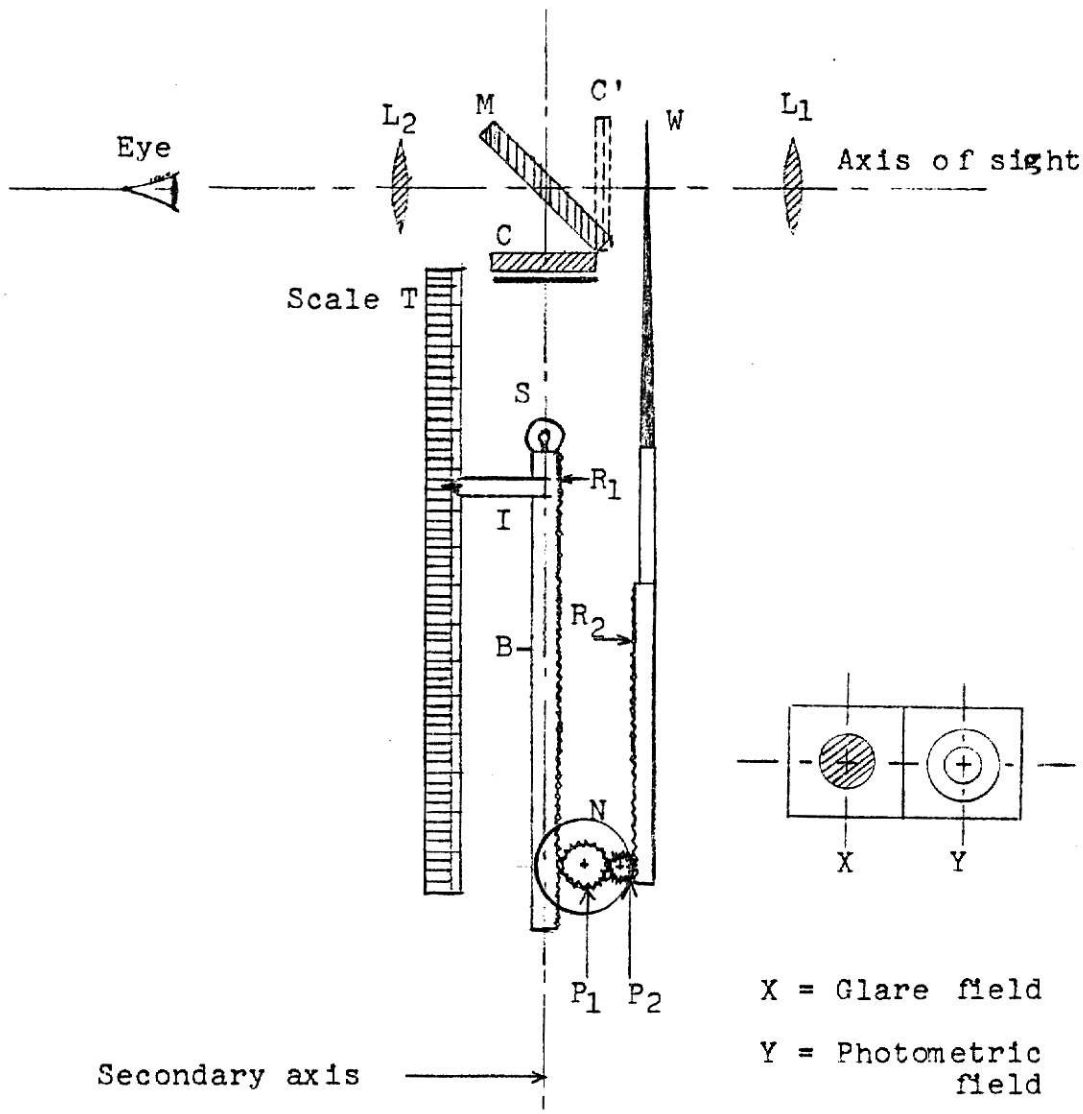



Figure 1. Diagrammatic illustration of Jones' visibility meter (Jones, 1920).

incident flux when the source moved nearer to the diffusing glass. In this manner the veiling luminance was increased while the object or incident flux was decreased. This principle would reduce the change in contrast between the veiling source and the background of the object.

The scale "T" (Figure 1) was calibrated to read the transmittance of the wedge and brightness of the veiling source. Visibility was expressed by the relation

$$V_b = \frac{B_v}{B_1}$$

where $B_v$ is the brightness of the veiling source which when superimposed over the background of the object and the object would reduce the contrast to threshold and $B_1$ is the brightness of the background.

<u>Bennett's Visibility Meter</u> (Bennett, 1931)

In 1931. M.G. Bennett reported a visibility meter designed for use in meteorology and illuminating engineering. This device consisted of twenty one obscuring glass lenses (discs) of equal obscuring power. These discs could be brought into the field of view one at a time until the object being viewed was completely obscured. The visibility of the object was expressed in terms of the distance and the number of obscuring glass discs used. If a tree was the object and was being viewed at a distance of 100 feet, and 14 glass discs were used to obscure the tree from the field of view, the visibility would be expressed as 14, at a distance of 100 feet.

<u>Luckiesh and Moss Visibility Meter</u> (Luckiesh and Moss, 1935)

The Luckiesh and Moss visibility meter is illustrated in Figure 2. The meter essentially consists of two colorless photographic filters with precise circular gradients of density which may be rotated simultaneously by means of a rack and pinion arrangement. The gradient filters reduce the apparant brightness of the visual field due to the absorption and lower the contrast between the object of regard and its background

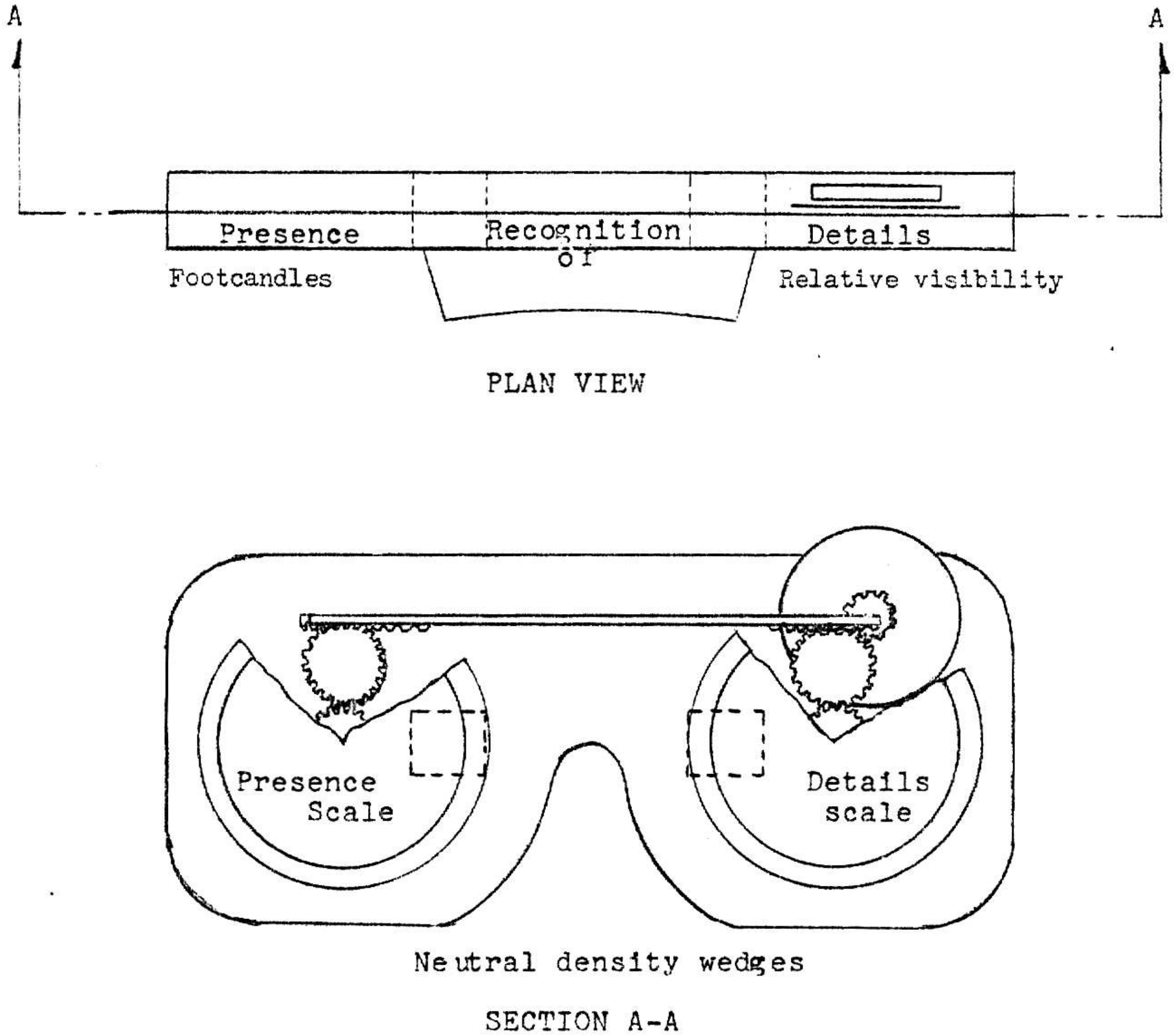



Figure 2. Diagrammatic illustration of the Luckiesh-Moss visibility meter (Finch and Palmer, 1955).

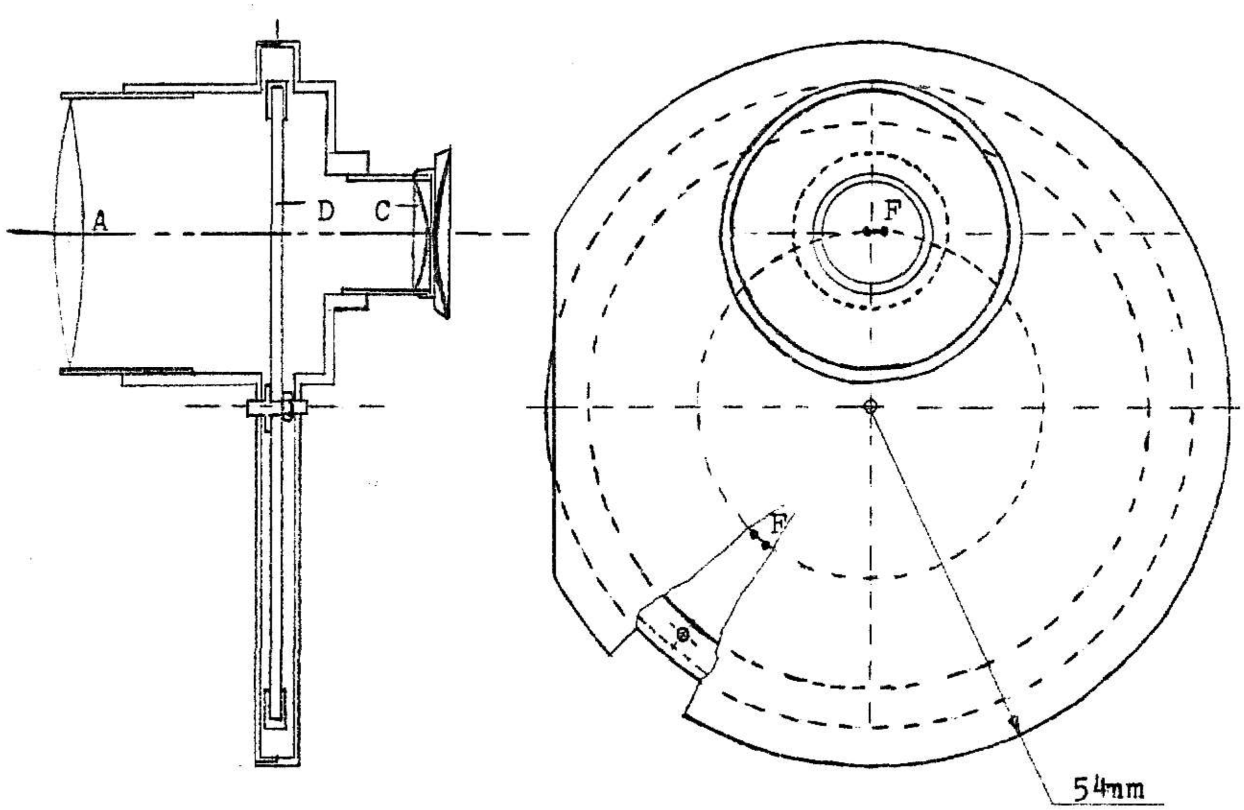
due to the diffusing characteristics of the filter. Rotation of the discs reduce the brightness of the object and background to threshold conditions by scattering the light from the more bright areas to the less bright areas.

A calibration scale on the scale of relative visibility is in terms of a pair of black parallel bars separated by their width, viewed against a uniformly bright white background. The reduction of visibility to threshold conditions by this meter employs the use of a reduction in the brightness difference, the contrast and the visual acuity of the object. The whole field of view is reduced in brightness level and fogged until the predetermined degree in difficulty of seeing is achieved. The setting gives the visibility in terms of the relative visibility.

Although extensively used and studied, questions were raised regarding the effect of the progressive change in apparant brightness of the task as seen through the filters, on the adaptation of the eye (Cottrell, 1951).

Phillips Visibility Meter (Finch and Simmons, 1953)

The Phillips Visibility meter was reported by Bouma and Host in 1936 and was the first instrument to be designed specifically for street and highway lighting use. Figure 3 illustrates the instrument which consists of 1:1 magnification system and a large disc upon which a series of 50 dots are placed on a circle. The dots are rotated so that they are seen successively in the same position in the center of the optical path and projected upon the roadway but with different transmittance (Finch and Palmer, 1957). The instrument is aimed at the spot to be tested and the disc is rotated until a black spot is selected which permits the target to be just perceptible against its background. The transmittance of the spot is used as a measure of relative visibility. The eye maintains a constant adaptation. The meter measures the brightness difference threshold.




A = Objective F = Spots

C = Lens D = Disc

Figure 3. Diagrammatic illustration of the Phillips visibility meter (Finch and Palmer, 1957).

Duckler Visibility Meter

In 1939 a visibility meter was described in a French periodical and was called the "Duckler Visibility Meter". This instrument is similar to the Luckiesh-Moss visibility meter except that a series of variable density glass discs are used (Finch and Simmons, 1953; Finch and Palmer, 1957). Threshold is determined when the object observed is no longer seen through a glass disc of slated absorptive power. The instrument is a brightness difference threshold meter and eliminates the influence of glare.

Annular Ring Visibility Meter ( Finch and Simmons, 1953)

The "Annular Ring Visibility Meter" was first reported in 1940. It consists of a series of paper rings having external and internal diameters of 0.8 and 0.2 inches respectively, placed side by side on a glass plate which can be mounted on a windshield of a car. The rings are lit by an adjustable incandescent source. The visibility of the road surface is observed by selecting the rings which most closely match the lighted road surface.

The Street Lighting Evaluator (Finch and Simmons, 1953)

Used primarily to evaluate visibility on road surfaces, the instrument consists of three parts: A miniature pavement bed mounted over the hood of the car; a glare integrator mounted over the windshield; and a control box in the operator's compartment. The pavement bed is fitted with a piece of simulated pavement, which by inspection, is matched to the street texture. Miniature pedestrains or obstacles are positioned on the pavement. Brightness and Luckiesh-Moss visibility readings are made on the pavement strip and obstacle. The readings are entered on a nomograph.

Basically, the three measurements made are (1) The brightness of the pavement, (2) The brightness of the representative obstacle on or near the pavement in question and (3) the glare effect from sources in the field of view. These three readings are integrated into one overall value of relative visibility which can be read off the nomograph.

Horton's Visibility Meter (Finch and Palmer, 1957)

This visibility meter is very similar to the Phillips Visibility Meter and works on the brightness-difference threshold principle. It consists of a lens system (Figure 4) with a 1:1 magnification and a transparant disc in the focal plane of the eyepeice. A series of transparant circular dots of varying transmittance are arranged around the periphery of the disc and are made such that the dots would obscure objects at approximately 200 feet ahead of the observer. The disc is rotated until the difference between the object brightness and its background brightness is below the brightness difference threshold.

Cottrell Visibility Meter (Cottrell, 1951)

Figure 5 is a schematic drawing of this contrast - brightness threshold meter. The device consists of a light source which is superimposed on the optical path by a system of mirrors and lenses. A variable polaroid filter controls the brightness of this veiling luminance. A circular neutral gradient filter is placed in the optical path and the brightness of the object is varied as the transmittance of the neutral gradient. When the transmission is 1.0 (maximum) the brightness of the total field is the brightness of the veiling glare source plus the brightness of the actual field. The equipment is adjusted so that the brightness of the veiling glare source is equal to that of the actual field. Therefore, under these conditions the total brightness is twice the brightness of the background. When the gradient is rotated until the transmission is a minimum (0.0) the brightness of the veiling luminance is equal to the brightness of the background.

For a visibility measurement the circular neutral gradient is rotated until the object in question is at the threshold state under the particular conditions of viewing described above. The veiling brightness is

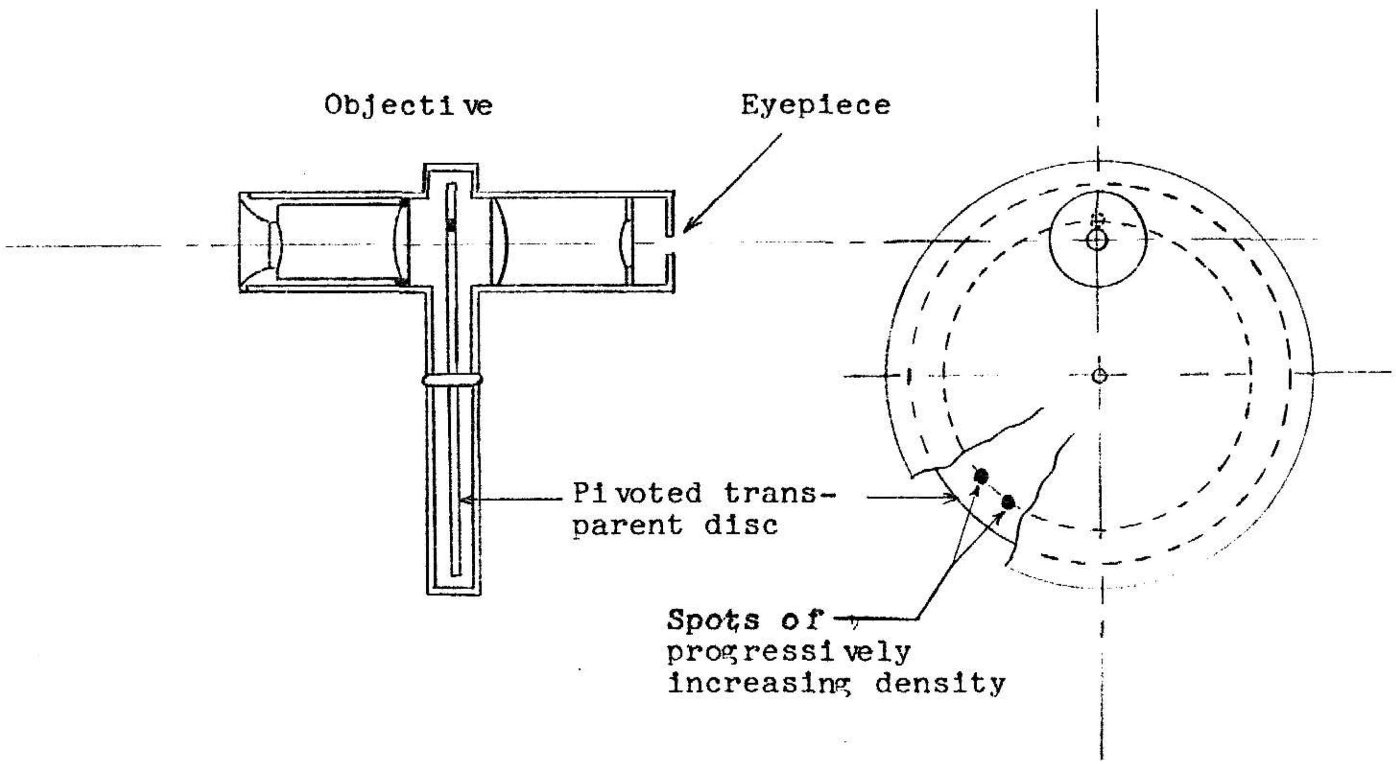



Figure 4. Diagrammatic illustration of the Horton's visibility meter (Finch and Palmer, 1957).

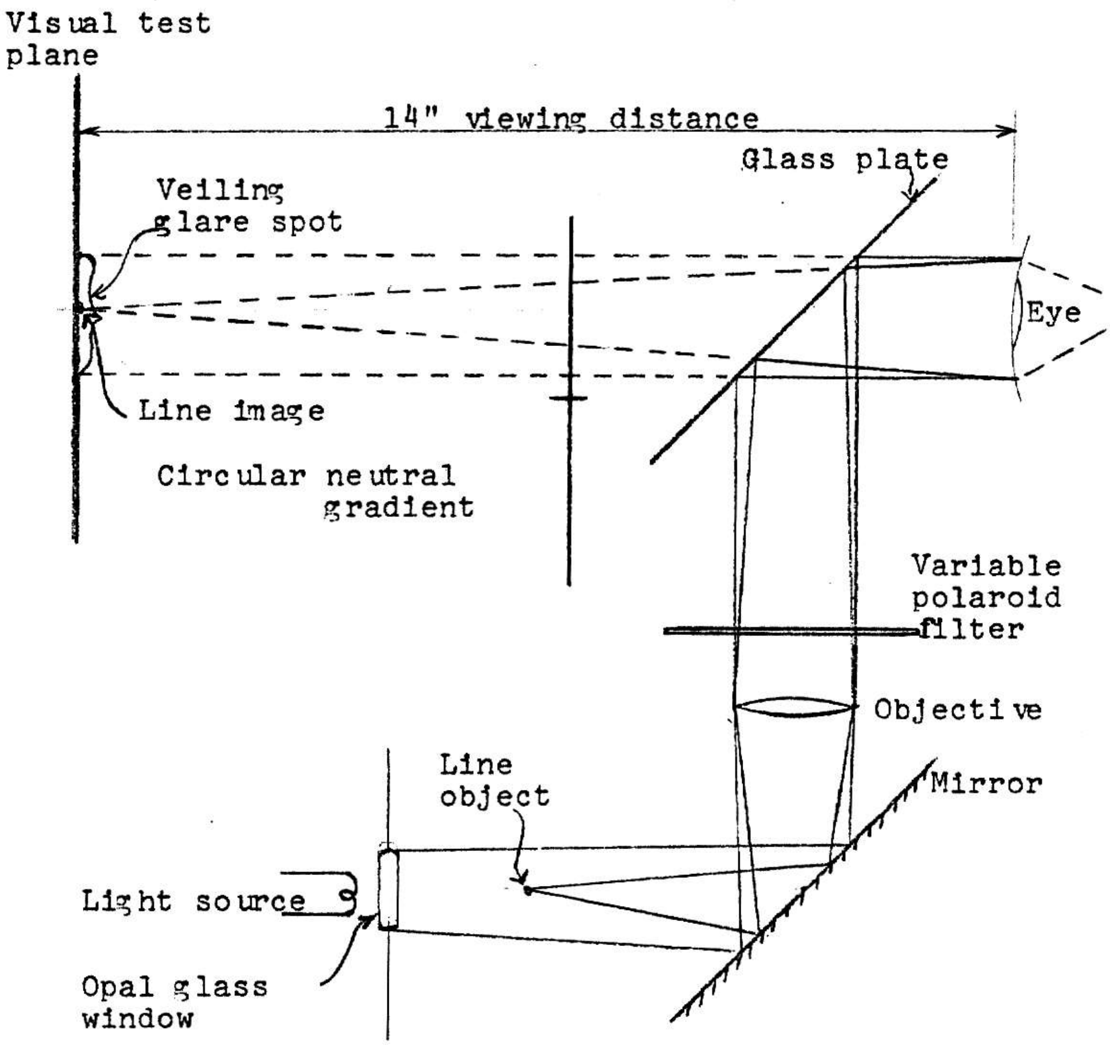



Figure 5. Diagrammatic sketch of the contrast-brightness threshold meter (Cottrell, 1951).

adjusted until it is equal to the background at maximum transmittance and the circular gradient filter is then turned until the target detail is just percieved. Visibility of the target is expressed in terms of the contrast threshold and inherent contrast of the object against its background.

*Finch and Simmons Visibility Meter*

In 1953, two researchers, D.M. Finch and A.E. Simmons, of the University of California reported a visbility meter designed specially to measure visibility at night on highways ( Finch and Simmons, 1953). Figure 6 is a schematic drawing of the contrast threshold meter meant to measure visibility without much of subjective appraisal.

In this instrument the eye adaptation is kept constant, only a small central area (3°-5° in total visual angle) would be changed in making a measurement and the total visual field was approximately symmetrical and included sixty degrees total visual angle.

The optical system consisted of an upper and lower monocular optical system. The upper monocular system consisted of an objective lens and an image erecting lens. The field of view as seen through the eyepiece shows in an outer annular ring. The central portion of the view is seen by the lower monocular system and has superimposed on it a veiling brightness source. The double neutral wedge reduces the central portion of the scene to contrast threshold by the dual action of the reduced brightness of the scene and the added brightness of the veiling source. The principal visual field is unaffected.

In operation the wedge is adjusted for full visibility of the scene and focussed. The wedge is now adjusted for full visibility of the veiling brightness source. This source is adjusted to match the brightness of the surround as viewed in the upper monocular system. The wedge is then rotated till the central portion is at threshold. Visibility is measured