PHOTOMETRIC TESTS *for* REFLECTIVE MATERIALS

MICHIGAN
STATE HIGHWAY DEPARTMENT

CHARLES M. ZIEGLER
STATE HIGHWAY COMMISSIONER

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Charles M. Ziegler
State Highway Commissioner

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By

B. W. Pocock
C. C. Rhodes

Research Laboratory
Testing and Research Division
Report No. 142
December 10, 1949

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SYNOPSIS

Photometric tests developed and now in use by the Michigan State Highway Department for reflectivity measurements and color determinations on reflex reflectors and diffuse reflecting materials are described. Detailed accounts of equipment and procedures used in both tests are accompanied by examples of data obtained and methods of computation.

Some fundamental physical concepts and the significance of measurements are discussed briefly, and several useful and interesting applications of the data are pointed out.

Included also are photographs illustrating the apparatus now in use by the Department.

PHOTOMETRIC TESTS FOR REFLECTIVE MATERIALS

The rapidly increasing number of applications of reflex reflecting materials to the field of highway engineering has stimulated a growing interest among road builders in the development of a sound yet practical test whereby the optical performance of these materials may be estimated.

Akin to knowledge of their optical performance, which usually refers to the ability of these materials to function adequately as reflectors under service conditons, there has arisen a growing awareness of the importance which the color of the reflected light is beginning to assume.

Recognizing the need for quantitative tests of reflectivity and color for this class of materials, the Michigan State Highway Department in July, 1948, initiated the development of such tests. A few months later the work assumed added importance because of the necessity of preparing specifications to cover reflective materials and signs of all types for a statewide Federal-Aid re-signing program. Specifications incorporating these tests have been completed and in force for almost a year and have proved adequate thus far. Revisions will be made from time to time as the need for them arises.

It is with the hope of furthering the development and general adoption of uniform specifications governing the production, purchase and use of reflective materials that the present paper on the Michigan State Highway Department reflectivity and color tests is presented.

The paper contains a description of the equipment and procedures for the reflectivity and color tests. Examples of data and methods of computation are also included. The significance of optical measurements employed in both tests is discussed and some useful applications of the data are pointed out.

REFECTIVITY TEST

The Michigan State Highway Department reflectivity test was developed for the purpose of measuring the reflectivities of all reflex reflecting materials normally coming within the scope of the Department. Such materials include plastic and glass reflector buttons, both colorless and colored; reflective sheet materials of all colors; prefabricated traffic marking signs; and laboratory specimens of beads on traffic marking paint, both white and yellow.

At the outset, several attempts were made at the Research Laboratory of the Department to secure satisfactory results by the use of relatively simple visual comparison methods. Optical wedges were tried out, and formulas were developed for their production and use. The Luckiesh-Moss extinction meter was studied in the hope that it might be adapted to the measurement of differences between reflectors. None of these attempts proved satisfactory.

Apparatus used by one manufacturer of reflector buttons for production control proved to be of value for subjective tests but obviously required the availability of a standard. Even when a standard was provided, however, no two operators agreed as to whether a sample was brighter or dimmer than the standard as the two approached each other in brightness, and if so, by how much.

Rotating disks of Polaroid were calibrated to extinction, yet no two people were in agreement as to when the same reflector was extinguished.

One well-known available commercial machine for testing reflector buttons was studied, but its use was vetoed on the ground that sufficient purity of divergence angles was not provided. As a last resort, the Department decided to assemble its own equipment.

Definitions of Terms and Significance of Measurements

Reflex Reflector, Retroreflector, and Retrodirective Reflector are all terms applied to reflective materials that have the property of returning light into the immediate neighborhood of its source regardless of the position of that source. To avoid confusion, a single term should be adopted in referring to this class of materials. In this paper the term reflector is used interchangeably with the longer forms.

Specific Intensity is the unit of reflectivity and is defined as the apparent candlepower of the reflector, per foot-candle of illumination falling on it, per unit area of reflecting surface. In the case of cube-corner reflectors, unit area of reflector surface is the square inch. For sheet material, signs, and beads on paint, unit area is the square foot.

Apparent Candlepower of a reflector is its luminous intensity expressed as the equivalent intensity of a point source producing an equal illumination at the same distance. Mathematically, it is the product of the illumination, in foot-candles, returned by the reflector to the point of measurement, and the square of the distance from that point to the reflector, in feet.

Angle of Incidence or Entrance Angle is the angle between the direction at which light strikes the reflecting surface and a normal to the surface at that point. In locations where cube-corner reflectors are ordinarily used, the most important range of incidence angles is from 0 to 10 degrees, which represents straightaway vehicle distances from the reflector all the way from infinity down to less than 100 feet. Entrance angles corresponding to various distances from car to reflector are listed in Table 1.

Reflectors of lower brightness than the cube-corner type are intended for use at shorter ranges of visibility and the optical characteristics of these and the so-called "wide-angle" sheet materials must be evaluated over a greater range of entrance angles.

Divergence Angle is the angle between the direction at which incident light strikes the reflecting surface and the direction from which the reflected light is seen or measured.

The pattern of the reflected light is a very important characteristic of reflex reflectors. High intensity of reflected light is achieved through the ability of the reflector to return the light incident upon it within a comparatively narrow cone around the axis of the incident beam. The greater the spread of the return beam, the shorter the effective perception distance becomes. For long range reflectors, most of the reflected light must be conserved within a cone whose half-angle (divergence angle) is not more than 1/3 degree. Assuming an average distance of 21 inches between the eye of the vehicle operator and his headlamps, a divergence angle of 1/3 degree corresponds to a car distance of about 300 feet. Values of divergence angles for various car distances are also given in Table 1. Average heights of the driver's eyes above his headlamps for three different types of vehicle are shown in Table 2.

Owing to the determinative nature of the divergence angle characteristic, any photometric test for the evaluation of reflex reflectors must be sufficiently selective with regard to divergence angle that

TABLE 1

DELINEATOR ANGLES AND DISTANCES
For Passenger Car in Right-Hand Lane,
Delineator on Right Shoulder

Car Distance, Ft.	Sight Distance, Ft.	Entrance Angle, Deg.	Divergence Angle, Deg.
12.5	21.1	53.67	4.74
25.0	30.2	34.22	3.32
50.0	52.8	18.78	1.90
75.0	77.0	12.78	1.31
100.0	101.8	9.65	0.99
150.0	151.0	6.47	0.67
200.0	200.7	4.86	0.50
300.0	300.4	3.25	0.34
400.0	400.2	2.43	0.25
500.0	500.1	1.95	0.20
600.0	600.0	1.62	0.17
700.0	700.0	1.39	0.14
800.0	800.0	1.22	0.13
900.0	900.0	1.08	0.11
1000.0	1000.0	0.97	0.10
1100.0	1100.0	0.89	0.09
1200.0	1200.0	0.81	0.08
1300.0	1300.0	0.75	0.08
1400.0	1400.0	0.70	0.07
1500.0	1500.0	0.65	0.07

TABLE 2

HEIGHT OF DRIVER'S EYES
ABOVE CENTERS OF HEADLAMPS

Type of Vehicle	Ave. Height, Inches*
30 Passenger Cars	23.38
8 Busses	38.03
6 Trucks	37.00

* Based on average of 35 men and 21 women

measurements at different divergence angles may be made without excessive overlapping. In conformity with this requirement, the sum of the angles subtended by the light source aperture and receiving photocell face should not exceed 1/2 degree, and preferably should be kept under 1/3 degree. For the same reason, geometric limitations imposed by the dimensions of suitable light sources and photocells ordinarily available make it necessary in most cases to use a distance of at least 50 feet between light source and reflector.

Orientation Angle is the angle, with reference to a given position, to which the reflecting surface is rotated about a central axis normal to that surface.

When measurements are made with a single photocell, reflectors of the cube-corner type exhibit more or less regular alternations of maximum and minimum intensity when rotated around their optical axes. In testing these materials, either the orientation of the reflector should be specified, or enough determinations should be made at random orientations to obtain a reasonably representative average. The latter method is preferable.

The optical performance of bead-reflectorized surfaces is not appreciably affected by variations in orientation.

Apparatus

Equipment for the reflectivity test, shown in Figures 1 through 4, consists of a goniometer for supporting the specimen, a bank of lights for illuminating it, and a photoelectric cell and accessories for measuring the light reflected. Incident light is measured by a separate foot-candle meter.

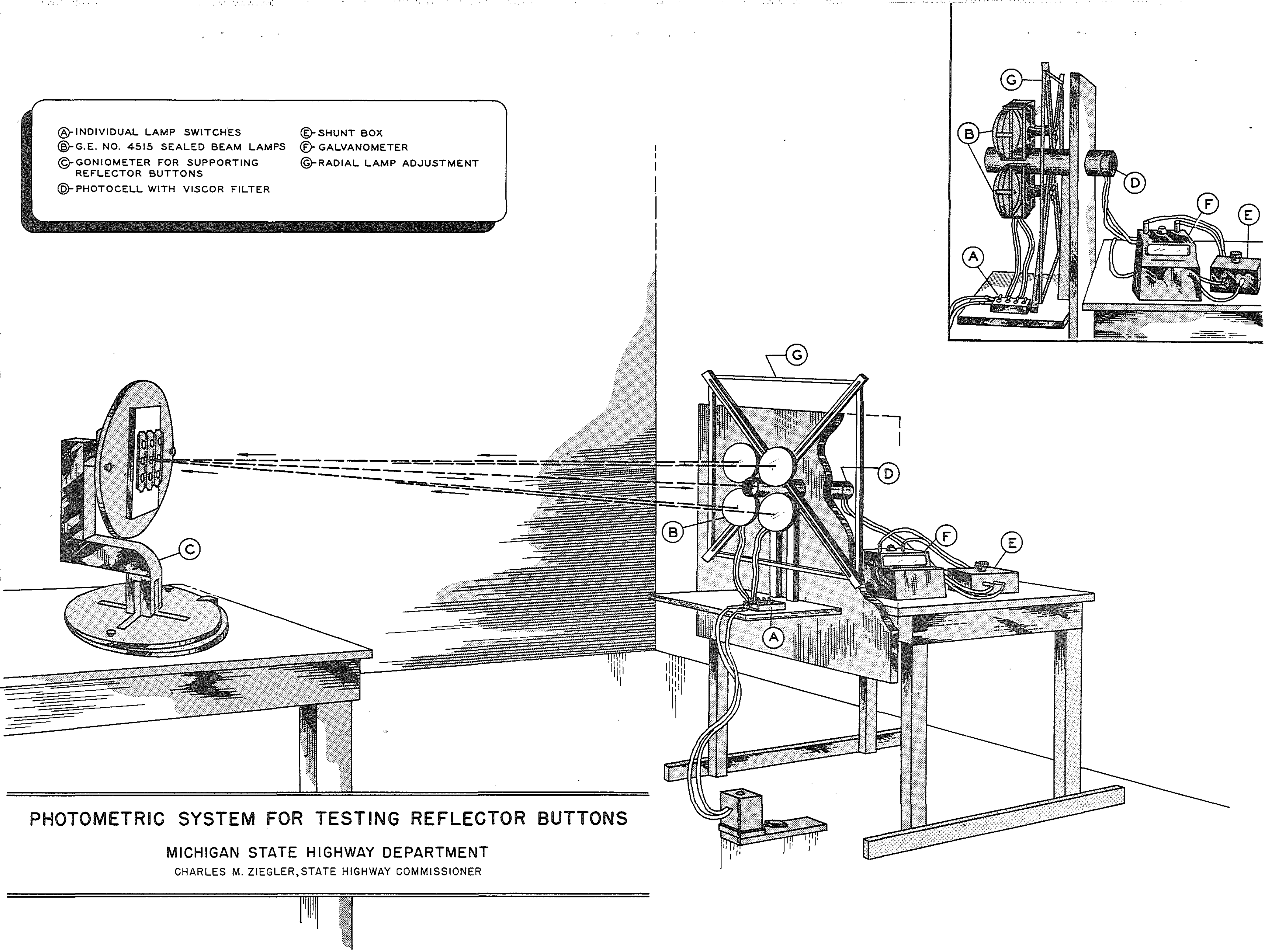
Left and right angles of incidence are established by turning the goniometer on its base, which is calibrated in degrees, to the proper angle as specified in the test procedure. For routine testing of reflector buttons, angles of 0, 10, 20, and 30 degrees are commonly used. In cases where wide-angle sheet materials are being tested it is necessary to include, in addition to these, angles of 40 and 50 degrees. For reflectorized traffic marking paints, very large angles of incidence are desirable, as these are utilized in actual practice.

Angle of orientation is established by rotating the face of the goniometer about its horizontal axis (optical axis), and is capable of adjustment to any value up to 360 degrees. Provision is also made in the goniometer design for elevation and depression of the normal as much as 15 degrees above or below the optical axis of the light source.

As shown in the illustrations, the light source consists of a bank of four equally spaced G.E. No. 4515 sealed beam lamps arranged in a group around a metal tube extending through the center of the cluster. Each lamp is supported in such a manner that it may be turned in any direction, as well as displaced laterally toward or away from the axis of the metal tube. Angle of divergence is controlled by radial displacement of the lamps from the tube.

Routine testing in Michigan currently requires an angle of divergence of 1/3 degree, which is attained by establishing a radial distance of 3-1/2 inches between the center of the tube and the center of each lamp, the distance from the reflecting surface to the surface of the receptor photocell being exactly 50 ft.

The receptor photocell is clamped tightly against the rear end of the metal tube. The cell is a Weston Photronic Cell (barrier layer



PHOTOMETRIC SYSTEM FOR TESTING REFLECTOR BUTTONS

MICHIGAN STATE HIGHWAY DEPARTMENT

CHARLES M. ZIEGLER, STATE HIGHWAY COMMISSIONER

FIGURE 1

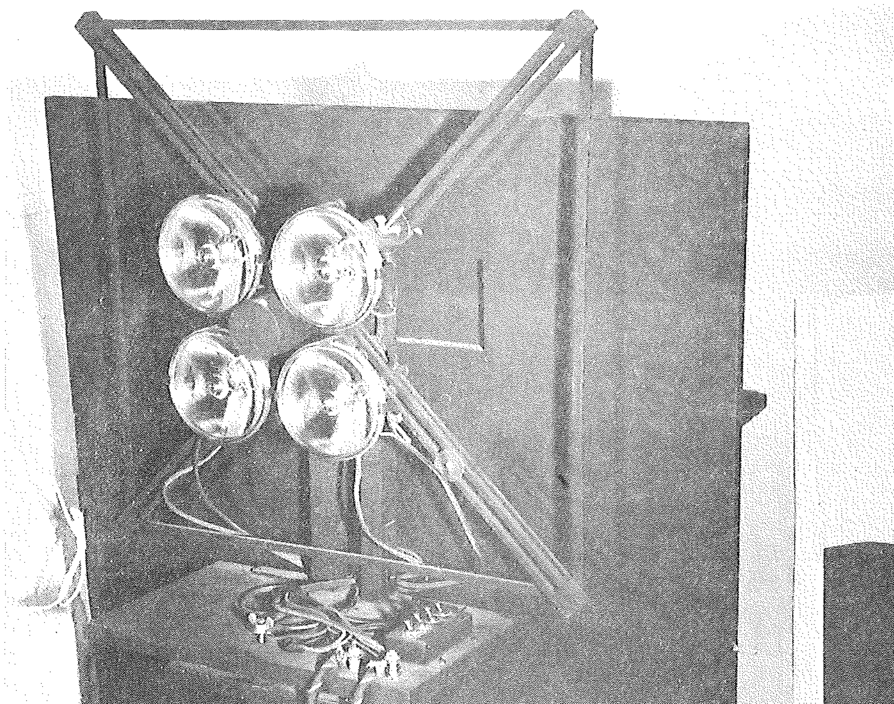


FIGURE 2
LIGHT BANK

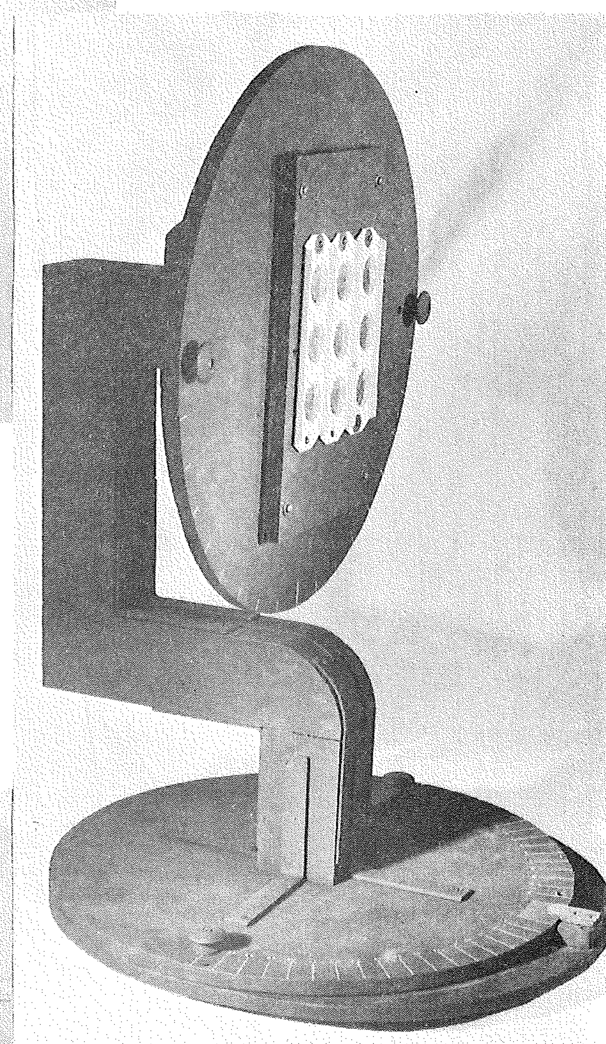


FIGURE 3
GONIOMETER

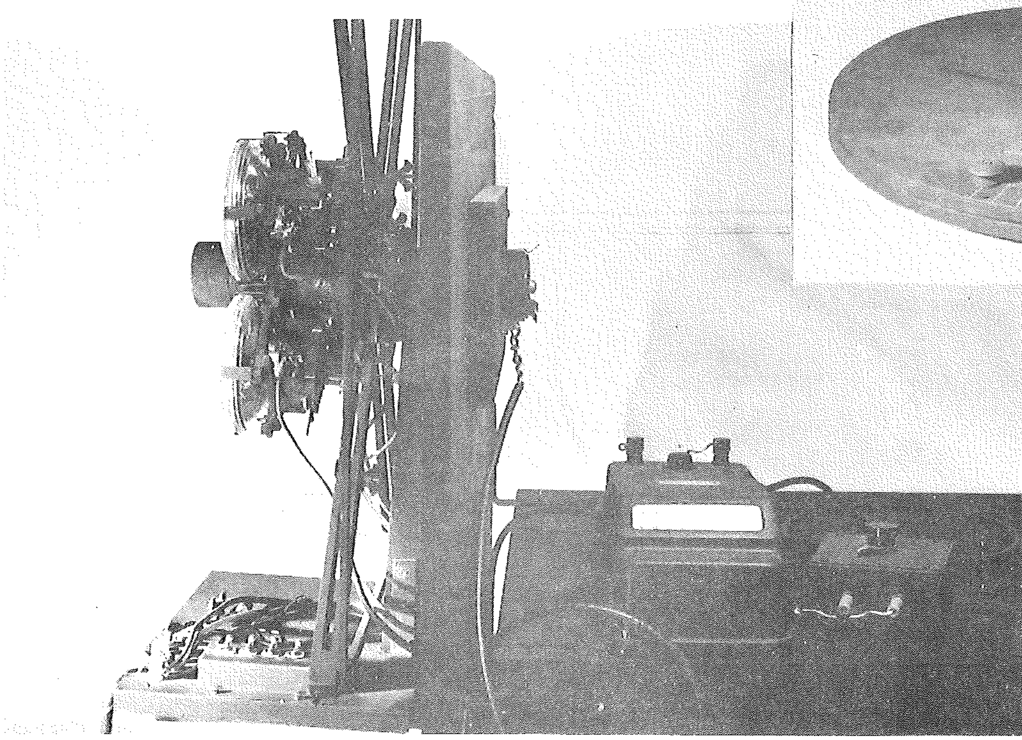


FIGURE 4
LIGHT MEASURING EQUIPMENT

type), Model 594RR, equipped with a Weston Viscor filter, and is thus chromatically corrected to have a spectral response comparable to that of the average human eye. It has a current output of approximately 1.75 microamperes per foot-candle of incident light with the visual correction filter in place.

The cell is connected to a measuring circuit containing a micro-ammeter with an original sensitivity of approximately 0.03 microampere per mm. division. A suitable shunt system is included in the circuit to increase the range of the instrument by steps of approximately 10 to 1 and 50 to 1.

Incident light on the reflector being tested is measured with the aid of a Weston Foot-Candle Meter, Model 614, containing a duplicate of the receptor photocell, also visually corrected.

Lamps have individual switches, and a master control is provided by a Square D, Class 9002, Type FB6 foot switch. A voltage regulator in the lamp circuit is desirable but, except under unusual conditions, is not essential.

Procedure

Requirements for placing the apparatus for routine testing necessitate establishing a distance of 50 ft. between the receptor photocell and the reflecting surface. Extraneous light should be kept at a minimum, although the light in a normally dim corridor has no effect upon the accuracy of the results. It is of distinct advantage to hang a black drop cloth behind the goniometer.

Considerable care should be exercised in the collimation of the apparatus, and the alignment should be checked at the beginning of each test. The 50-ft. distance should be measured exactly. The specified divergence angle should be checked after adjustment of the lamps.

The sample is mounted on the goniometer in such a manner that its center is opposite the center of the goniometer face and its optical axis normal to that face. For precise collimation, the entrance angle of the goniometer should be set at 0 degrees and the sample replaced by a specular mirror. Adjustment of the goniometer may then be carried out until the operator, sighting through the metal tube in the center of the multiple light source, sees the reflected image of his eye in the mirror.

The lamps are turned on and individually adjusted so that the sample is illuminated uniformly, the 3-1/2-inch lateral displacement of each lamp being finally checked after uniform illumination of the sample has been achieved. Uniformity of illumination is considered satisfactory when the incident light as measured at five points by the foot-candle meter varies by no more than plus or minus 5 per cent from the average value. The average illumination in foot-candles is recorded as total incident light.

From the total incident light must be subtracted the ambient incident light, which is the illumination from the room falling on the sample. The latter illumination is so small (usually about I foot-candle) that its contribution in terms of reflex reflection along the optical axis is minute, and is quite beyond the sensitivity of the galvanometer to evaluate. The ambient light is diffuse, not unidirectional, and this diffuse light is added by the photocell to the unidirectional light from the artificial source, so that it is significant in the record of the incident light and should be subtracted.

The difference between the total incident light and the ambient incident light is recorded as the incident light.

A black mask coated with dull optical black is next placed in front of the reflecting surface with the lamps turned on, and the reflected light measured by the receptor photocell. This value, which includes stray light entering the tube from other sources, is also very small, usually about 0.02 foot-candle, and is recorded as the basic reflected light. The mask is removed from the face of the sample and another reading taken, this being recorded as the total reflected light. The basic reflected light is subtracted from the total reflected light and the difference is recorded as the reflected light at each setting of the goniometer.

In testing reflector buttons having reflecting surfaces less than 6 square inches in area it is frequently desirable to group two or more buttons about the center of the goniometer face in order to provide sufficient reflecting surface area for adequate galvanometer response.

Essentially the same procedure is carried out in determining the specific intensities of reflectorized sheet materials. With these materials, however, considerably larger areas are required in order to produce adequate galvanometer deflections. A black mask having a central circular cut-out of 2 sq. ft. area is fastened over the sample of sheet material and the latter centered on the goniometer as in the case of reflector buttons.

Traffic marking signs may be given the same treatment as that of reflectorized sheet materials, either with or without use of the circular cut-out mask. Care must be taken, however, to mask out portions of signs the reflective characteristics of which differ from those of portions under study.

Reflectorized paint is usually applied to 6- by 18-in. laboratory panels in stripes 4 inches in width. Any convenient reflecting area of these may be masked out for measurement on the goniometer, although as many as three complete panels have at times been required.

Practical Considerations

The reflectivity test requires one operator and one assistant. The assistant adjusts the angles of the goniometer as directed by the operator and manipulates the optically black mask. The time required for average routine testing varies from 10 to 15 minutes, depending upon the number of collimating adjustments necessary. Computations require about 10 minutes.

Reproducibility of results is within plus or minus 3 per cent, even without the use of a constant-voltage regulator, but this presupposes a periodic check on the calibration of the foot-candle meter and receptor photocell. (These calibrations are easily checked by the use of secondary standards and do not involve return of instruments to the manufacturer.) This degree of precision compares favorably with the guaranteed accuracy of most commonly available electrical measuring instruments on the American market, and is well within the requirements for accuracy of any state highway department. Total cost of the entire equipment is moderate.

Although the apertures of the photocells used in this test are larger than those of the human eye, sufficient purity of divergence angle is available to satisfy essential engineering requirements within practical limits. The larger photocell apertures are compensated for to some extent by the fact that the aperture of the light source is substantially less than that of the conventional automobile headlamp.

Electronic photocells of very small aperture and high sensitivity are available on the market, but their use does not seem warranted in quality control testing at this time. Electronic cells cannot be color-corrected as easily or as accurately as the barrier layer type of cell. Moreover, their electrical response is much weaker and must be amplified by costly additional apparatus. The greater purity of divergence angle obtainable does not seem to be of great practical significance in view of the relatively large range of angles represented by differences in vehicle types and individual driver heights.

On the credit side, their use might prove valuable in further fundamental research and would make possible shorter distances between reflector and light source in photometric tests.

Test Results and Applications

Specimen results from a reflector test are given in Table 3 to illustrate the mathematical treatment of the data. Net galvanometer readings (column4) are first converted to equivalent illumination in foot-candles (column 5). Reflected light in foot-candles is converted to apparent candlepower of the reflector (column 6) by multiplying by 2500 (square of the distance, 50 ft.). This is simply an application of the inverse square law. Final values for specific intensity (column 7) are then computed by dividing the apparent candlepower by the incident light in foot-candles, and again by the area of the reflecting surface.

The three-dimensional graphs of Figures 5, 6, and 7 are presented to show how the data from the photometric tests of different makes and types of reflectors may be used effectively for the purpose of comparison. From the graphs, figures were obtained which made it possible to predict, in the laboratory, the field performance of the reflectors whose characteristics are shown. These reflectors were then put into use on the highway and their performance was found to be exactly as predicted.

Similar checks of field performance against laboratory tests have been observed repeatedly in the case of reflectorized sheet materials, traffic marking signs, reflectorized paints and railroad crossing markers.

By means of the data on automobile headlamp illumination shown in Figure 8, the test results for the two delineators of Figures 5 and 6 were extended further to indicate the true brightnesses of the reflectors as they are approached by a vehicle. The curves of Figure 9 are a graphic illustration of important differences in reflector characteristics.

Reflectivities of various types of bead-reflectorized materials are given in Figures 10 and 11. None of these materials approaches the cube-corner type of reflector in brightness but each finds an appropriate application in highway signing and marking.

TABLE 3

COMPUTATION OF SPECIFIC INTENSITY

Distance, Photocell to Reflector: 50 ft.
Divergence Angle: 1/3 degree

Entrance Angle, degrees	Galvanometer Reading* Basic	Total	Net (Mean, L. & R.)	Illumination Returned, F.C.	App. C.P.	Specific Intensity,** C.P./F.C./sq. in.
0	1.4	86.0	84.6	1.85	4625	7.0
10 L	1.4	77.2				
10 R	1.4	71.7	73.1	1.59	3975	6.0
20 L	1.4	35.0				
20 R	1.4	34.8	33.5	0.73	1825	2.8
30 L	1.4	17.0				
30 R	1.4	17.9	16.1	0.35	875	1.3

* Shunt box setting: 45.85 scale divisions per foot-candle.
** Incident light 108.2-1.4 106.8 F.C. ; Area 6.204 sq. in.

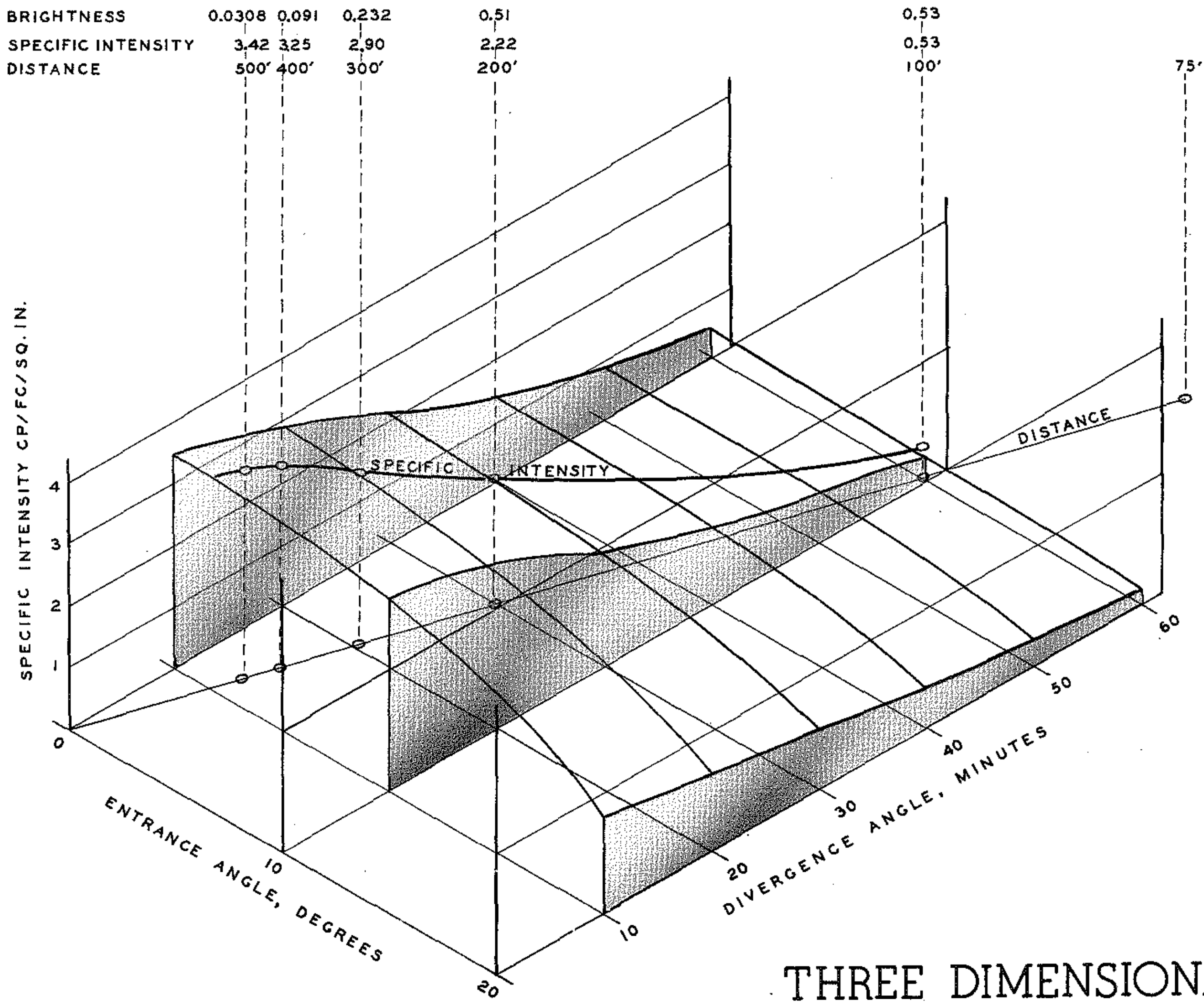


FIGURE 5

THREE DIMENSIONAL DIAGRAM
of SPECIFIC INTENSITY
VS.
ENTRANCE and DIVERGENCE ANGLE
BUTTON "E"

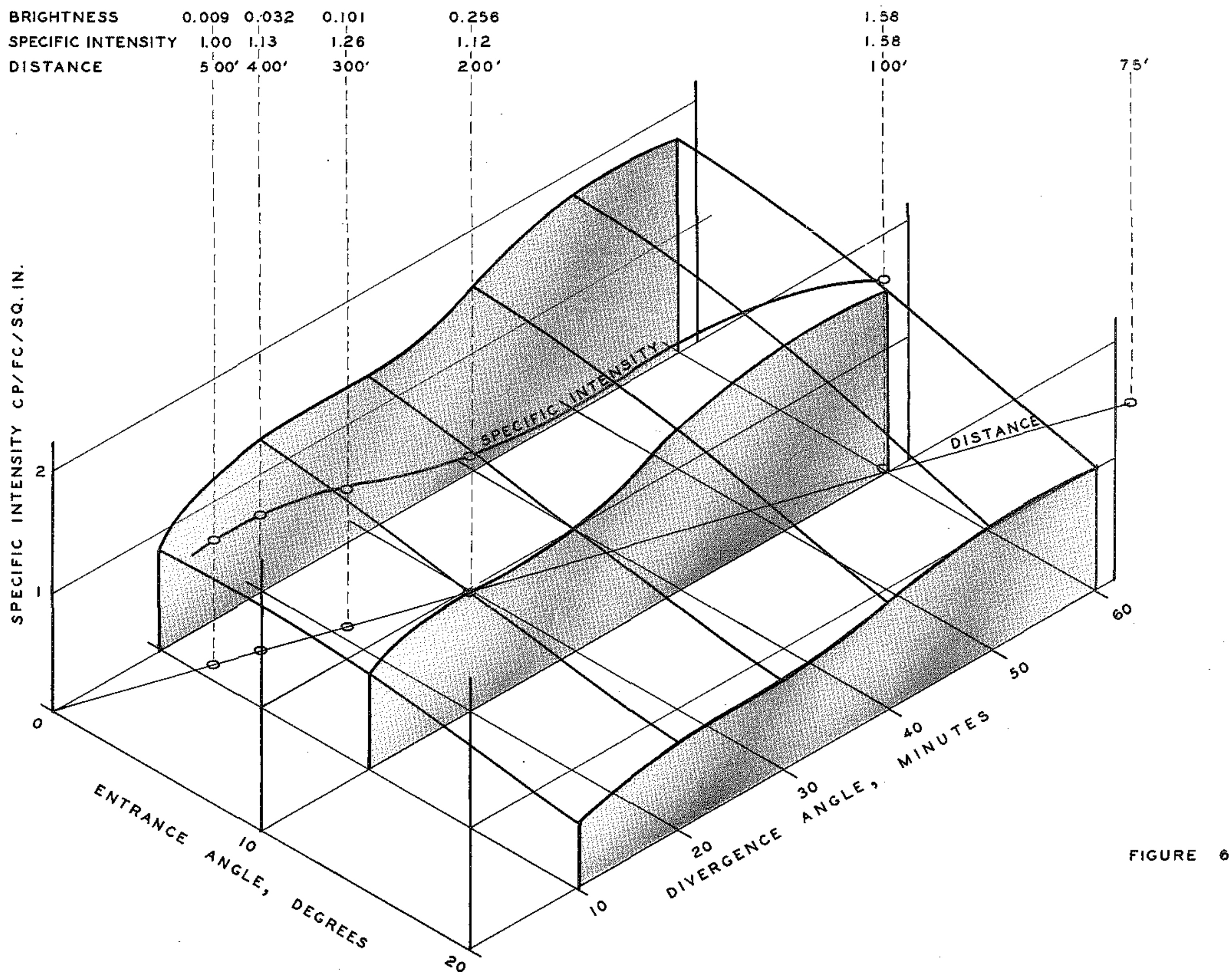


FIGURE 6

THREE DIMENSIONAL DIAGRAM of SPECIFIC INTENSITY VS. ENTRANCE and DIVERGENCE ANGLE BUTTON "F"

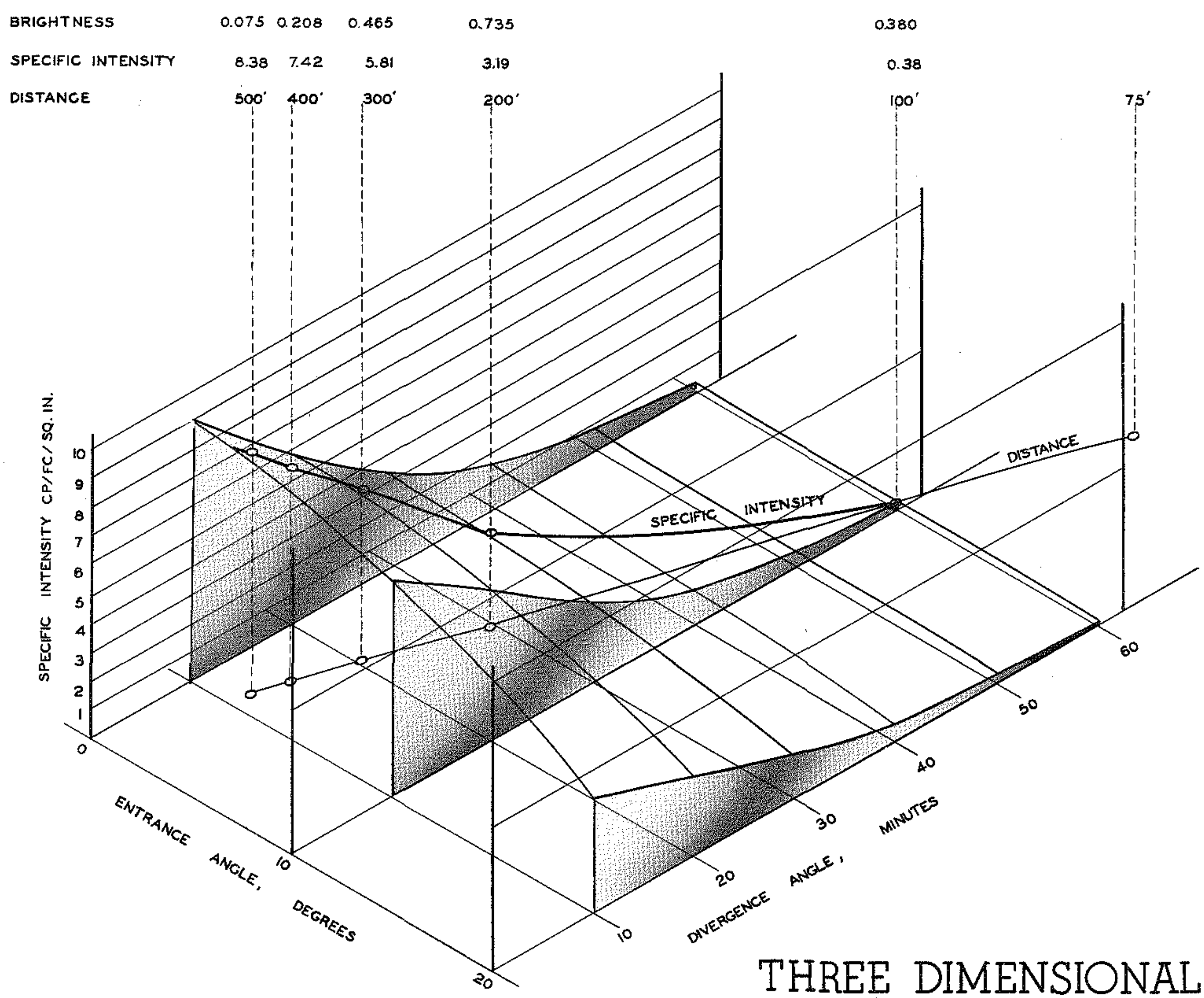
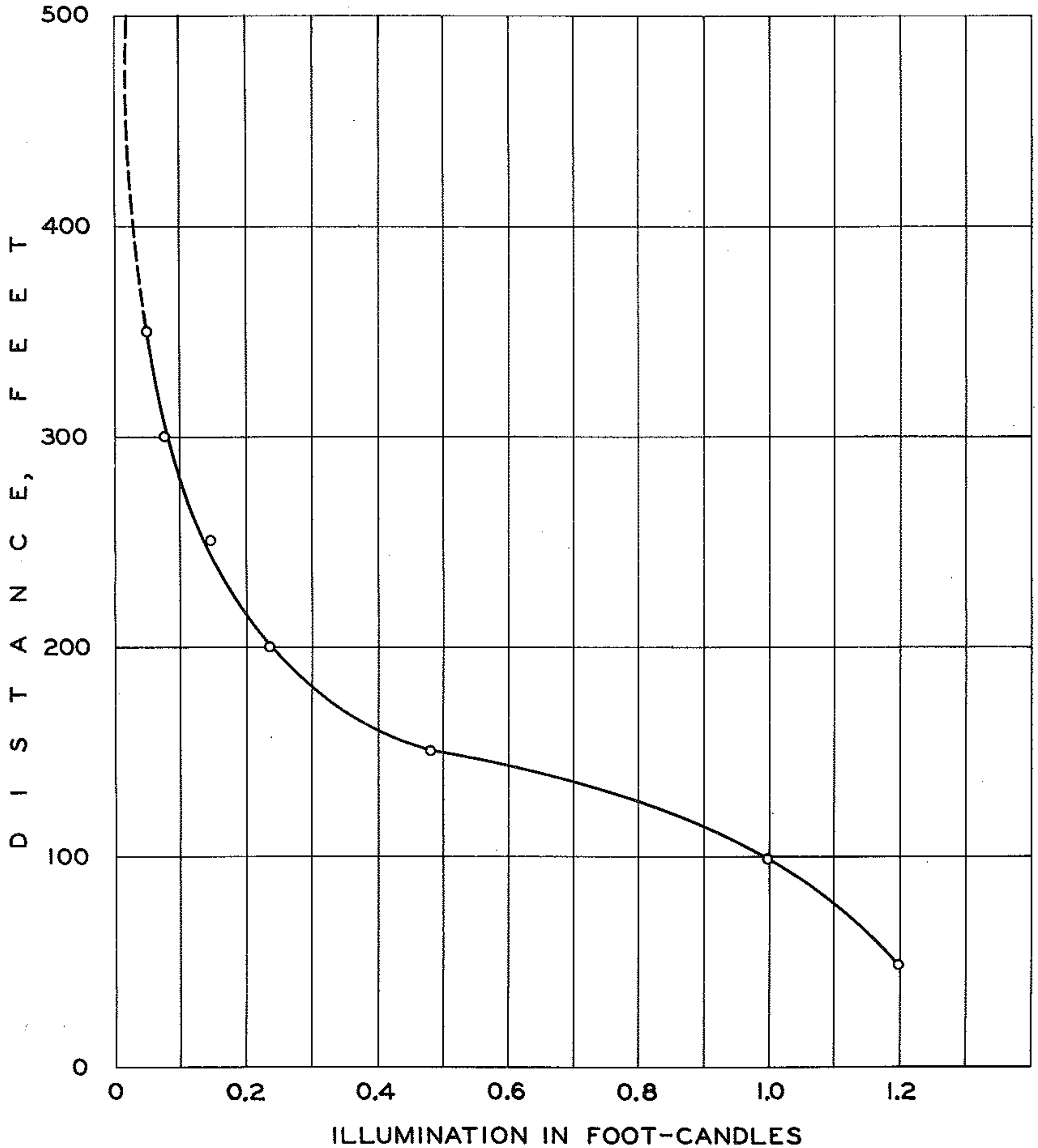


FIGURE 7

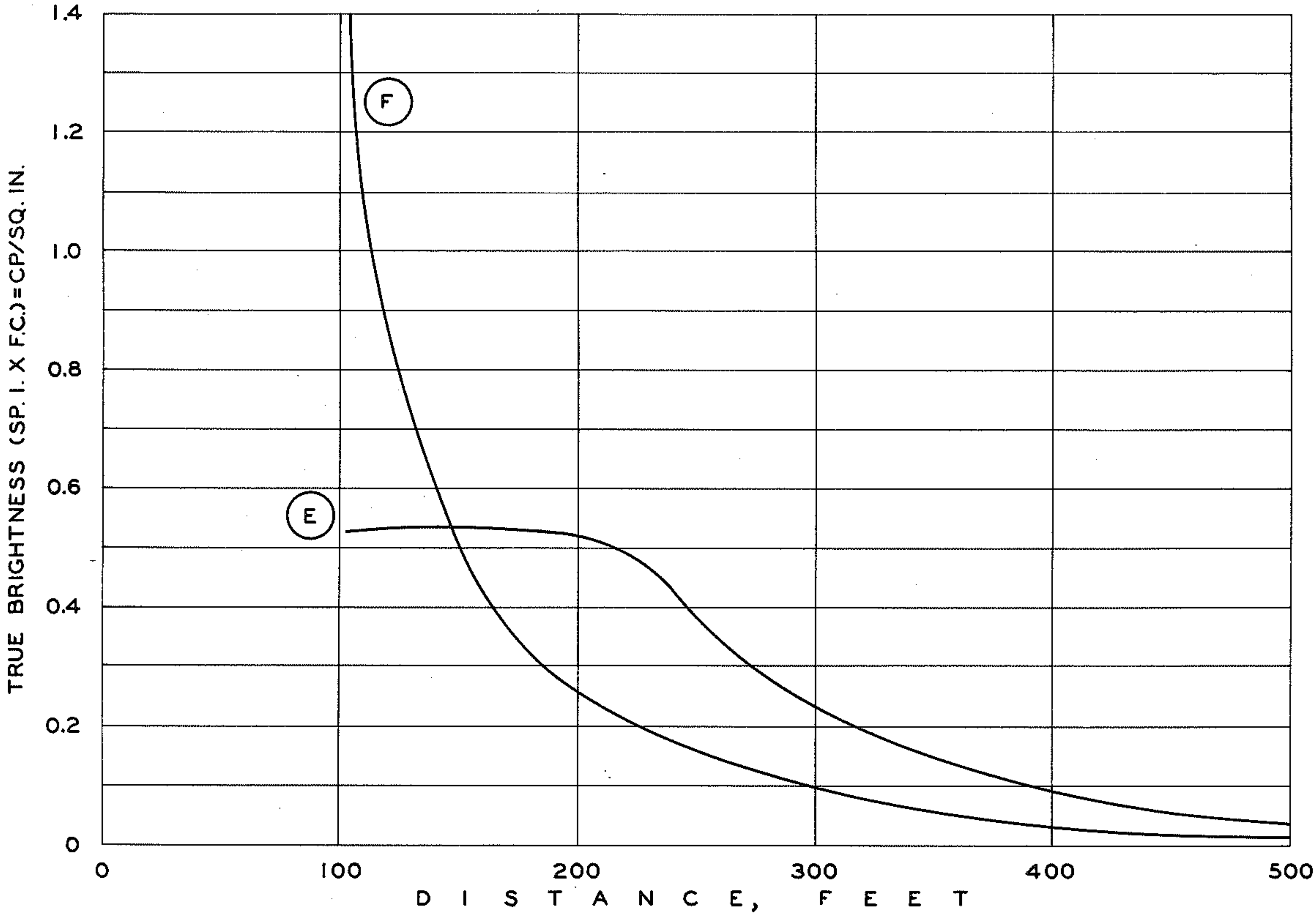
THREE DIMENSIONAL DIAGRAM *of* SPECIFIC INTENSITY VS. ENTRANCE *and* DIVERGENCE ANGLE OVAL SIGN BUTTON "D"



ILLUMINATION *of* ROAD *by* 1938 CAR, MULTIBEAM HEADLAMPS

(AT POINT SIX FEET TO RIGHT OF CAR)

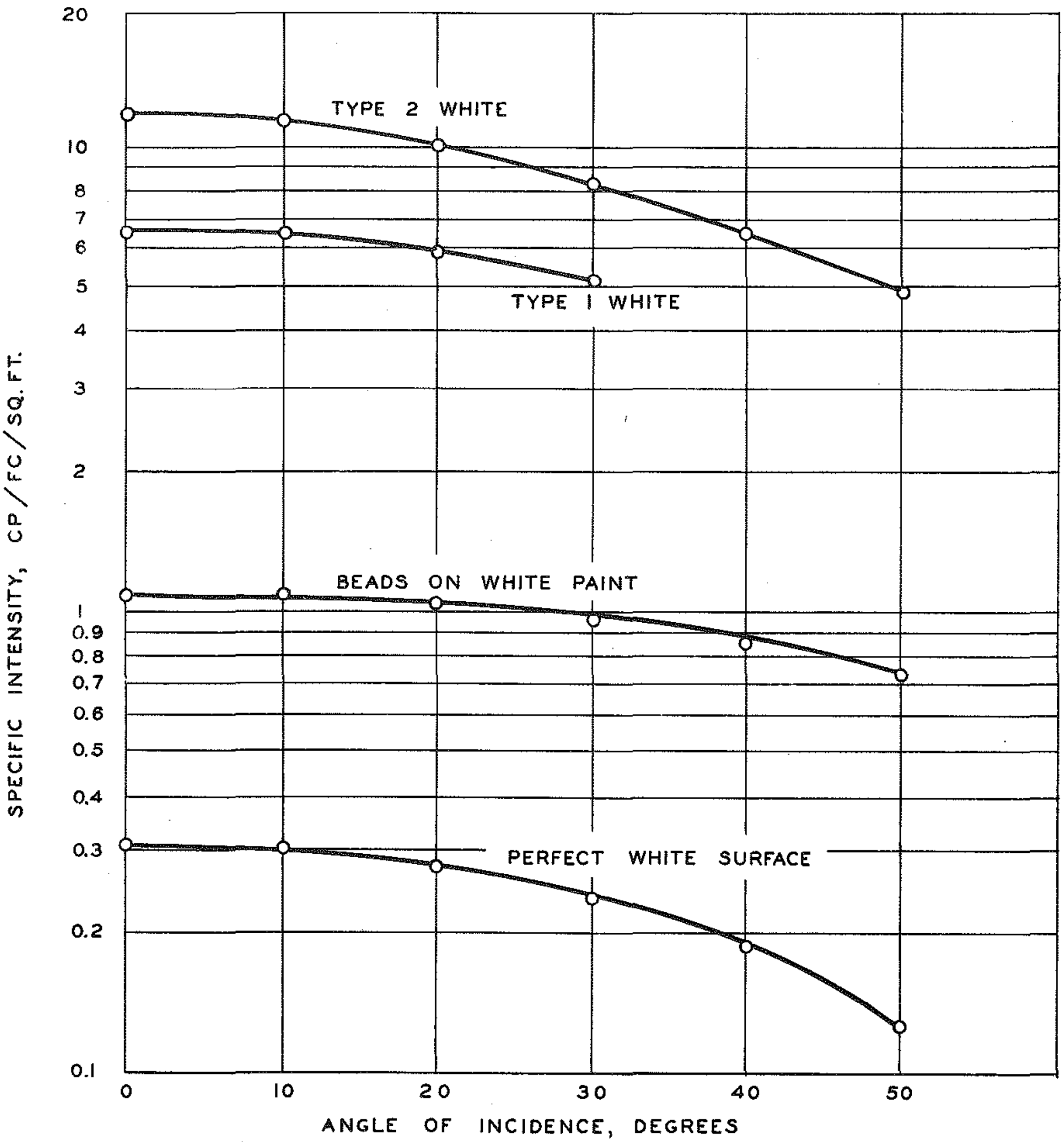
FIGURE 8



TRUE BRIGHTNESS *of* DELINEATORS VS. DISTANCE *from* CAR

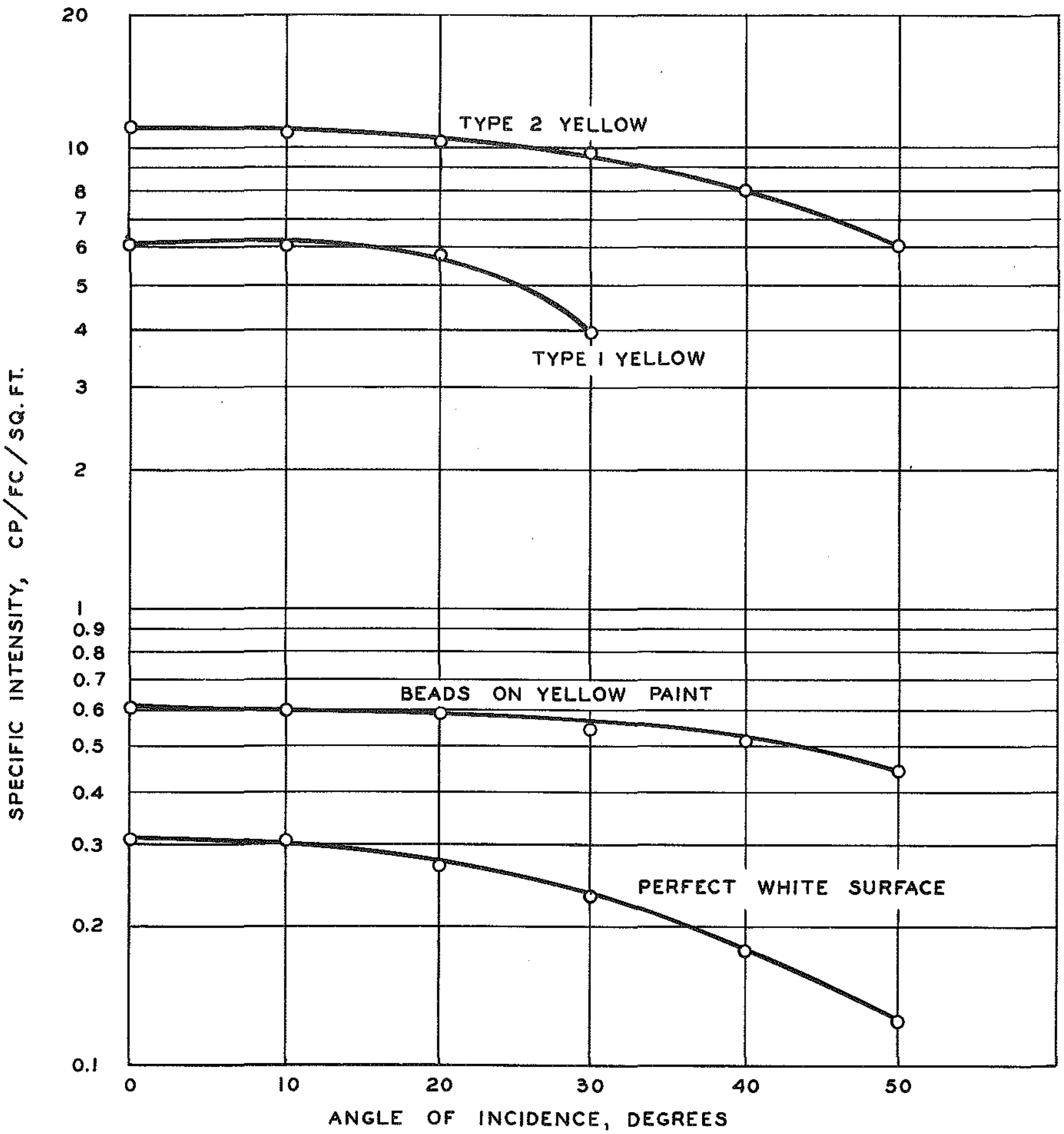
(APPARENT CANDLEPOWER PER SQ. IN.)

FIGURE 9



REFLECTIVE PROPERTIES of BEAD-REFLECTORIZED SURFACES

FIGURE 10



REFLECTIVE PROPERTIES of BEAD-REFLECTORIZED SURFACES

FIGURE 11

COLOR TEST

The Michigan State Highway Department color test was adopted to satisfy a growing need for a means of identifying the hues of colored reflector buttons, and has been adapted to the evaluation of the reflected colors of all reflex reflecting materials and of the spectral apparent reflectances of traffic paints and similar diffuse reflecting materials normally coming within the scope of the Department.

Equipment and test procedure are based on the pioneer work of Professor Arthur C. Hardy of the Massachusetts Institute of Technology and follow in general the requirements set forth in "Standard Method of Test for Spectral Characteristics and Color of Objects and Materials", ASTM Designation: D307-44.

Apparatus

Equipment for the color test shown in Figures 12, 13 and 14 is built around the major piece of apparatus, a Central Scientific Company Cenco-Sheard Spectrophotelometer, catalog No. 12315, and accessories. The spectrophotometer contains a barrier layer photocell, which actuates a G.E. No. 32C245G13 galvanometer having a sensitivity between 1.2 and 1.5 x 10^{-9} ampere per mm. division. For purposes of stability, the galvanometer is mounted upon a 65-lb. block of concrete. Although the spectrophotometer is a rather expensive instrument, it is a versatile one that has many other useful applications in the laboratory.

The light source is a single G.E. No. 4560 sealed beam lamp (airplane landing type) operating at 28 volts and requiring 600 watts for peak operation. A maximum intensity of 600,000 candlepower is produced at beam center. The lamp is operated on the 110-volt line in series with a bank of 7 cone-shaped heating coils, the coils themselves being in parallel.

A rotatable target is provided as shown in the illustration for alternately positioning (a) the sample, (b) the standard and (c) a dull optically black surface in front of the entrance slit of the spectrophotometer.

Distance from reflecting surface to entrance slit is maintained at approximately 52 inches for maximum galvanometer response. A 2-inch inside diameter cardboard tube 20 inches in length, painted inside and out with dull optical black, is held tightly against the entrance slit and pointed directly at the reflecting surface. Collimation is so adjusted that the entrance slit and reflecting surface are at the same elevation, and the optical axis is normal to both.

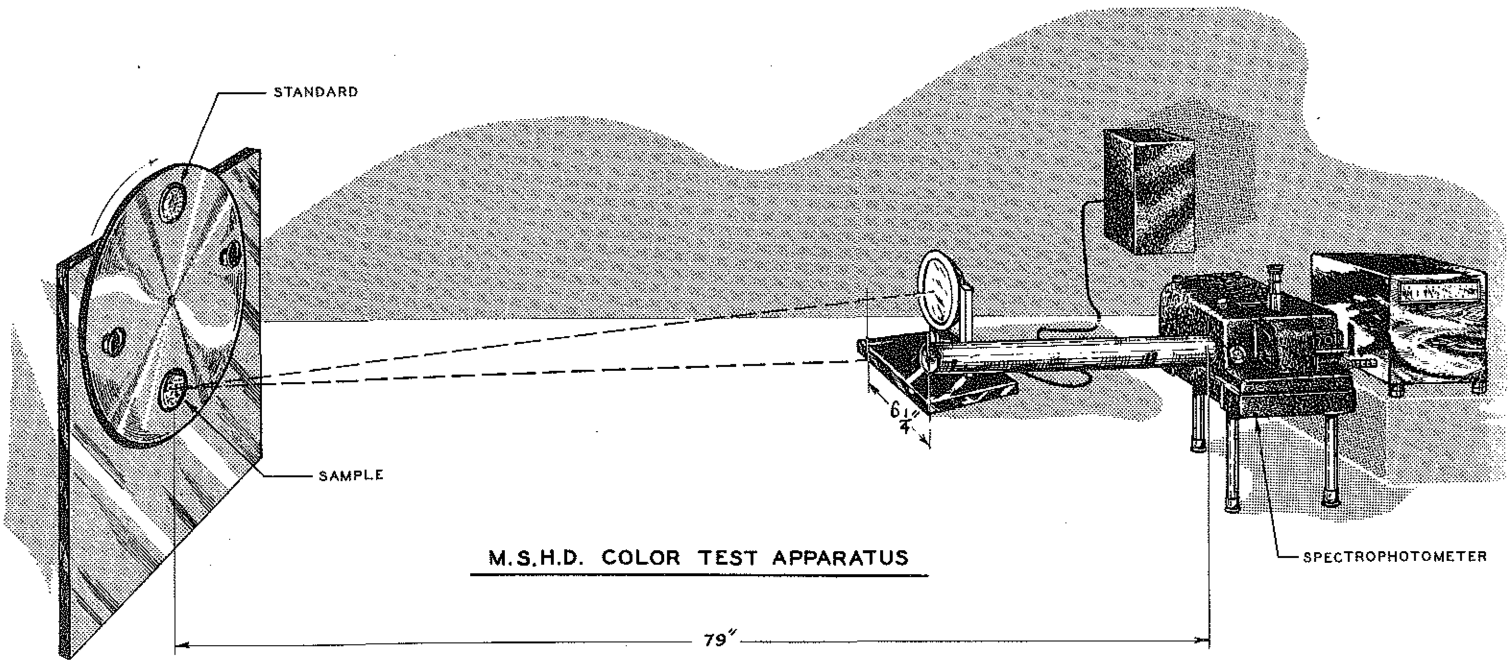
For the testing of reflex reflectors, the lamp is placed at a point in front of the target, above and behind the spectrophotometer, with a distance of 7 ft. between the reflecting surface and the lens of the lamp, and the angle between the optical axis of the entrance slit and that of the lamp (angle of divergence) is kept as small as geometrical considerations allow. With distances less than 7 ft., heat from the lamp becomes objectionable.

For the testing of diffuse reflectors, specular gloss is eliminated by adjusting the incidence angle to approximately 45 degrees.

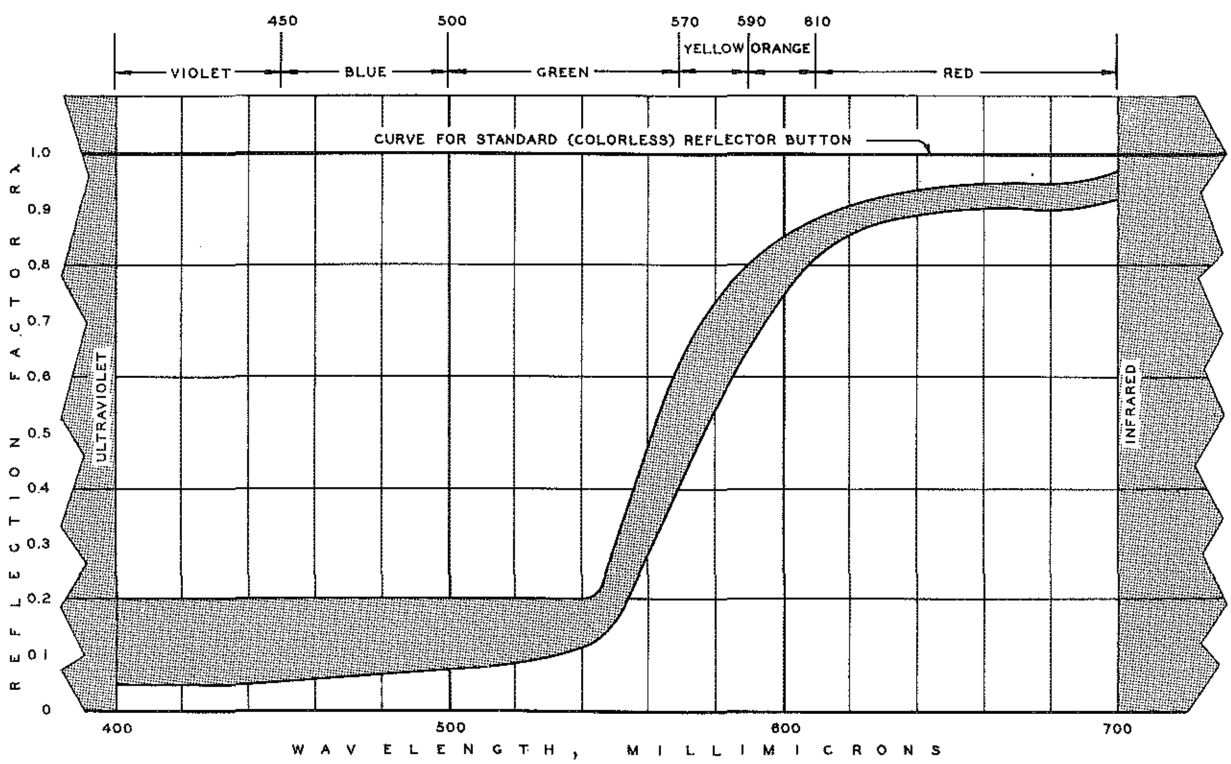
Procedure for Reflex Reflectors

In the case of reflex reflectors the standard employed is a crystal (colorless) reflector of the same size, shape, configuration and composition as those of the colored sample, the only difference between standard and sample being one of color. Differences in specific intensity are automatically compensated for in the method of computing results.

Sample and standard are placed in their respective positions on the



M.S.H.D. COLOR TEST APPARATUS



SPECTRAL APPARENT REFLECTIVITY
ICI ILLUMINANT "A"
COLORED PLASTIC REFLECTOR BUTTON
(AMBER)

FIGURE 12

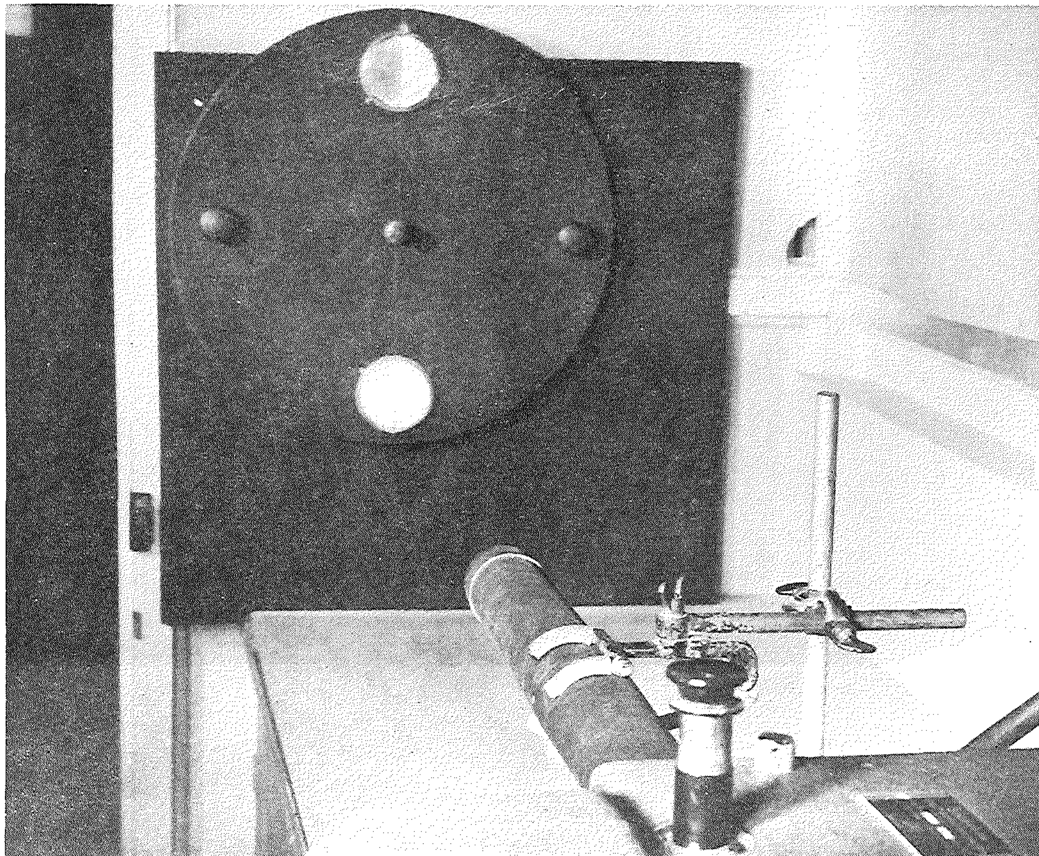


FIGURE 13
TARGET

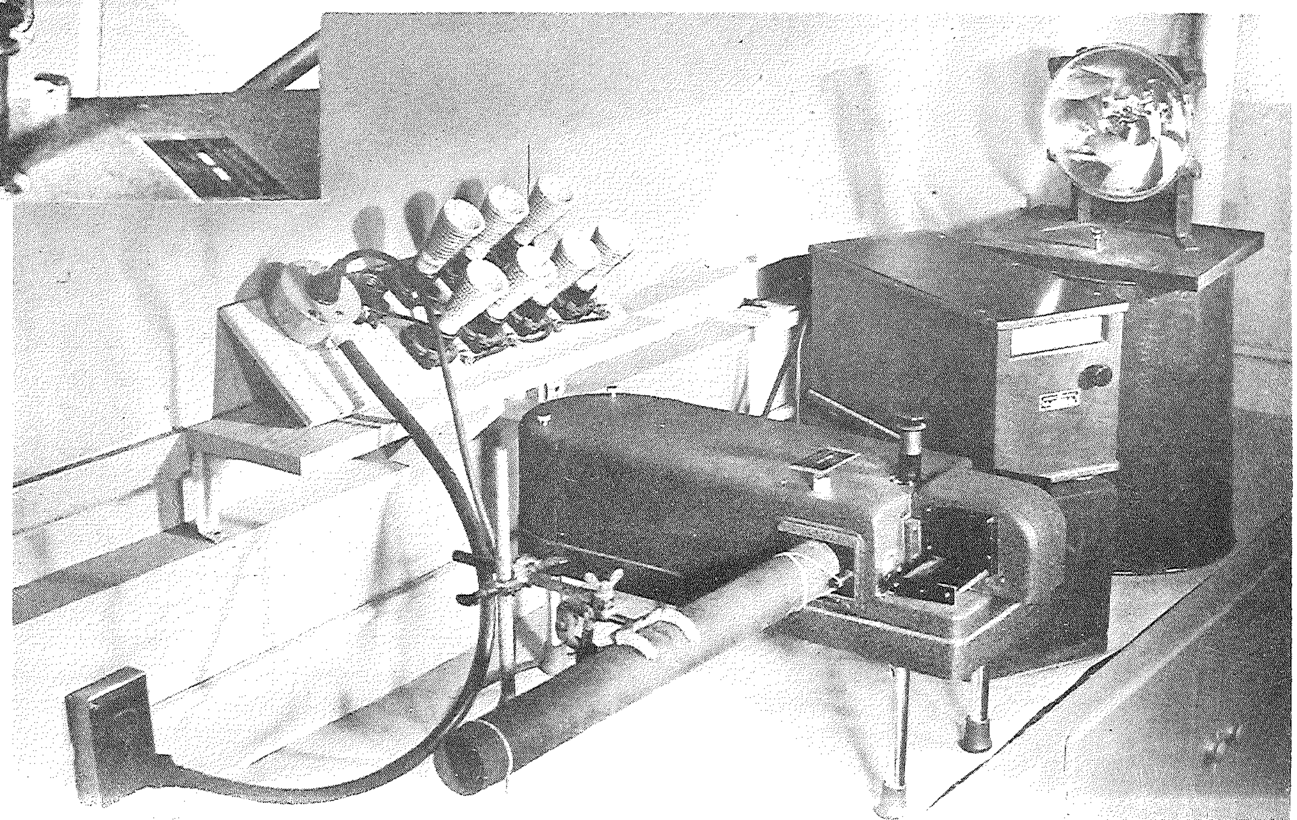


FIGURE 14
SPECTROPHOTOMETRIC
ASSEMBLY

target. The entrance slit of the spectrophotometer is adjusted to 2.5 mm. and the exit slit to a nominal 20-millimicron width.

The spectrophotometer is set to a wavelength of 400 millimicrons, the lamp is turned on, the standard is swung into the optical axis and a reading is taken. The sample is next rotated into position and its reading recorded. The blank value is found by swinging any black portion of the target into position and taking the "black" reading. These readings are repeated at wavelength increments of 20 millimicrons throughout the visible spectrum up to and including a wavelength of 700 millimicrons. In the absence of a constant-voltage transformer it is essential to check the readings taken at the same wavelength until the operator is certain that no significant voltage fluctuations have occured during the time the three readings were recorded at that wavelength.

Computations. Data from an actual color test are shown in Table 4. The basic "black" reading is subtracted from the crystal and colored readings at each wavelength. The resulting reading for the sample is divided by that for the standard at the same wavelength, and the ratio, R_λ, is recorded as the spectral apparent reflectivity of the sample for each wavelength included in the determination.

Spectral apparent reflectivities are plotted against wavelength, as in the ASTM procedure. As a rule, however, these values have to be corrected for differences in specific intensity between sample and standard. In the case of amber plastic reflector buttons, is is Michigan State Highway Department practice to determine the factor required to convert R_λ at 660 millimicrons to the value, 0.925. All values of R_λ are then multiplied by the same factor, and the corrected values of R_λ

are plotted against wavelength. It is found that this method works very well in avoiding elevation or depression of "amber" curves, and there is no reason why similar adjustments are not possible in the case of any other color.

Applications. With the help of the color test, the Department has succeeded in establishing appropriate specifications for the color of amber plastic reflector buttons. Similar specifications for reflectors of other colors will doubtless be forthcoming when and if reflectors of other colors are brought into use by the Department.

Once a color curve has been established, it is possible to identify that color objectively at any time thereafter and to follow with precision the extent or absence of fading, darkening, or of any other alteration of the color without recourse to visual comparison with color chips or with a so-called master color standard. A color curve obtained by this test is definite and reproducible, and constitues a permanent record.

Procedure for Diffuse Reflectors

In the case of diffuse reflectors, of which traffic paints are examples, the same procedure is followed except that a disk coated with freshly deposited magnesium oxide is used as the standard white, and the sample is sprayed on a similar disk of the same diameter. The light source is placed at the same distance, but at an entrance angle of 45 degrees to eliminate specular gloss.

Computations follow the ASTM procedure for calculating the luminous apparent reflectance, R_S, in percent.

Time and Personnel Required

A single operator handles all Department tests involving work with the spectrophotometer. Color tests on reflector buttons require 45 min-

TABLE 4

COLOR TEST DATA AND COMPUTATIONS

Wave length, millimicrons	Crystal + Black	Amber + Black	Black	Crystal	Amber	Reflectivity Factor, R_λ	Ibid Corrected @ 660 mu	Specification
400	0.38	0.14	0.07	0.31	0.07	0.226	0.146	0.05 - 0.20
20	0.50	0.18	0.08	0.42	0.10	0.238	0.154	0.05 - 0.20
40	1.25	0.48	0.18	1.07	0.30	0.280	0.181	0.05 - 0.20
60	1.81	0.53	0.25	1.56	0.28	0.179	0.116	0.06 - 0.20
80	2.40	0.72	0.33	2.07	0.39	0.188	0.122	0.07 - 0.20
500	3.15	0.95	0.40	2.75	0.55	0.200	0.129	0.08 - 0.20
20	3.65	1.00	0.42	3.23	0.58	0.180	0.116	0.09 - 0.20
40	4.07	1.30	0.50	3.57	0.80	0.224	0.145	0.12 - 0.20
60	5.02	2.97	0.50	4.52	2.47	0.546	0.353	0.30 - 0.50
80	5.30	5.09	0.53	4.77	4.56	0.956	0.619	0.55 - 0.75
600	5.00	6.10	0.52	4.48	5.58	1.245	0.805	0.75 - 0.85
20	4.60	6.10	0.52	4.08	5.58	1.365	0.883	0.86 - 0.91
40	3.52	4.80	0.52	3.00	4.28	1.428	0.923	0.89 - 0.94
60	2.47	3.32	0.50	1.97	2.82	1.430	0.925	0.90 - 0.95
80	1.50	2.00	0.49	1.01	1.51	1.495	0.967	0.90 - 0.95
700	0.93	1.01	0.49	0.44	0.52	1.181	0.765	0.92 - 0.97

utes for the determinations and 30 to 45 minutes for computing and plotting the curve. Determination of R_S for traffic paints and similar materials requires 1 hour for the test and 1 hour for the calculations. As many as four determinations on diffuse reflecting materials are frequently completed in a single day. This includes the time required for all calculations and for four separate depositions of magnesium oxide.

CONCLUDING STATEMENT

The reflectivity and color tests just described have been proved over a period of more than a year to satisfactorily fulfill essential requirements so far established by the Department. The simplicity, availability, and reasonable cost of the equipment employed recommend it for use in quality control by both producer and consumer. Ease of assembly and operation are additional advantages; any laboratory technician of ordinary ability can perform the tests.

Refinements of equipment and procedures, and extension of the applications of photometric tests are bound to come. In the meantime, the Michigan tests should serve a useful purpose in the highway industry as a first step toward the effective evaluation of reflective materials.