Two Photo-voltaic Cell Photometers for Measurement of Light Distribution

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For many years those engaged in photometric tests have hoped for less burdensome methods, especially with regard to measurements of light distribution. The authors describe two types of photometers to which light-sensitive cells have been adapted. Any discussion of the color, fatigue, sensitivity and other characteristics of the cells themselves has not been considered within the scope of this paper. Sufficient experience with these photometers has been obtained to prove their practical worth. Further development of light-sensitive cells should make them of increasing value in the field of photometric measurements.

RECENT developments in photo-voltaic cells commonly known as light-sensitive cells to differentiate them from the conventional photoelectric tubes, have opened up not only simpler methods of electrical control but also new applications in the photometric field.

While it is true that there is still much to be desired in the improvement of cell output, color sensitivity relationship, fatigue characteristics, etc., nevertheless there are undoubtedly many applications where these characteristics may be of secondary importance.

The purpose of this paper is to discuss the development of two photometric devices in which light-sensitive cells have been incorporated. The first piece of apparatus has been named the Quadrant Distribution Reflectometer, designed primarily for rapidly determining the reflection factors of flat samples of diffuse and semi-specular surfaces and for analyzing the distribution characteristics of reflected light from such surfaces. The second photometer may be referred to as a Photo-Voltaic Cell Integrator for determining complete data on luminaires.

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QUADRANT DISTRIBUTION REFLECTOMETER

For some time a local enameling manufacturer had been confronted with the problem of speeding up check measurements on samples taken regularly from the various furnaces. Since it had previously been found that the reflection factor was a very good indication of opacity, any method which would expedite these determinations would result in a more accurate control of the product. The Taylor Reflectometer[1] had been very valuable in making these measurements but the time required in taking the large number of visual observations, the delay in obtaining the final results, eye fatigue of the observers, etc., all justified a more rapid method so that the time element could be reduced and the variations between observers minimized.

In order better to describe this new reflectometer, reference may first be made to the measurement of reflection factor by the visual distribution method. This is accomplished by first directing a beam of light on the test sample and then measuring the light reflected from the sample through an angle of 90 degrees with the projected beam as a starting point. Inasmuch as the light striking a very specular sample perpendicularly would be reflected back into the projector, it is necessary to shift the beam slightly off this line as shown in Fig. 1.

To obtain the total light reflected from a sample, the relative illumination values at the various angles should be multiplied by the proper zone constants. The areas of the various zones are computed from the formula:

$$\text{Area of any zone} = 2\pi R(\cos\theta_1 - \cos\theta_2)$$

where R = Radius of the sphere (unity). In measuring flat samples by this method it is assumed, of course, that the light is reflected uniformly from the surface of the sample.

The various visual instruments available at present measure total reflection of both specular and diffuse surfaces without regard to the character of light reflection distribution. However, the distribution of reflected light is of extreme importance in porcelain enamel and other surfaces in connection with re-direction of light rays. Also these visual instruments necessarily require the services of a trained operator. For these reasons probably, the use of such equipment by the enameling and paint companies has not become general. Recently, however, it has been more fully realized that greater accuracy

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[1] TRANS. I. E. S. 15, 1920, 811.

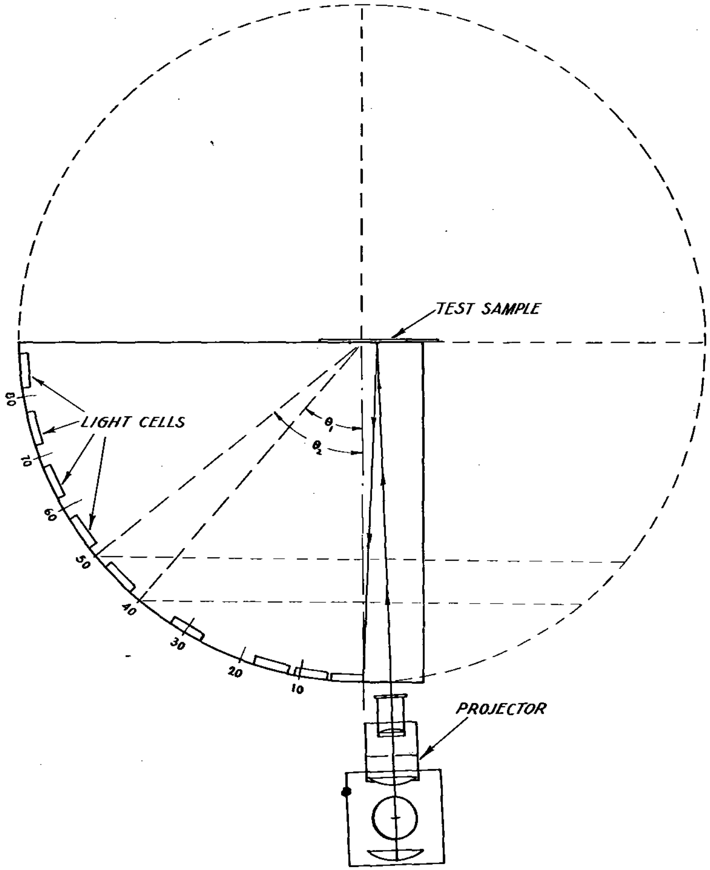


FIG. 1—Principle of operation of quadrant distribution reflectometer.

in the control of the product could be obtained by frequent periodic measurements if a more simplified method were available.

By referring again to Fig. 1, it is apparent that the visual method may be replaced by the use of a light-sensitive cell mounted on a movable arm traveling over the various angular divisions throughout the 90 degree quadrant. The procedure followed would be the same as in the case of the visual method, that is the total light reflected is obtained by multiplying the cell readings by their proper zone constants.

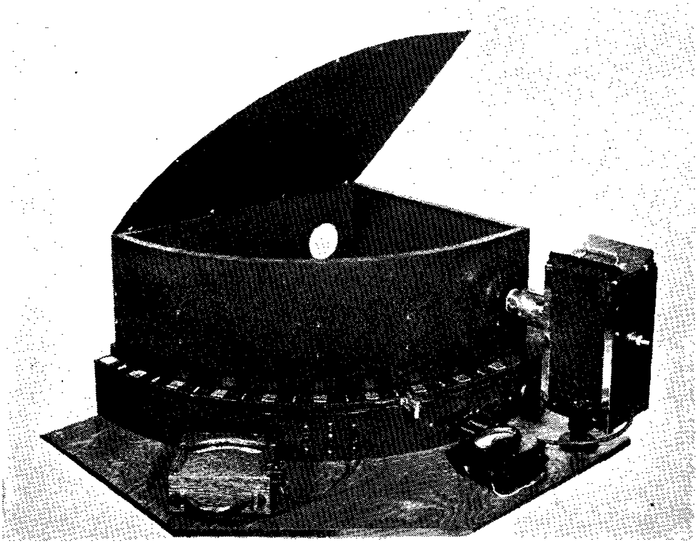


FIG. 1-A—Quadrant distribution reflectometer—front view.

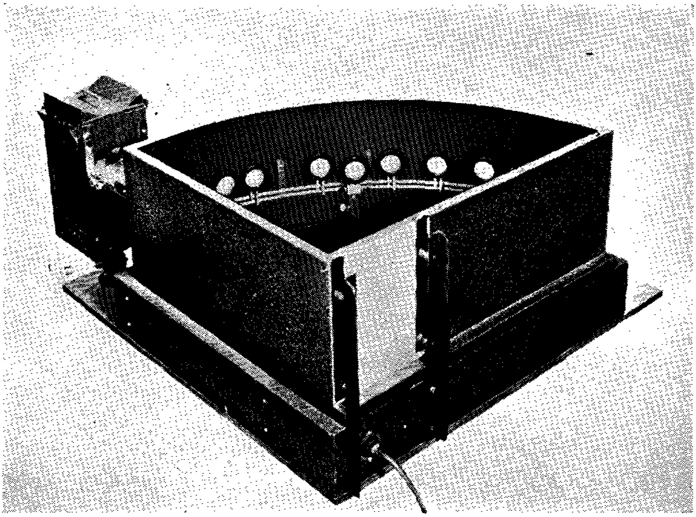


FIG. 1-B—Quadrant distribution reflectometer—rear view.

It must be now apparent, however, that the same result can be better accomplished by permanently mounting cells at the various angular positions; the application of the proper zone constants is accomplished by placing carefully-calibrated apertures or screens over the light-sensitive cells. The cells are all connected in parallel and this cumulative output read on a microammeter or galvanometer is indicative of the total light reflected from the sample.

The apparatus may be calibrated to read absolute values by the substitution method, that is by reading unknown samples in terms of a known standard.

The use of a movable arm with a single cell previously mentioned swinging throughout the 90-degree quadrant becomes very valuable in exploring the type of distribution of reflected light and makes it possible to readily classify the various samples as to degree of diffusion or specularity.

Computation of Cell Apertures

Table I shows the angular positions at which the cells are mounted, the zone which each cell represents and weighs, and the zone constant which has been calculated by the well-known method commonly used for computing zone areas.

The rather unusual angles selected are for the purpose of more accurately integrating the light reflected from the more specular samples. Also, on account of the physical size of the active cell surface, it was found necessary to use two apertures on the same cell at the first four angles. That is, the apertures for the 0–2 and 2–5 degree

TABLE I—ANGULAR POSITIONS OF CELLS, ZONE LIMITS AND CONSTANTS

Angle Degrees	Zone Degrees	Zone K	Per cent of 80–90° Zone K
1	0–2	.0038	.35
3½	2–5	.0201	1.84
6½	5–8	.037	3.39
9½	8–11	.054	4.95
15½	11–20	.263	24.1
30	20–40	1.091	100.0
45	40–50	.774	70.9
55	50–60	.897	82.2
65	60–70	.993	91.0
75	70–80	1.058	97.0
85	80–90	1.091	100.0

zones are placed on the first cell; the apertures for the 5–8 and 8–11 degree zones on the second cell. At the remaining angles, one aperture is placed on each cell. A total of 9 cells are used.

Since the output of these cells is proportional to the area of the exposed surface, the aperture areas vary in the same proportion as the zone constants. As a matter of convenience, the area of the 80–90 degree zone is taken as 100 per cent.

The other essential elements of this device consist of a projector, a voltmeter and a rheostat for controlling the lamp. A circular opening about 3½ inches in diameter is located at the back of the housing against which the test sample is securely held in position on a spring clamp. The beam of light is projected through a distance of 24 inches to the test sample and almost entirely covers the part of the sample exposed through the circular window. The cells which are mounted on the inside of the quadrant are on a 22-inch radius.

The cell housing is made light-tight by a cover removable from the top. The use of the apparatus is, therefore, not limited to a dark room. All surfaces inside ot the housing are painted a flat black to minimize the effect of reflected light from the interior surfaces.

Measurements on Flat Acoustical and Enameled Samples

Table II shows reflection factor measurements taken on a number of flat samples by three different methods:

A—Visual Reflectometer
B—Single Cell on Movable Arm (Quadrant Reflectometer)
C—Cumulative Reading—9 Cells (Quadrant Reflectometer)

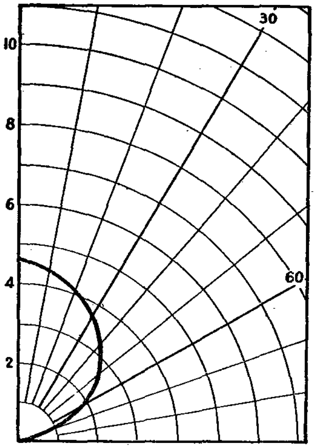
Several of these samples are colored, ranging from brown to a white mat surface with intermediate colors such as yellow and buff. Under these circumstances, the agreement between the three methods is considered to be very acceptable. There are at least two important reasons, however, why Method C is believed to be more reliable than Method B. The cells are exposed to the reflected light a much shorter period of time which reduces the effect of fatigue or drift. Also, with Method C, the higher light intensities fall on cells having the smaller apertures, further minimizing cell variations.

Not only is the time consumed in taking distribution data by the light-sensitive cell method greatly reduced as compared with the visual method, but only one operator is required who is not necessarily experienced in photometry.

TABLE II—REFLECTION FACTORS—FLAT SAMPLES

Sample	Color	A Visual Reflectometer	B Quadrant Single Cell—Movable Arm	C Quadrant Cumulative Reading—9 Cells
Upson Board				
No. 1	buff natural	51.4	52.1	53.5
2	buff natural	50.8	51.7	53.5
3	buff natural	52.3	53.7	55.5
4	med. brown natural	22.4	23.8	24.0
Absorbex				
No. 1	cream paint	72.1	75.4	73.0
2	flat white paint	81.4	84.7	83.0
3	ivory paint	73.7	75.4	72.5
4	white paint	80.7	82.3	80.0
Armstrong Temlock				
No. 1	flat white paint	86.3	91.1	91.5
2	cream paint	82.2	91.1	87.0
3	yellow buff paint	67.8	73.1	71.0
4	light brown paint	25.8	27.8	29.0
5	white paint	76.6	82.3	79.0
6	cream paint	72.2	75.4	73.0
7	yellow paint	67.4	68.7	66.0
Glyptal				
No. 1	white	79.9	80.0	80.0
2	white	78.5	81.0	80.5
Porcelain Enamel				
No. 1	white	76.6	73.1	75.0
2	white	73.6	75.2	73.5
3	white	63.6	61.0	60.5
4	white	74.4	78.4	77.0
5	white	75.5	78.3	75.5
Test Plate	etched opal	83.0	St'd	St'd

In order that some idea may be obtained of the wide variation in the character of the surfaces of these samples, two distribution curves representing the extremes are shown in Figs. 2 and 3. These data were obtained by Method B. Both of these samples, it will be noted, have approximately the same reflection factor.



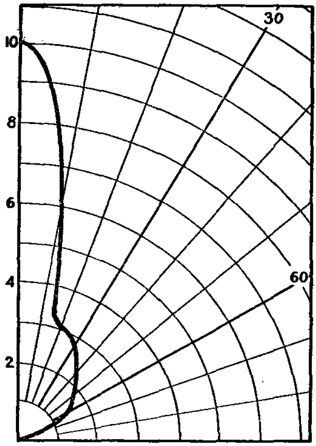


FIG. 2—(Left) Distribution curve: etched opal test plate having reflection factor of 83.0 per cent.
FIG. 3—(Right) Distribution curve: Glyptal, having reflection factor of 80.0 per cent.

Up to the present time the greatest amount of work on the Quadrant Distribution Reflectometer has been confined to the measurement of samples of a diffuse and semi-specular nature; it was for this purpose that the apparatus was originally designed. However, preliminary tests indicate that surfaces of a more highly specular character may also be measured provided several necessary precautions are taken. The incident light beam with respect to the test surface must be in perfect alignment. Also, the design of aperture shapes and dimensions on the cells must be very carefully executed so that proper integration of reflected light may be obtained. The importance of this is appreciated when it is recalled that most all of the reflected light from polished surfaces is in a concentrated beam.

PHOTO-VOLTAIC CELL INTEGRATOR

There has always been a need for a method or device which would shorten the time in obtaining the complete photometric data on a luminaire.

A method in general use is to place the lighting unit in a spherical photometer from which the total output is determined. The unit is then transferred to a distribution photometer where the candlepower values at the various angles are measured. The lumen values at these angles are then calculated using as a basis the total output measured in the sphere. In some cases the total output of the unit

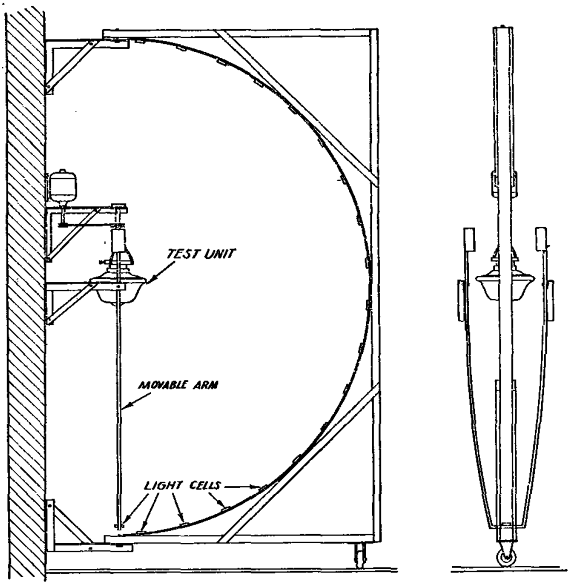


FIG. 4—Principle of operation of photo-voltaic integrator.

is computed directly from the candlepower distribution curve; however, for greater accuracy it is desirable to have an independent total output reading.

As mentioned before, measurements taken in this manner require operators who are experienced in photometry. It can be readily seen, however, that the further application of the light-sensitive cell in a manner similar to that used in the Quadrant Distribution Reflectometer simplifies greatly this procedure.

In Fig. 1 the luminaire replaces the flat sample except that it is located at the center. The light-sensitive cells are similarly located except that they are continued through the next quadrant making a complete semi-circle.

Fig. 4 shows more clearly the positioning of the light-sensitive cells with respect to the unit under test. Since the cells lie only in a vertical plane, provision is made for rotating the unit continuously in order to obtain the average output around a unit having a symmetrical distribution. A unit of non-symmetrical distribution may be rotated step by step in order to determine the output.

It is desired to mention again that the cells are equipped with apertures which correct their outputs in proportion to their respective zone areas. Also, as previously described, these cells are connected in multiple and their combined output is indicated on a microammeter or sensitive galvanometer.

A single cell mounted on a movable arm can be rotated through the 180-degree vertical plane to obtain the light pattern. The usual precautions must be taken which are always necessary for accurate photometric measurements. Experience with this type of integrator has shown that perhaps the most important source of difficulty is due to extraneous light reflections. It is very important, therefore, to prevent any light from being reflected back into the cells such as might come from the side walls, floor or ceiling.

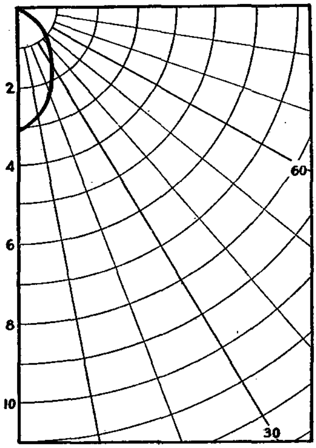
Measurements on Direct Lighting Reflectors

In Table III will be found comparative output efficiencies of a group of spun aluminum reflectors, obtained by the candlepower distribution method and by means of the integrator. These reflectors are all identical in contour but range in reflecting surface from highly polished to satin oxidized aluminum.

TABLE III—Output Efficiencies

Bare Lamp Output—100%

Reflector Sample	Reflector Surface	Visual Method	Integrator	Per Cent Variation from Visual Method
1-A	All Polished	74.0	77.0	+4.0
1-B		76.9	73.5	−4.4
2-A	Combination, Polished and Brushed	74.6	73.5	−1.5
2-B		75.9	76.5	+0.8
3-A	All Brushed	70.6	69.0	−2.3
3-B		70.1	70.3	+0.3
4-A	Semi-Specular Oxidized	69.0	68.0	−1.4
4-B		63.3	63.2	−0.2
5-A	Satin Oxidized	69.8	69.4	−0.6
5-B		68.5	67.1	−2.0
6-A	Satin Oxidized	68.2	66.4	−2.6
6-B		70.8	70.2	−0.8



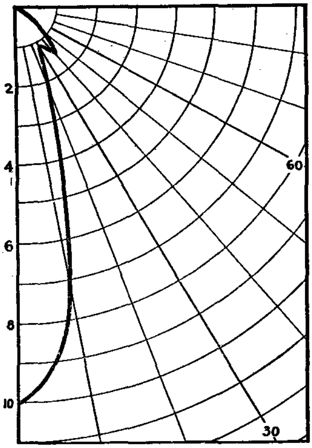


FIG. 5—(Left) Distribution curve of reflector sample No. 6-A having satin oxidized reflector surface with efficiency of 68.2 per cent.

FIG. 6—(Right) Distribution curve of reflector sample No. 1-A having all-polished reflector surface with efficiency of 74.0 per cent.

The range in the character of the surfaces of these reflectors is indicated in Figs. 5 and 6 which show the distribution curves of Sample 6-A and Sample 1-A respectively.

Measurements on Bare Lamps

A considerable amount of comparative bare lamp output data have been obtained on the spherical photometer and the integrator and it is believed that a summary of these tests will be of general interest. Table IV shows the per cent variation between the sphere readings and those taken in the integrator on four groups of various lamp sizes, each group consisting of fifteen lamps. In each case these readings are based on a checkup with a lamp of similar wattage and efficiency in order to eliminate any variation due to color.

TABLE IV—SUMMARY OF BARE LAMP TESTS IN INTEGRATOR

	25-W, 115-V A-19 Mazda B	40-W, 115-V A-19 Mazda C	100-W, 115-V A-23 Mazda C	150-W, 115-V PS-25 Mazda C
Average* Per Cent Variation from Sphere..................	−0.22	+1.25	−0.45	−0.73

* Average of 15 lamps in each group.

Conclusions

Experience in the laboratory with these two devices indicates beyond any question of doubt that a further application of the light-sensitive cell to photometry involving light distribution measurements is practical.

The importance of a more detailed analysis of various materials for re-directing light has been recognized. The Quadrant Distribution Reflectometer has already proved of commercial value in this field except for highly specular surfaces; with further improvement it should be entirely satisfactory even in this respect. Also, with slight modification this device can be used for determining transmission of translucent materials and their light distribution characteristics.

Some form of integrator to which photo-voltaic cells have been adapted will undoubtedly become of increasing value in the testing of lighting equipment.

The reduction in time, the low initial outlay for equipment, and the simplicity of operation are the most outstanding advantages to be gained by continued research in the application of light-sensitive cells to photometric measurements.

The authors wish to acknowledge their appreciation of the valuable assistance given by Mr. E. P. Meko in the preparation of the data presented in this paper.

DISCUSSION

CHAIRMAN SHARP: Gentlemen, you have heard the paper. We saw yesterday how in the matter of sources of light we are approaching a new deal. We have some more higher efficiency sources of light, and we haven't had anything of the kind for quite a good many years now. In photometry we are approaching something which is pretty new. That is the use of these cells which the authors have called "Photo-Voltaic" cells. May I ask you what you mean by a photo-voltaic cell?

G. R. BAUMGARTNER: Dry disk type of cell.

CHAIRMAN SHARP: Is it a voltaic cell?

G. R. BAUMGARTNER: It is commonly referred to as such?