IES Transaction

Luminance Measurement by Photographic Photometry

By I. Lewin and W. B. Bell

IN THE field of illuminating engineering, a great deal of time and effort is currently being devoted to the subject of luminance design. Throughout such considerations, problems frequently arise with respect to the actual determination of the luminance values themselves. For this purpose several methods can be used.[1] It is probably true that all these methods have, to a greater or lesser extent, disadvantages associated with their use, due largely to the complex nature of the quantity to be measured. This paper is a summary of a system of luminance measurement which relies on the photosensitive reaction of photographic film. The authors feel that the technique has certain advantages over other methods, and is worthy of consideration.

The idea of photographic photometry is not entirely new. Useful investigations have been carried out at various times by several others.[2, 3, 4] The technique presented in this paper, however, differs from the work of other investigators, both in the method of utilizing the photographic reaction, and in the depth to which the parameters have been studied.

Basically the technique relies on the fact that, under certain conditions, the amount of blackening of a photographic emulsion after development is dependent upon the luminance of the photographed object. Thus, by photographing the test scene under regulated conditions of camera exposure and film development, a negative can be produced which is a record of the luminance distribution. By providing a system of measuring and calibrating the blackness of the negative image in terms of luminance, a means of precise luminance measurement is provided.

The technique has numerous advantages:

1. A highly detailed analysis can be achieved, providing a complete iso-footlambert diagram of the test field with complete continuity.
2. The use of a highly comprehensive densitometer for measuring negative optical density allows the degree of detail recorded to be preset, according to the purpose of the measurement.
3. The use of various camera lenses allows any size of angle of view to be selected, from a wide angle lens for the full field of view, to a telephoto lens for high magnification of a small object. The camera position can thus be fixed, and true geometry maintained.
4. Measurement does not rely on a large number of spot readings, and the entire field is recorded almost instantaneously. Hence, there is no need for any time-consuming scanning system, which could cause difficulties in maintaining steady conditions for tests outside the laboratory. It is also conceivable that the technique would accommodate the photometry of moving objects.
5. In comparison with any visual or physical luminance measurement systems, the method is independent of errors of the human eye, or errors of photo-sensitive devices, respectively.
6. Only the short period of photographing the test scene is made in situ, all other work being laboratory routine.
7. The negative can be retained as required and may therefore be used at any time for the extraction of additional information.

Consideration of the Technique

We may subdivide the development of the technique into five sections, these being:

1. The selection of a suitable camera, lenses and accessories.
2. The selection of a suitable photographic ma-

A paper presented at the National Technical Conference of the Illuminating Engineering Society, September 9-12, 1968, Phoenix, Arizona. AUTHORS: Respectively, Holophane Co., Inc., New York, N. Y. and University of Newcastle upon Tyne, Newcastle, England.

terial and also of suitable filters to correlate the spectral response of the photographic system to that of the human eye.

3. The design of standard luminance apparatus for use as a calibrator for the photographic system.

4. The selection and control of the conditions of exposure and development of the photographic material.

5. Investigations into a method of image blackness measurement, so that the degree of blackness may be related quantitatively to luminance by the photographed standard luminance apparatus.

In choosing a camera for this type of work, the following factors must be taken into account:

1. The type of emulsion base to be employed.

Photographic emulsions are commonly used on glass plate, film or paper bases. Paper bases have several disadvantages, particularly as transparency is required for the image evaluation system, and may be disregarded. The use of roll film is conducive to both accuracy and convenience, as the ability to make numerous recordings on a single strip of film allows mutual processing and standardization. A single photograph can be used for the standardization of the whole film, whereas plate photography requires an individual calibration for each plate, superimposed upon the area to be analyzed. Photographic plates are, however, simple to develop uniformly because of their rigidity. After investigating both systems, there appeared to be no doubt that the use of roll film was preferable.

2. The size of the photographic negative required.

Clear definition is more easily obtained by the use of a large negative size, but complete uniformity of negative development, which is essential for correct analysis, is considerably simplified by employing a small negative area. Small size is related also to great depth of focus.[5] The use of a small negative size is recommended, together with a fine grain high resolution emulsion to overcome the definition problem.

3. The camera optical system.

It is highly desirable that a "single-lens reflex" camera is used. This form of camera incorporates a mirror system which reflects the rays entering through the lens into the eyepiece, in such a way that the view in the eyepiece is exactly that which will be recorded on the film. This is conducive to accurate operation, particularly where interchangeability of lenses is required, as is very likely in photographic photometry.

The optimum camera type, therefore, appears to be a high quality 35mm roll film single-lens reflex camera, with interchangeable lenses. The camera should be checked with the lenses to be used, to verify freedom from flare and ghost images, which can result from imperfect design or poor quality.

Several points arise regarding the choice of lenses. In general, we are more interested in the quality of transmission than the quantity, and thus, for a lens of a given cost, we should be prepared to sacrifice the use of a wide lens aperture for decreased light scattering and increased resolution. Furthermore, a wide maximum aperture will often be unnecessary. An automatic diaphragm is a good investment, as it allows the field of view to be seen at full aperture while setting up the camera, with no chance of resultant accidental incorrect camera exposure.

The focal length of the lens, which fixes the angle of view of the camera, is an important factor, the choice of which is regulated by the purpose for which the technique is to be used. We have the relationship:

$$\text{Focal Length} = \frac{\text{Length of Frame Side}}{2 \times \tan\ (\frac{1}{2} \times \text{angle of view})}$$

For a 35mm film the frame size is 24mm × 36mm. Which of these two values should be substituted in the numerator of the expression will depend upon whether it is desired to use the camera horizontally or vertically. Thus it is a simple matter to select the required focal length for a given application.

When a very short focal length lens is used, giving a wide angle of view, it may be necessary to compensate for geometrical distortion when tabulating results.

Selection of the Film and Filters

The average size of the silver halide grains of which a photographic emulsion is essentially composed is dependent upon the type of emulsion. Although coarse-grained emulsions show a faster response to incident light, they are likely to cause "irradiation" effects,[5] giving a blackened area different from that

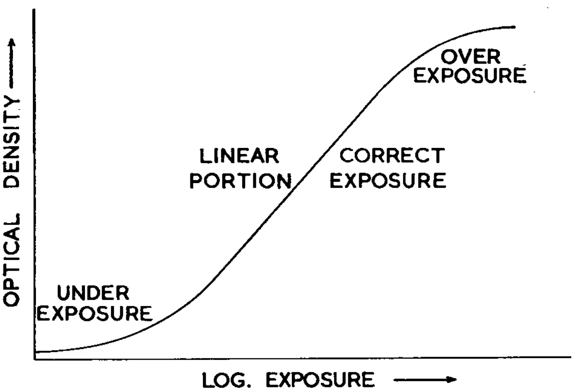

Figure 1. The characteristic curve of an ideal photographic emulsion.

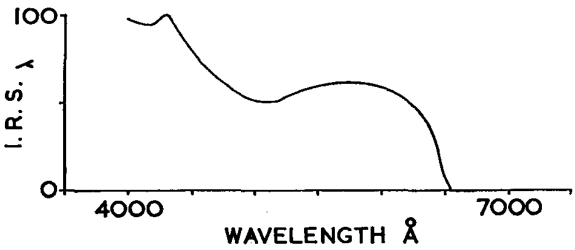

Figure 2. The intrinsic relative spectral sensitivity of Panatomic-X film.

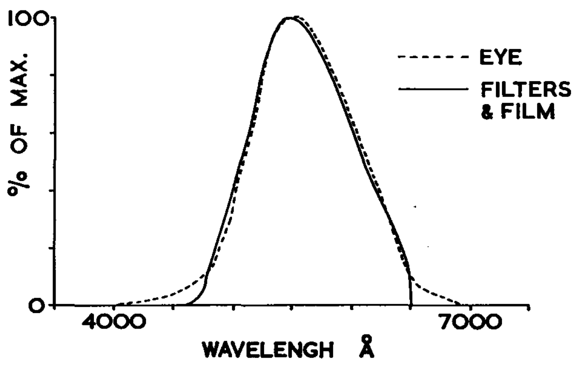

Figure 3. A comparison of the photopic response curve of the eye to the film and filter combination.

of the true image area, due to granular reflection and refraction within the emulsion. It is important that this effect is small, and therefore the use of a fine-grained emulsion is preferable.

Error can be introduced also by "halation," which is due to total internal reflection from the film surface, but may be overcome by the use of an anti-halation film backing.

Fig. 1 shows a theoretical response curve of a photographic emulsion to the logarithm of exposure, exposure being defined as the product of incident illumination at a point on the film and the time of incidence. Although the characteristic curves of most photographic emulsions are basically similar, certain variations in shape occur. As the toe and shoulder regions are unsuitable for use in photographic photometry, the emulsion used should have a long linear portion, in order to allow the recording of a wide luminance range within a single negative.

As a result of these considerations, the film we selected was Kodak Panatomic-X.

The spectral responses of photographic emulsions differ greatly from that of the eye, in particular in that they have a higher red sensitivity and a very high blue sensitivity. It is essential that this difference is compensated by the use of correction filters. Fig. 2 shows the response curve of the film employed, determined by the use of a wedge spectrograph. From this curve the transmission curve of the ideal correction filter was calculated. A combination of filters was used for the correction, consisting of one pale yellow and two cyan gelatine units, determined by comparison of transmission curves to the ideal. A Wratten No. 9 filter (pale yellow) was used to give the desired blue absorption, combined with Wratten filters CC2OC and CC50C (color correcting cyan), to provide the necessary red absorption. The resultant response curve of the film and filter combination is shown in Fig. 3, alongside the photopic response curve of the eye, and will be seen to be, for practical purposes, perfect.

Calibration Equipment

The luminance measurement technique is dependent upon the ability to relate any given value of image blackness to a corresponding object luminance value. This necessitates having a series of areas of known luminance which can be photographed and used as a film calibrator.

Fig. 4 shows the "standardization box," which consists essentially of a uniform step wedge formed by a series of two-inch square neutral density filters, having optical densities of 0.3 to 3 in steps of 0.3, these filters being uniformly illuminated by tungsten filament or fluorescent lamps under an opal glass screen.

The step-wedge luminance is measured photoelectrically by a calibrator which clips in front of an

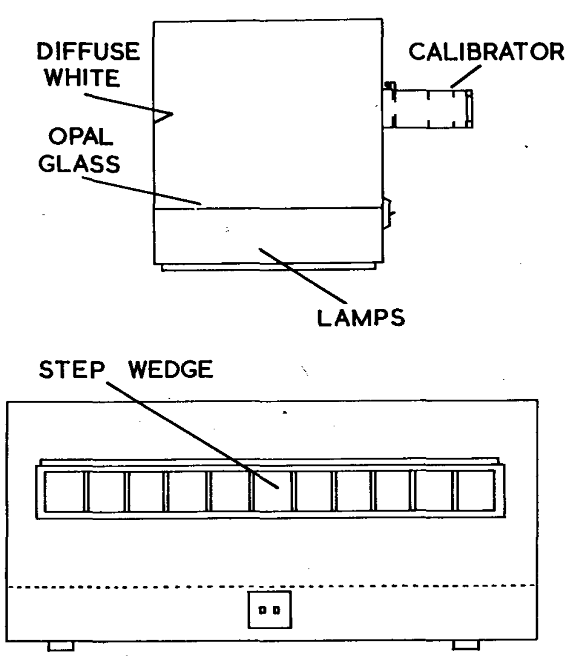

Figure 4. Diagram of the standardization box.

individual step-wedge aperture. The calibration device is a matte black tube with interior reflection masks, containing a circular orifice at one end and a color-response-corrected photoelectric cell at the other. The orifice is smaller in diameter than the side of a step-wedge aperture, and thus when positioned in front of an aperture, becomes fully flashed. We therefore have the situation of a finite uniform disc source illuminating a circular receiver at a short distance of separation, which is governed by the relationship:[6]

$$E_p = \frac{L}{2}\left[1 - \frac{d^2 + p^2 - r^2}{\sqrt{(d^2 + p^2 - 4^2)^2 + 4d^2r^2}}\right]$$

where E_p = the illumination at any point on the cell. (fc)

L = source luminance. (fL)

d = the distance of separation of the cell and orifice

r = the radius of the source, *i.e.* the orifice

p = the distance from the center of the cell to the point considered.

From this expression, E_p/L can be calculated for any value of p by measuring d and r, and the relationship graphed. Dividing the area under the graph by the maximum value of p will give the weighted mean value of E_p/L, which will be a constant expressing the ratio of the mean cell illumination to step luminance. The cell can be calibrated on a photometric bench and the relationship between mean cell illumination and cell output determined. Thus, knowing the ratio of mean illumination to luminance, the step-wedge luminance for any aperture can be measured.

Measurement of Optical Density

Measurement of the optical density of the photographic negatives should be carried out by a highly accurate densitometer capable of measuring very fine detail, and preferably having an automatic scanning and plotting or punch-out system. The instrument used operates on a double-beam system, whereby two exactly similar beams are produced from a single source, one of which is passed through the test specimen. The two beams are exposed alternately to a photo-multiplier tube, which generates a signal dependent on the difference in beam intensities, and thus dependent on specimen optical density. The signal is amplified and used to drive a graphing pen on a null balancing system, such that a linear trace of optical density is obtained.

This type of instrument has numerous measurement parameters which may be accurately adjusted, thus allowing great scope, and was found to be extremely reliable.

Exposure and Development of the Film

The following factors are important:

1. The camera lens settings.
2. The method of film development.
3. The method of film calibration.
4. The duration of exposure, for medium luminances.
5. The analysis of high luminances.
6. The analysis of low luminances.
7. The "cosine fourth" and vignetting effects.

Within certain limits, image definition is improved by reducing the lens aperture, but of course this is accompanied by a loss of transmission. We decided to use a lens setting of $f/8$ throughout our work, and found that this was satisfactory in both respects.

The degree of development of a photographic film depends on several variables, notably the development time and temperature, and the type of development solution. Variation of these factors will alter the nature of the characteristic curve of the film, and it is a matter of experimentation to find the best conditions for the purpose in hand. The authors used Paterson FX-18 developer for seven minutes at a temperature of 68°F, although it is always possible that other combinations may prove as good or even better. A black polystyrene cylindrical developing tank was used, with constant agitation. No difficulty was experienced from lack of uniformity in development. This was probably a result of the small negative size.

Photograpic development is such that small fluctuations cannot be avoided, and thus for exact calibration, the standardization box step-wedge is photographed on each test installation film, thereby being subjected to development conditions identical to the photographic negatives of the installation. Each film is calibrated by exposing two frames to the standardization box, one being used to check the other. Using the microdensitometer to scan the resultant image, the optical density of each step of the step-wedge is measured, and can be plotted against the corresponding step luminances, so providing the required calibration curve.

The optical density of the image is regulated by the duration of incidence as well as the object luminance. Thus the exposure time must be fixed for any calibration to be applicable. The selection of the optimum exposure time for a given luminance range is achieved by the determination of a family of response curves for the film. Fig. 5 was obtained by photographing the standardization box at various exposure

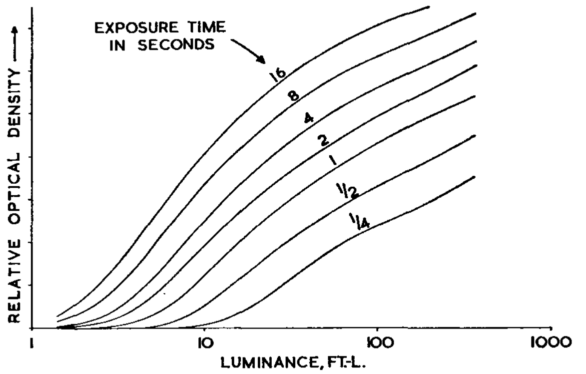

Figure 5. The relationship between object luminance and film optical density.

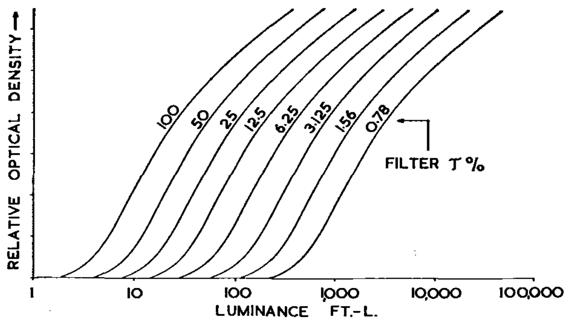

Figure 6. Calibration curves for the measurement of high luminances.

times. It was found that long exposure times caused irradiation. This effect was measured on a relative basis by determining the film density in the space between the respective images of the two brightest wedge steps, which should theoretically be zero, but in practice will not be zero if irradiation is present. Short exposure times resulted in a major portion of the wedge luminance range being underexposed, that is, lying in the toe of the curve. An intermediate time of two seconds was chosen as optimum.

Luminance values longer than those provided by the standardization wedge can be recorded by increasing the exposure time. A similar series of curves could be determined by photographing the step-wedge through a neutral density filter and applying the necessary correction to the object luminance scale. A four-minute exposure enables the extension of the measurement range to 0.1 footlamberts, and standardization is achieved using a 1.56 per cent transmittance neutral filter. High luminance values may be recorded by placing a neutral density filter in front of the camera lens when photographing the installation. Fig. 6 shows the calibration curves resulting from the use of various numbers of 50 per cent transmittance neutral density filters, these being obtained by replotting the curve for a two-second exposure time given in Fig. 5, to a luminance scale increased in proportion to this transmittance. The use of six such filters, giving an overall transmittance of 1.56 per cent, was found to cover the upper range as required.

Due to the geometry of a photographic system, when a field of uniform luminance is photographed, the resultant negative density will reduce with increasing distance from the negative center, due to the "cosine fourth" and "vignetting" errors.[5] By measuring the degree of fall-off with respect to distance on the negative, a correction factor for this effect can be determined (Fig. 7). This test must be performed for each lens, as the magnitude of the effect is variable.

Example Analysis

Having obtained all the necessary apparatus, and selected the exposure and development conditions together with the required calibrations, a system of routine analysis is provided.

An engineering drafting office was chosen to illustrate the method (Fig. 8). The office is lighted by four-foot by two-foot recessed prismatic luminaires, daylight being screened by venetian blinds. The ceiling is finished in high-reflectance diffuse one-foot square panels, and in general, most surfaces in the room are of fairly high reflectance.

The field of view required to be analyzed was photographed on Panatomic-X film using a 24mm focal length lens, through the selected correction filter combination. With a lens aperture of $f/8$, a photograph was taken using an exposure time of two seconds, and another then taken through a 1.56 per cent transmission neutral density filter using the same exposure time. These two photographs gave correct exposure for the complete coverage of the medium and high luminance ranges, that is, from slightly more than one footlambert to approximately 23,000 fL. Lumi-

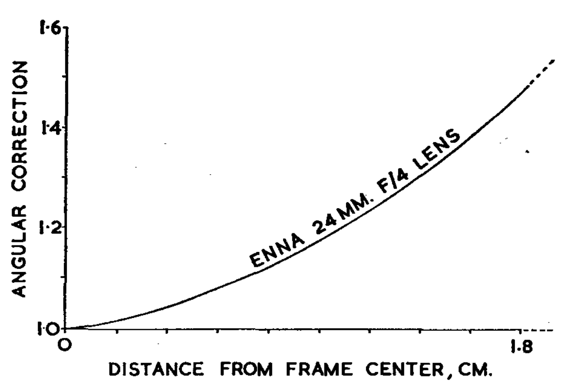

Figure 7. The correction factor characteristics for vignetting and cosine fourth law effects.

Figure 8. *The analysis of the example installation.*

nances of less than one fL were insignificant in this instance.

The standardization box was photographed before and after the photographing of the installation, again using a camera exposure of two seconds at *f*/8.

The film was developed under the recommended conditions, and a microdensitometer scan made of the step-wedge images. The optical densities so obtained (measured above the "fog" level of the film[5]) were plotted against the known values of step luminance, providing the medium luminance calibration curve. The curve was replotted to luminance values increased by a factor of 100/1.56, to provide the high luminance calibration curve.

Both photographs of the installation were then scanned in a radial pattern, the density values taken from each respective scan being entered in a table as shown. The indicated luminance values at given increments along each scan were determined from the calibration curves, and the angular fall-off correction factors, which are fixed for a given lens, were entered in the table. The multiple of the correction

Table I—Results From Microdensitometer Scan

Distance From Frame Center (Cm.)		Relative Optical Density	Luminance Range	Measured Luminance fL	Angular Correction Factor	Actual Luminance fL
Left of Center	Right of Center					
0.1	—	7.40	Medium	17.9	1.01	18.1
0.2	—	8.62	"	25.0	1.04	26.0
0.3	—	8.18	"	21.9	1.08	23.6
0.4	—	7.21	"	17.0	1.12	19.0
0.5	—	7.23	"	17.3	1.18	20.4
0.6	—	9.06	"	28.6	1.24	35.5
0.7	—	10.99	High	1380.0	1.31	1808.0
0.8	—	9.02	Medium	28.2	1.38	38.9
0.9	—	8.51	"	24.2	1.46	35.3
Center		10.93	"	52.4	1.00	52.4
—	0.1	8.12	"	21.6	1.01	21.8
—	0.2	10.83	"	51.2	1.04	53.2
—	0.3	8.24	"	22.4	1.08	24.2
—	0.4	13.71	"	183.0	1.12	204.9
—	0.5	8.78	"	26.2	1.18	30.9
—	0.6	8.64	"	25.2	1.24	31.2
—	0.7	8.32	"	22.9	1.31	30.0
—	0.8	0.51	"	2.6	1.38	3.6
—	0.9	10.27	"	43.2	1.46	63.1

factor and indicated luminance will give the actual luminance at any position.

The luminance values can then be presented as required. Fig. 8 shows selected iso-footlambert contours of some of the areas of interest, superimposed over the installation photograph.

This paper is a summary of the authors' attempts to produce a system of luminance measurement which overcomes disadvantages inherent in the currently accepted methods. Vigorous investigations have shown that a high degree of accuracy is obtainable, comparable to or greater than that of other modern techniques, providing exposure conditions are wisely chosen.

The authors feel that photographic photometry is an advantageous method for use in such applications as the determination of luminaire luminance patterns and average luminances, luminaire optical design investigations, measurement of interior and exterior installation luminances, and measurement of adaptation luminance and glare magnitudes. Work is continuing in several of these fields.

References

1. "IES Guide for the Measurement of Photometric Brightness," ILLUMINATING ENGINEERING, Vol. 56, July 1961, p. 457.
2. Marsh, C. and E., "A Photographic Method of Brightness Recording," ILLUMINATING ENGINEERING, Vol. 53, June 1958, p. 355.
3. Meyers, G. J., and Mooney, V. J., "Measuring the Brightness of Streets by Means of Photography," ILLUMINATING ENGINEERING, Vol. 36, June 1941, p. 643.
4. Waldram, J. M., "Road Surface Reflection Characteristics and Their Influence on Street Lighting Practice," *The Illuminating Engineer* (London), 1934, p. 305.
5. *Ilford Manual of Photography*, Ilford Publishing Co., London, England.
6. Keitz, H. A., *Light Calculations and Measurements*, Cleaver-Hume Press, Ltd., London, 1955.

DISCUSSION

CARL J. ALLEN:* The camera technic of evaluating photometric brightnesses is a very intriguing subject, but it seems that there are many potential pitfalls in its use.

Experienced photographers tell me that the density of a roll of film uniformly exposed (as by flashing by a single light source outside the camera), can vary considerably from point to point due to variations in the film and in the developing process. Did the authors so expose any film and explore the results with the densitometer to determine the order of this variation?

Cameras are not perfect black boxes. Light from outside the lens' angle of view can enter the camera and by interreflections and lens-flare action expose the film in a nonuniform manner. Was this condition investigated?

The mathematics of the authors' calibration technic assumes that the neutral density filters of the 'standardization' box emit light perfectly diffusely, and that the photocell is perfectly cosine-corrected, and that the interreflected light in the calibrator is reduced to zero. Any departure from these ideal conditions can introduce inaccuracies in the calibration.

It was assumed by the authors that the transmission of six 50 per cent filters is equal to the sixth power of 0.5. It has been my experience that multiple interreflections in stacks of filters does not permit this simplified arithmetic and that the actual transmission is different from the calculated value.

One simple test that would indicate the order of importance of the several items mentioned above would be to compare the luminance values determined by this camera technique against actual brightness meter values of the same points in the same scene. Was such a test performed to evaluate the degree of accuracy of this system?

From a crude evaluation of the size of the small areas of brightness reported in Fig. 8, it appears that the scanning spot of the densitometer must have been of the order of a sixty-fourth of an inch in diameter. It would be appreciated if the authors would further describe the densitometer in this respect.

*General Electric Co., Nela Park, Cleveland, Ohio.

ISAAC GOODBAR:* The presentation of the paper indicated that color photography was used in the method. If this is so, how were the measurements on color film reduced to luminance values?

R. D. BRADLEY:** This is a very interesting paper, particularly in view of the fact that it contains the details of the authors' experimentation so that others might actually benefit by their techniques.

While this discusser realizes that the brightnesses shown in Fig. 8 are not truly representative of the negative densities, this figure is quite representative of the number and types of luminance involved in the field factor used in VCP glare formulas. One can almost get the feeling of discomfort from the high luminance of the open venetian blind on the left-hand side of the picture. By holding one's hand over this white area, one can almost experience a feeling of added comfort—this reflection coming from actual experiences which most everyone has had. It is also quite indicative of why end-wall brightnesses cannot be used as truly indicative in determining the field factor.

It should also be noted that there are usually many worse glare sources than the lighting fixtures where daylight is employed.

B. F. JONES:† We should be aware that the shutter speed of a camera may vary considerably, and that this factor would substantially upset the accuracy of results obtained by this technique. It must also be realized that the reduction of illumination by a lens with increasing angle from the axis will vary for individual lenses, because of the effect of focal length and suchlike. The calibration for one lens cannot be used as a calibration for all lenses.

*Edison Price, Inc., New York, N. Y.
**Day-Brite Lighting Div. of Emerson Electric Co., St. Louis, Mo.
†Smoot-Holman Co., Inglewood, Calif.

P. F. O'BRIEN:* This technique appears to be readily applicable to data processing by computer. A digital output could be taken from the microdensitometer at predetermined intervals over the scan, and the computer programmed to plot the iso-footlambert contours. This is one instance of several uses to which this method could be applied.

I. LEWIN AND W. B. BELL:** Mr. Allen is correct in stating that there are many potential pitfalls in the technique; this is the reason so much detailed research was carried out, in order that all pitfalls could be avoided.

Regarding the possible variation of optical density over the film for uniform luminance, very thorough investigations were made. Suitably exposed films were tested for uniformity in the longitudinal and lateral directions, and also in both diagonal directions. As well as testing the uniformity of the film itself, this was also a test of the uniformity of development. The greatest variation obtained was ±2 per cent, which was a freak value; the normal variation was approximately ±1 per cent. We concluded therefore that the uniformity of both the film and the development technique were of a sufficiently high standard for our purposes.

Image imperfections from stray light can arise in several ways, which may be summarized as "camera flare," caused by interreflections within the body of the camera, "lens flare," caused by reflections from the interfaces of the lens elements, and "ghost images," which are incorrectly cast images of bright objects. This indicates a further benefit of employing a single lens reflex camera, for any ghost images or such could readily be seen in the viewfinder, as this is illuminated by the main lens. However, none of these possible errors will result from the use of a high quality camera. We are not concerned with the cheap cameras used by amateur hobbyists, but with good quality scientific instruments, such as are available from $200 to $300.

Concerning the light emitted by the neutral density filters of the standardization box, this can be tested for perfect diffusion by photographing the steps and analyzing the result on the microdensitometer. A uniform optical density, after correcting for angular fall-off, will indicate uniform luminance with changing angle. Tests showed that the emission was perfectly diffuse, which was as expected due to the solid angle concerned having a half-apex angle of only five degrees.

The calibrator was carefully designed to prevent interreflections. The calibrator tube contains three screens with circular orifices, placed at strategic positions. The interior of the tube was painted matte black. The authors feel that the screening so provided is equally adequate or more so, than that normally used for other purposes in photometric laboratories.

Concerning the use of 50 per cent transmittance neutral density filters, these were used in a stack only to determine the approximate overall transmittance required to cause a small overlap of the luminance ranges, so that complete coverage could be provided. This method was convenient as one 50 per cent filter is directly equivalent to one camera stop. Having decided that six such filters were required, a single filter of 1.56 per cent transmittance was obtained and used for subsequent work.

The photographic technique has been compared only to measurements using an S.E.I. meter,[1] and all values were found to correspond to within the accuracy of this meter. The S.E.I. meter is not of the highest accuracy, and we would like to carry out further tests with a more comprehensive instrument. The repeatability of the photographic results, however, has an accuracy of ±2 per cent. Also, the calibration of the standardization system was carried out at yearly intervals over a period of four years, and a variation no greater than ±½ per cent was found.

Mr. Allen is astute in his estimation of the size of the scanning spot. The microdensitometer allows adjustment upwards from a spot size of 0.01 mm. by 0.01 mm., the size used by the authors being 0.5 mm. by 0.5 mm., which is approximately 1/50-inch square.

In reply to the discussion by Isaac Goodbar, the investigations were carried out using black and white photography only color being used only for illustrating the lecture.

We agree with Mr. Bradley that the photograph gives a direct feeling of glare, and the investigations into photographic photometry were, in fact, part of an overall study of glare. It is logical to presume that this technique could provide a useful tool for those concerned with glare and its measurement.

Regarding the determination of F, work is progressing towards the measurement of a similar quantity, adaptation luminance. It will be appreciated that the full field record lends itself readily to this type of analysis.

A wide variation of shutter speed should not occur with a high quality camera. Furthermore, it must be remembered that the recommended exposure times are long, the shortest being two seconds. Taking even a 10 per cent inaccuracy at a normal shutter speed of, for instance, 1/100th second gives an inaccuracy of 1/1000th second, which in such a case may have an appreciable effect. Applying such a timing inaccuracy to the recommended two-second exposure, however, gives a variation of 0.05 per cent. (There is no reason why the inaccuracy should increase in proportion to the exposure time, due to the nature of the camera mechanism.) It should also be remembered that in the testing of the repeatability of results, a figure of ±2 per cent was obtained. Such testing gives an overall figure for repeatability, which includes shutter speed as one of the possible variable factors.

Mr. Jones is correct in stating that the angular fall-off characteristic of one lens will be dissimilar to that of another. If more than one lens is to be used, therefore, each should be calibrated separately, at the aperture setting which is subsquently to be used.

The computerization of the microdensitometer has interested us for some time, but as yet, only initial work has been done, and no program has been established. Automatic data processing coupled with the used of this machine greatly increases the capabilities and application of the technique. The authors agree with Prof. O'Brien that great possibilities lie in this idea.

It should be mentioned that an 'isodensitracer,' which plots a type of contour diagram, is available for use with the microdensitometer, but the authors do not have experience with this instrument.

The cost of the microdensitometer used in this work was approximately $4000, which could tend to restrict the widespread use of this technique. Universities, research institutions and larger companies may find this no problem, but it would be preferable if the method were readily available to all organizations interested in obtaining luminance data, including utilities, small manufacturers and consultants. Promising research is currently being devoted to this important point, and it is hoped that modifications will be presented in the near future to further increase the possibility of wide acceptance of this technique.

*School of Engineering, University of California, Los Angeles, Calif.
**Authors.