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CALIBRATION

and Re-calibration of Photoelectric Meters to Correct for the Spectral Characteristics of the Measured Light

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Because the spectral response of a photoelectric device differs, in general, from that of the standard observer, it is impossible for one calibration of a photoelectric meter in photometric units to be accurate for various light sources of different spectral characteristics. Correction factors are derived, with which a reading must be multiplied, if the measured light has a spectral distribution different from that used in the original calibration. Also given is a relatively simple method for calibrating any photoelectric meter if a source of known intensity and spectral distribution is available.

BECAUSE of the wide-spread use of photoelectric devices for the measurement of illumination and brightness, it should be of general interest to investigate the applicability of absolute readings of luminous flux with such devices. In some cases, these instruments are calibrated in arbitrary units, permitting only relative readings. In other cases, the meters are calibrated directly in footcandles or other photometric units, ostensibly making it possible to determine illumination or brightness in absolute terms.

Unfortunately, the superiority of the latter calibration is to a certain extent illusory. The calibration must be based on an assumed spectral distribution of the light source and when the instrument is then used on a light source with a different spectral distribution, the calibration will no longer be valid, except if the spectral response of the photoelectric device follows accurately that of the standard observer. Since this latter condition is very difficult to achieve, even with optical filters,[1] the calibration of the footcandle meter or brightness meter will frequently be useless. This is particularly true with the increased use of fluorescent and arc lamps. Due to the line-spectrum inherent in these light sources, a minor discrepancy of the spectral characteristics may result in a major error in the measurement.

In view of the above difficulties, it might be of interest to users of electric photometers to have available a method for converting their relative brightness readings into absolute photometric units and to be able to compute correction factors to compensate for the discrepancy between the response of the photoelectric device and that of the standard observer.

Such correction factors are frequently mentioned in the literature[2,3,4,5] and may be obtained empirically by using the calibrating source and the source to be measured in conjunction with a visual photometer. The alternative, a numerical computation of the correction factor, does not seem to be available in the literature. A report of the Committee On Photoelectric Portable Photometers of the Illuminating Engineering Society[6] derives some of the basic relationships but does not give a calibrating procedure nor a complete formulation of the correction factor to be applied to a previously calibrated "footcandle meter."

It is therefore felt that, despite its relative simplicity, a presentation of the required results might be useful to a large number of users of photoelectric photometers, especially to those who are not too familiar with photometric principles.

Spectral Calibration and Correction

The spectral calibration and correction factors involve integrals of the products of the following functions of the optical wavelength (λ): the relative spectral response of the standard observer (k), the relative spectral response of the photosensitive device (p), the relative spectral characteristic of the calibration light source (c), and the relative spectral characteristic of the light source to be measured (m). It is assumed that the above functions, k,p,c and m are all known; they may be chosen to any linear scale. Their magnitudes will be designated by K_k, K_p, K_c and K_m, respectively,

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only for the purpose of deriving the desired factors. These magnitudes need not be known.

In addition to the above relative spectral characteristics, only the intensity of the calibrating source must be known in order to calibrate any photoelectric device for any given light source.

Let us assume that a known amount of luminous flux (F_c) from the calibrating light source produces a meter reading (M_c). An unknown amount of flux (F_o) from the light source to be measured produces a meter reading (M_o). We may then clearly write

$$M_c = K_p\ K_c \quad \int p\ (\lambda)\ c\ (\lambda)\ d\lambda \qquad (1)$$
$$F_c = K_k\ K_c \quad \int k\ (\lambda)\ c\ (\lambda)\ d\lambda \qquad (2)$$
$$M_o = K_p\ K_m \quad \int p\ (\lambda)\ m\ (\lambda)\ d\lambda \qquad (3)$$
$$F_o = K_k\ K_m \quad \int k\ (\lambda)\ m\ (\lambda)\ d\lambda, \qquad (4)$$

where all the values of the left hand members will be known, with the exception of the last one. It follows from the above equations that

$$F_o = \frac{M_o\ F_c}{M_c}\ \frac{[\int k\ m\ d\lambda]\ [\int p\ c\ d\lambda]}{[\int p\ m\ d\lambda]\ [\int k\ c\ d\lambda]}, \qquad (5)$$

where all the factors of the right hand member are known.

NOTE: The integrals are probably most readily determined by choosing a series of wavelengths $\lambda_1, \lambda_2 \ldots\ldots\ \lambda_N$, such that successive wavelengths differ by a conveniently small amount $\triangle\lambda$. The integrals can then be approximated by summations as follows:

$$\int a\ b\ d\lambda \doteq \triangle\lambda \sum_{n=1}^{N} a_n\ b_n \qquad (6)$$

If the meter is already calibrated in photometric units, it is, of course, not necessary for the user to use his own calibrating light source. In that event, $M_c = F_c$ in equation 5 and the spectral correction factor to be applied to the reading M_o will be simply:

$$\frac{[\int k\ m\ d\lambda]\ [\int p\ c\ d\lambda]}{[\int p\ m\ d\lambda]\ [\int k\ c\ d\lambda]} \qquad (7)$$

The values of the latter integrals in the numerator and denominator could be supplied by the manufacturer together with a tabulation of p. The user can then compute the former integrals for the particular light source he is measuring.

Radiant Flux Measurements

In some cases it may be of interest to measure radiant flux (in watts) rather than luminous flux (in lumens). In that case the above expressions (5) and (7) may still be used, merely setting $k = 1$, $F_o = R_o$, $F_c = R_c$, where R_o is the amount of radiant flux to be measured and R_c is the radiant flux of the calibrating source.

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