RCA Application Note

AN-187

Photometry as Applied to Camera- and Cathode-Ray-Tube Applications

This Note defines the terms, symbols, and units used in photometry, and shows their relationship to corresponding radiometric terms. In addition, methods for the calculation of tube-face illumination for camera tubes and screen luminance for cathode-ray tubes are outlined.

Definition of Photometric Terms and Symbols

Photometry deals with the evaluation of radiant energy with respect to its ability to produce visual sensation. Because the degree of visual sensation depends on the wavelength of the radiant energy, there is a difference between radiant and luminous measurements. The actual energy which is transferred by electromagnetic waves is called radiant energy, but only the radiant energy which stimulates visual sensation is called luminous energy.

A luminosity curve shows the relative effectiveness of various wavelengths of radiant energy to evoke visual sensation for a particular observer under particular conditions. The standard luminosity curve (photopic vision) shown in Fig.1 has been adopted to make photometry as objective as possible and to provide a standard for the specification of photometric data. This curve represents an average of a number of observations; it is not necessarily the response of any one observer. The ordinate at any point on the relative luminosity curve is often called the "visibility factor" for the wavelength corresponding to that point.

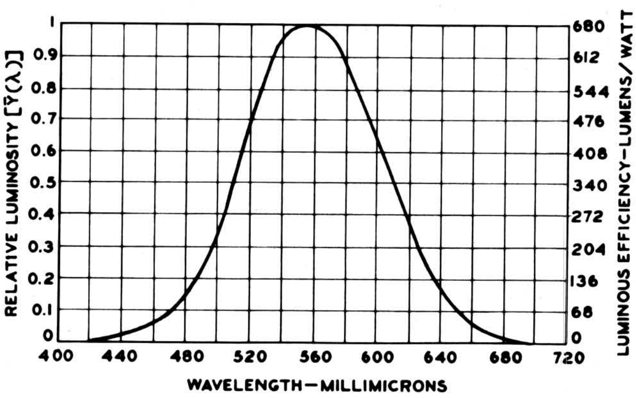

Fig.1 - Standard luminosity curve.

The luminous efficiency of a source of light is the rate of emission of luminous energy per watt of input power. Luminous efficiency should not be confused with the luminous coefficient, which is a ratio of the luminous energy to the radiant energy emitted from a source.

The committee on colorimetry of the Optical Society of America has recommended the following table, which gives the names, symbols, and basic MKS units used in photometry and radiometry:

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10-60

Radiometry			Photometry		
Term	Symbol	MKS Units	Term	Symbol	MKS Units
Radiant Energy	U	joule	Luminous Energy	Q	talbot
Radiant Flux	P	watt	Luminous Flux	F	lumen
Radiant Emittance	W	watt/m^2	Luminous Emittance	L	lumen/m^2
Radiant Intensity	J	watt/ω	Luminous Intensity	I	lumen/ω (candle)
Radiance	N	watt/ωm^2	Luminance	B	lumen/ωm^2 (candle/m^2)
Irradiance	H	watt/m^2	Illuminance	E	lumen/m^2 (lux)
	m	meter		ω	steradian

Table I - Recommended names, symbols, and MKS units for radiometric and photometric terms.

Any radiometric unit is converted into the corresponding photometric unit by evaluation with respect to the standard luminosity function, $\bar{y}(\lambda)$. As an example, the standard luminosity curve of Fig.1 shows that a source at 600 millimicrons will produce 430 lumens of luminous flux for every watt of radiant flux.

Luminous flux F is the rate of flow of luminous energy Q. One lumen corresponds to a luminous flux of one talbot per second. One lumen is also defined as the luminous flux F_e emitted through a unit solid angle from a point source of one candle; i.e., a one-candlepower point source emits a total of 4π lumens.

Luminous emittance L is the luminous flux density of an emitting surface and is expressed as follows:

$$L = \frac{F_e}{A}$$ lumens per square meter, or lumens per square foot

where A is the area of the emitting surface.

Luminous intensity I is the ratio of luminous flux emitted by an element of source in a solid angle to the solid angle, or the luminous flux per steradian ω emitted by a source. It is expressed as follows:

$$I = \frac{F_e}{\omega}$$ lumens per steradian

Luminance B is the quantitative attribute of light that correlates with the sensation of brightness. The term "brightness" should be used only for nonquantitative statements, especially with reference to sensations and perceptions of light. Units of luminance fall into two classes. The first, "intensity-luminance", is given by:

$$B_i = \frac{I}{A\cos\theta}$$ lumens per steradian per square meter, or candles per square meter

where I is the luminous intensity of the area A, as viewed along a direction that makes an angle θ with the normal to the surface. The second unit of luminance applies to sources obeying Lambert's Law, which states that "the intensity from a surface element of a perfectly diffusing radiator is proportional to the cosine of the angle between the direction of emission and the normal to the surface." An element of a surface which obeys this law appears equally bright when observed from any direction. This unit, called lambert-luminance B_l is given by:

$$B_l = \pi B_i \quad \text{footlamberts, meterlamberts, or the like}$$

Illuminance E, or illumination, is the density of luminous flux F_r on a surface which is uniformly illuminated. Expressed mathematically,

$$E = \frac{F_r}{a} \quad \begin{array}{l}\text{lumens per square meter (luxes),}\\ \text{lumens per square foot (footcandles), or}\\ \text{lumens per square centimeter (phots)}\end{array}$$

where a is the area of the illuminated surface.

For perfectly diffusing radiators, the luminous emittance L is equal to π times the "intensity-luminance" B_i. Therefore, a perfectly diffusing radiator having a luminance of B_i candles per square meter emits πB_i lumens per square meter.

Fig. 2 graphically illustrates the important terms used in photometric calculations.

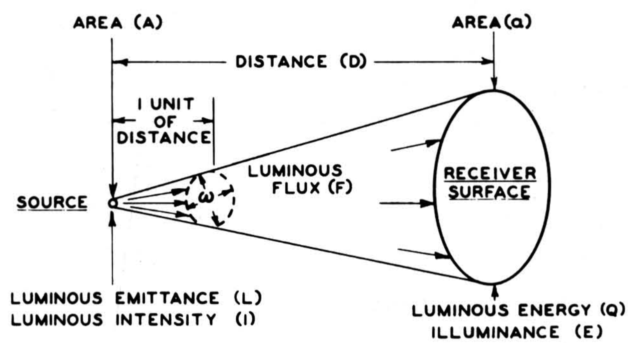


Fig. 2 - Graphic representation of important photometric terms.

Calculation of the Tube-Face Illumination of Camera Tubes

A scene to be televised is optically focused on the face of a camera tube by means of a lens. For practical purposes, the illumination of the camera-tube face can be calculated from the following formula:

$$E = \frac{E_s RT}{4f^2(m+1)^2}$$

where E is the tube-face illumination in footcandles,

E_s is the scene illumination in footcandles,
R is the reflectance of the scene,
T is the transmission of the lens,
m is the linear magnification from scene to tube face, and
f is the f/number of the lens.

These factors are obtained as follows:

As shown in Fig. 3, the illumination of a scene E_S is usually obtained

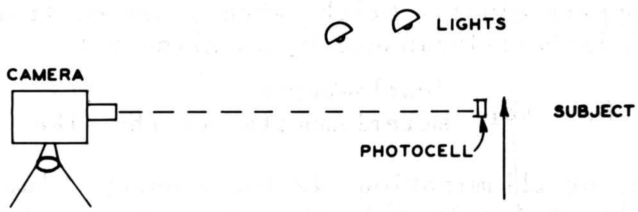


Fig. 3 - Set-up for determining illumination of a scene with a photocell meter.

by means of a calibrated photocell placed near the principal subject in the scene, with the cell facing the camera. The illumination is indicated in footcandles on the photocell meter. For outdoor camera-tube use, Table II may be useful as a "rule-of-thumb" in determining the approximate scene illumination.

Lighting Conditions	Scene Illumination (Footcandles)
Full daylight*	1000-2000
Overcast day	100
Very dark day	10
Twilight	1
Deep twilight	0.1
Full moon	0.01
Quarter moon	0.001
Starlight	0.0001
Overcast starlight	0.00001

* Not direct sunlight.

Table II - Approximate scene illumination under various outdoor conditions.

If a neutral density filter is used over the lens, the tube-face illumination is decreased by a factor equal to the filter transmission.

The value of reflectance R of the principal subject in the scene must usually be estimated. The value of reflectance for a test pattern is about 0.9; for live scenes, 0.5 is often used as a typical value.

The product $E_S R$ may be replaced by the luminance of the principal subject, as obtained with a luminance meter. If E is to be in footcandles, the luminance reading must be in footlamberts.

The transmission T of lenses varies. For standard Eastman Kodak Ektanon image-orthicon lenses, 0.9 is a typical value; for some lenses, however, the transmission may be 0.75 or less.

The symbol f is the actual f/number used. It should be remembered that the lower the f/number, the greater the illumination on the face of the camera tube.

The magnification m is the quotient of the image size divided by the object size. So long as the distance from the camera lens to the subject is large compared to the focal length of the lens, this term is negligible. For example, if the lens-to-subject distance is 17 times the focal length, the value of the term $(m + 1)^2$ is only 1.12; i.e., a 12-per-cent error is introduced if the magnification is neglected. (The focal length of a lens is usually stamped on the front of the lens mounting.)

Measurement and Calculation of the Luminance of Cathode-Ray-Tube Screen

In general, there are four methods used to measure the luminance of a cathode-ray-tube screen. Methods I and IV measure the average luminance of the area directly beneath the measuring device. Methods II and III measure average luminance over the entire raster area. In these measurements, there are many sources of error and accuracy within 10 per cent is considered satisfactory.

Method I—Use of a luminance meter or "brightness" meter

When a "brightness" meter is used (several types are commercially available), luminance, usually expressed in footlamberts, can be read directly from the meter provided it is properly calibrated and is pointed at the cathode-ray-tube raster. Because these meters usually view a small area, they can be moved to other areas of the raster to measure luminance variations over the face of the tube. The value obtained from a luminance meter is not a function of distance from the tube face.

Method II—Use of an illumination meter when cell-to-tube-face distance is at least five times the largest dimension of the raster.

The eye-corrected Weston Photronic cell is a popular unit for measuring illumination from a source in footcandles. The measured value is a function of distance from the tube face, which can be less than five times the largest raster dimension if errors due to geometry of more than one per cent can be tolerated. Fig.4 shows per-cent error in luminance as a

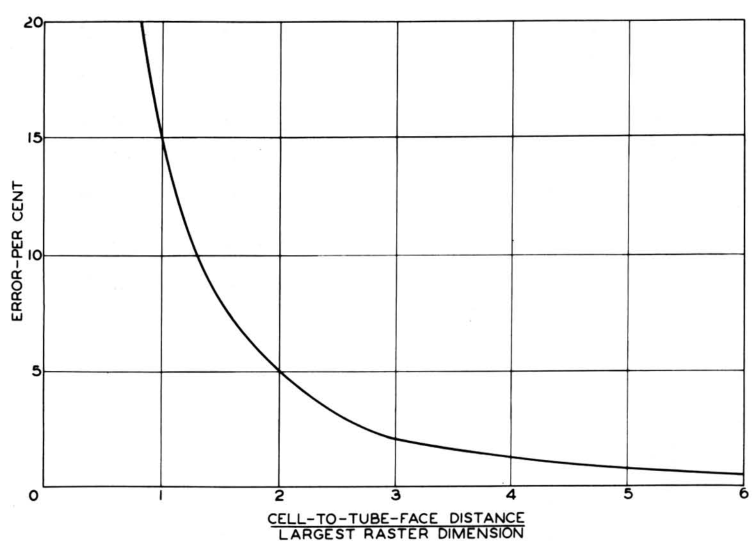


Fig.4 - Per-cent error in luminance calculation of Method II, when cell-to-tube-face distance is less than five times largest raster dimension. Luminance value is low by indicated per cent.

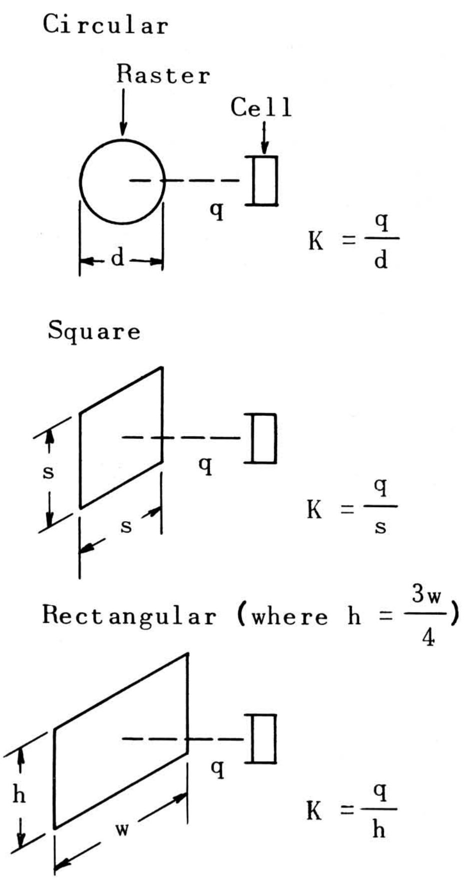
function of the ratio of cell-to-tube-face distance to largest raster dimension. Luminance B_i in footlamberts may be obtained from the following equation:

$$B_i = \pi E \frac{D^2}{A}$$

where E is the illumination read on the meter in footcandles, D is the distance from the cell to tube face in feet, and A is the area of the raster in square feet. The cell must be placed perpendicular to the centerline of the tube.

Method III—Use of an illumination meter when cell-to-tube-face distance is less than five times the largest raster dimension.

Calculations of luminance are more complicated in this case and must take into consideration the shape of the raster, as well as its area and distance from the cell. The results of such calculations for circular, square, and rectangular (3-by-4 aspect ratio) sources are tabulated in Table III as the ratio of luminance to illumination for various values of K, where K is the ratio of cell-to-raster distance divided by some raster dimension. Because the cell has a finite area an error exists in the calculations, but this error is small when the cell area is small compared to the raster area. The B_i/E value given in the table multiplied by the meter reading in footcandles equals the luminance in footlamberts.



K	Circular	Square	Rectangular
0	1.0	1.0	1.0
1	5.0	4.4	3.4
2	17.0	13.8	10.5
3	37.0	29.6	22.6
4	65.0	51.3	38.8
5	101.0	79.8	60.4
6	145.0	114.7	86.2

Table III - Ratio of luminance B_i to illumination E for various values of K.

Method IV—Use of an illumination meter to read luminance directly.

Table III indicates another method of measuring luminance. For values of K equal to zero, or when the cell is placed directly against the tube face, the reading in footcandles is numerically equal to luminance in footlamberts. This relationship is true only if the raster is larger than the cell.

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