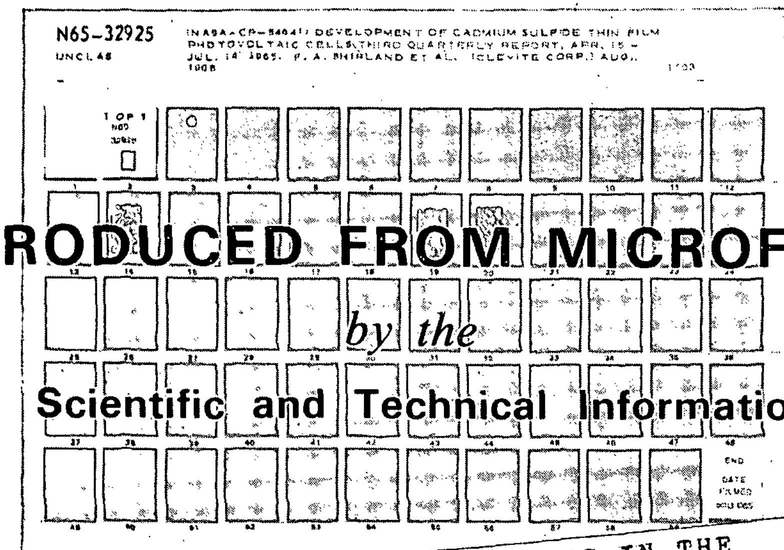

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PHOTOMETRIC UNITS IN THE MKS SYSTEM

by

Arthur C. Hardy, Consultant

March 1962 14 p

INSTRUMENTATION LABORATORY

CAMBRIDGE 39, MASSACHUSETTS

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Photometric Units in the Mks System

Introduction

The Instrumentation Laboratory has recently circulated a reprint of a paper by Moon and Spencer entitled "Utilizing the Mks System," which was published originally in the January issue of the American Journal of Physics for 1948. This reprint contains tables of conversion factors which are often useful. Unfortunately, however, in the fields of radiometry and photometry (pages 34-37), these authors employ terms which, so far is known, have never been accepted by any of the national or international standardizing bodies.

In the pages that follow, there will be listed and discussed briefly photometric units and symbols adopted by the Optical Society of America after a committee of twenty-three members of that Society had worked over the subject matter for almost twenty years. The report of that committee matured into a volume entitled "The Science of Color," published by the Thomas Y. Crowell Company in 1953. (Both radiometric and photometric terms and symbols are treated in Chapter 7 of this volume.)

With minor exceptions, these O. S. A. recommendations have been approved in this country by the Illuminating Engineering Society and by the American Standards Association. They have been sanctioned internationally by the International Commission on Illumination (Commission Internationale de L'Eclairage), usually referred to as the C. I. E.

Luminous Flux

Even a layman feels that he knows what is meant when the FCC authorizes a radio station to radiate 50,000 watts. Unfortunately, even many scientists and engineers would not understand the statement that a source of light radiates 50,000 lumens. Actually, the watt and the lumen can be thought of as equivalent, except that the lumen represents radiant power (watts) evaluated in terms of its capacity to excite a visual sensation. For example, the so-called luminous efficiency of monochromatic green light is in excess of 600 lumens per watt; the luminous efficiency of sunlight is of the order of 100 lumens per watt; and the luminous efficiency of the ordinary tungsten lamp is usually somewhat less than 20 lumens per watt. The letter-symbol adopted by the O. S. A. to represent luminous flux in lumens is F.

Luminous Intensity

Just as a radio station may be so beamed as to send more radiant flux in certain directions than in others, so also may a source of light send more luminous flux in certain directions than in others. The applicable terms are radiant intensity and luminous intensity, respectively. The symbols recommended by the O. S. A. are J for the radiant intensity and I for the luminous intensity.

It will be understood that, if a source is to radiate in a specified direction, the dimensions of the source must be small by comparison with the other distances involved. Often the dimensions need not be too small, because, even in the case of a searchlight, for example, the illuminance (see below) falling on a small surface that is removed from the searchlight by twenty times (or more) the diameter of the searchlight is identical (within the precision of ordinary photometric measurements) with the illuminance that would have been produced by a small source having the same luminous intensity in the direction of this small surface.

Such a concentrated source is often called a point source. The illuminance that it produces on a small surface set perpendicularly to the direction of the luminous flux received from the source decreases as the square of the distance between the source and the surface. If the surface is not perpendicular to the direction of the flux falling upon it, the illuminance decreases further as the cosine of the angle between the normal to the surface and the direction of the impinging flux.

Incidentally, the illuminance produced on a small surface by an extended source of light is (to a close approximation) equal to the product of the luminance of the source and the solid angle that it subtends at the receiving surface.

For the reasons cited above, the luminous intensity of a point source in a given direction is measured by the infinitesimal amount of flux dF radiated per solid angle dω in that direction. One unit of luminous flux per solid angle has for years been called a candle, and the O. S. A. report recommends that it be designated by the symbol I. (See Appendix A)

Illuminance

The concept of illuminance was implied in the preceding section. Basically, the term illuminance connotes the number of lumens that impinge normally on a unit area of a given surface. The recommendation of the Optical Society of America is that the illuminance of a surface be designated by the symbol E and that it be expressed in terms of lumens per square meter. Obviously, in the case of a surface whose illuminance varies from point to point, it is to be understood that the illuminance at any given point is to be expressed by the ratio of the flux impinging on a small area surrounding the point to the size of that small area, both quantities still being expressed in lumens and in square meters, respectively. (See Appendix B)

Luminance

Of the four principal photometric quantities mentioned above, the concept of luminance is often the most confusing, partly, perhaps, because it was called "brightness" for so many years. In terms of the system of units listed herewith, the luminance of an extended surface would be measured (possibly only as a mental exercise) by masking off all but a conveniently small area of that surface and then measuring its luminous intensity as seen from some particular direction. Inasmuch as the candle is the unit of luminous intensity, the preferred unit of luminance is the candle per square meter of the (projected) area of the source. The recommended symbol is B. (See Appendix C)

In the above paragraphs, it was assumed that there was a surface present. Offhand, it may seem absurd to describe the luminance of the sky in candles per square meter. The absurdity disappears if one simply imagines a surface that obscures the sky entirely except for an aperture of convenient area. Obviously, either this area should be suitably small or the remoteness of the imagined surface sufficiently great to permit the application of the concept of luminous intensity.

Conclusion

No attempt has been made to describe the above-mentioned photometric quantities in terms of operational definitions. To have done so would have resulted in a treatise on photometry, which, with all its ramifications, is a highly specialized subject.

It has been assumed throughout that the source being investigated has the same spectral quality as the conventional photometric standards. No attempt has been made to indicate the various procedures that have been devised to cope with situations when this assumption is not valid. Nor has there been any discussion of the case when the spectral-sensitivity characteristics of the receptor differ markedly from those of the human eye.

Appendix A

By international agreement, the candle has recently been redefined in terms of a blackbody radiator. More specifically, one square centimeter of a blackbody radiator at the temperature of freezing platinum is said to have a luminous intensity of 60 candles. The C.I.E. has recommended that the word candela be substituted for the word candle when the new unit of luminous intensity is employed. It remains to be seen whether the term candela will receive general acceptance. The point is somewhat academic because the difference between the old candlepower standard and the new candela standard is small. The word candle has been used herein, even though the luminous intensity may be expressed in terms of the new candlepower standard.

Appendix B

The term illumination is frequently used by illuminating engineers to connote the concept of illuminance. However, the Optical Society of America and others are of the opinion that terms ending in "-ation" are appropriate to a process rather than to a measurable quantity. More confusing is the common practice among illuminating engineers of expressing "illumination" in foot-candles. By definition, a source with a luminous intensity of one candle will produce an "illumination" of one foot-candle when the source is one foot distant from the receiving surface and the light from the source falls perpendicularly on that surface. It is easy to show that one foot-candle is the numerical equivalent of one lumen per square foot, and that, correspondingly, one meter-candle is the numerical equivalent of one lumen per square meter.

Appendix C

In general, the luminance of a surface depends upon the direction of observation, but most surfaces are rough (rather than mirror-like) and Lambert's law may then be a close approximation. According to Lambert's law, and element of a surface that radiates or reflects diffusely has a luminous intensity that varies as the cosine of the angle between the normal to the surface and the direction of observation. In other words, the luminous intensity of a unit area of the surface becomes less when the surface is viewed obliquely. However, the projected area incorporated in the definition of luminance varies also as the cosine of the same angle, so that, in the case of surfaces which radiate or reflect in accordance with Lambert's law, the luminance is independent of the angle of observation.

Because surfaces that radiate or reflect diffusely are encountered more often than not, the luminance of such surfaces is often expressed in Lamberts. By definition, a surface is said to have a luminance of one Lambert when it radiates or reflects one lumen per square centimeter. The conversion values of luminance expressed in candles per square centimeter to lumens per square centimeter (Lamberts) involves simply multiplying the former by π. One might reason intuitively that if he knows the number of lumens radiated or reflected per unit-solid-angle by a given small

surface he could find the total number of lumens radiated by multiplying by 2π, inasmuch as there are two π units of solid angle in a hemisphere. Actually, when Lambert's cosine law is introduced in the integration process, the multiplying factor is found to be π and not 2π.

The original definition of the Lambert has been modified in many ways. For example, this unit is frequently used to express the luminance of a surface that does not obey Lambert's law. That is, when such a surface is observed from some particular direction, its luminance is sometimes stated in terms of the total number of lumens that a unit area of this surface would emit or reflect if it were to obey Lambert's law. Also, whereas the unit of area embodied in the definition of the Lambert was the square centimeter, some authors use the foot-Lambert, which the British sometimes refer to as the equivalent foot-candle. In other words, a surface with an area of one square foot which radiates or reflects diffusely one lumen would be said to have a luminance of one foot-Lambert.

Appendix D

Conversion of Units of Illuminance

To convert n units of illuminance (expressed in terms of one of the quantities listed below) into E units of illuminance (expressed in terms of lumens per square meter), multiply n by the indicated multiplying factor.

Foot-candle	10.764
Lumen per square foot	10.764
Lux	1.000
Meter-candle	1.000
Miliphot	10.000
Phot	10,000.

Note: In conversation, the words illuminance and luminance may sound very similar unless the first syllable of each is accented.

Appendix E

Conversion of Units of Luminance

To convert n units of luminance (expressed in terms of one of the quantities listed below) into B units of luminance (expressed in terms of candles per square meter), multiply n by the indicated multiplying factor.

Apostilb	0.3183
Foot-Lambert	3.426
Lambert	3,183.
Meter-Lambert	0.3183
Milli-Lambert	3.183
Nit	1.000
Stilb	10,000.

Note: In conversation, the words illuminance and luminance may sound very similar unless the first syllable of each is accented.