Photometry: Tasks, Problems, and Organizations

C. L. Sanders

This paper discusses some of the tasks and problems of photometry. It describes some of the international and national committees, organizations, and laboratories that carry out these tasks and define and resolve these problems.

Introduction

The purpose of this editorial is to acquaint nonphotometrists with some of the problems of photometrists and with some of the organizations that are involved in defining and solving these problems. Of course some of these problems go back a very long time as you will find from reading Middleton's[1] article in this issue. Still I cannot help feeling that if vision had been discovered at the same time as the hologram or the laser, vision would have rightly attracted much more public attention and financial support than either of the others. Therefore, the use of a little space in *Applied Optics* on the mundane subject of photometry can be justified.

Light may be defined as radiant energy which is capable of stimulating the eye, and photometry is concerned with the measurement of such radiations in respect of their ability to stimulate the eye. Following this definition given by Wright[2] in an excellent extensive treatment of the problem of photometry and knowing the visual phenomena involved, the photometrist must decide which radiometric quantities are important, measure them, and convert them to visual quantities using appropriate factors. If the photometrist must also decide the weighting factors and the acceptable limits of the results, he will need to have knowledge of psychology, statistics, and physiology. Many of the factors for converting radiometric quantities have been accepted by international committees, and it is only necessary that the photometrist know which to use in the case at hand.

The visual phenomena to be considered will include brightness or lightness, glare, resolution or acuity, the functions of photopic, scotopic, and mesopic vision, effect of field size, position, color, movement, duration, shape, observer differences, effect of adjacent and distant sources, additivity (or nonadditivity), and adaptation. Some knowledge is required about the required accuracy and precision of measurement. The extent of observer differences give some indication of required accuracy.

Since radiant energy in the visible region of the spectrum also affects processes[3] other than the human visual mechanism, these radiant quantities may be measured and reported by some scientists for other than photometric use. (In some cases, such as in photographic sensitometry, one finds photometric quantities used because of the absence of more appropriate spectral weighting functions.) These scientists, serving a wider purpose than the production of visual quantities, may be called radiometrists or spectroradiometrists.

Photometric measurements are made at the International Bureau of Weights and Measures (BIPM) in Sèvres, France, national standards laboratories, commercial standardizing laboratories, industrial laboratories, and universities and by illuminating engineers. The end result of all these measurements is to ensure that in the living environment people are able to see adequately and comfortably.

Types and Functions of Laboratories

The BIPM serves as an independent laboratory where the basic standards from a few national laboratories are sent to be compared. The quantities compared are the national candelas and the national lumens. From these measurements an international mean unit for each is determined. The results of the comparisons at the BIPM are used by the national laboratories to assess the accuracy of the derivation of their standard units and the maintenance of these units. The national laboratories have the option of using the mean unit instead of the nationally derived unit. There is the added complication that the lamps used operate at different color temperatures,

The author is with the Division of Physics, National Research Council of Canada, Ottawa, K1A OS1, Ontario.

Received 10 June 1971.

and thus intensity standards at three color temperatures and lumen standards at two color temperatures are intercompared at the BIPM in most intercomparisons.

These intercomparisons are made at intervals of 4–6 yr. The results and pertinent photometric papers are published in Proceedings of the Comité Consultatif de Photométrie. This committee, created in 1937, is a committee of the Comité International des Poids et Mesures. It has two working groups, one on the Primary Standard of Light and one on Absolute Radiometry. These groups consider the best method of calibrating secondary standard lamps in terms of a basic standard.

It is not easy to determine the photometric level of activity at which the basic units should be independently derived by a national laboratory. The BIPM issues secondary standard lamps (calibrated in these international mean units) to laboratories not having the facilities to calibrate secondary standards from the primary standard of light. In smaller or still developing countries, the national laboratory measures photometric quantities for industry, university, or other laboratories. In larger developed countries where more photometric work is required, the national laboratory may authorize other laboratories to perform these functions and confine its activities to supplying secondary standards to these authorized laboratories. In all cases it is expected that the national laboratory will provide expert advice as required and will serve as an arbitor in the case of a disagreement between measurements made in other laboratories in that nation.

The size of a national laboratory and the balance between it and other laboratories are difficult to decide and maintain. There must be two-way communication in order that the national laboratory will change with the times to meet the demands for measurements, and the other laboratories will benefit from experience acquired in the national laboratory. It would seem essential that photometry experts from across the country should meet periodically to assess the work of a national laboratory and recommend changes of scope, emphasis, or staff to the agency with authority over the laboratory. Since the process of training in photometry is a lengthy one, any recommended expansion of a government laboratory would be a slow process.

Illuminating engineers are perhaps the largest single group of people who use the standards and equipment developed and built in the laboratories. They, with personnel in university laboratories, do most of the work that is still required in developing and using better photometric techniques. The basic standards are a small but necessary part of the total process.

Dissemination of Information by Technical Journals, Committees, and Associations

In addition to dissemination of photometric information by writing and reading articles in technical journals and books, all photometrists benefit from a certain amount of involvement in national or international committee work or photometric comparisons. These committees not only resolve many problems but also inspire individuals to study and report on current difficulties.

Committee E 1.2, Photometry, of the International Commission on Illumination, CIE, is one of the principal organizers of international photometric comparisons. There are several other CIE committees involved in photometry, *e.g.*, Photopic and Scotopic Vision, Visual Performance, Sources of Visible Radiation, etc. Every 4 yr each committee collects and publishes lists of papers and other publications that form a useful source of reference. Reports on the work of the CIE committees are published in CIE *Compte Rendu* at 4-yr intervals.

The committees of the CIE and the International Electrotechnical Commission (IEC) are also involved in standardizing terminology and publishing specifications and recommended procedures. The *International Lighting Vocabulary*,[4] prepared and published jointly by the CIE and IEC, should be used to ensure a common international vocabulary. The *Principles of Light Measurement*[5] prepared by CIE Photometry Committee (E 1.2) contains a summary of the principles of photometry based on CIE recommendations and is a useful source of basic photometric information and internationally accepted procedures. Nationally there are illuminating engineering societies and standards association that recommend procedures and specifications on lighting. The work of the various groups is usually complementary, and all tend to consolidate a body of knowledge. Insufficient use is made of the publications of these committees and organizations, and more legislation to enforce the recommendations would be beneficial. Thus photometrists could usefully do more to publicize the publications and to press for such legislation. More effective use of the available knowledge would in turn foster the production of the new knowledge that is still needed.

Comments on Standards and Techniques

The ability to use the primary standard of light improves with experience, but it is such a specialized procedure that the primary standard is usually not used oftener than every 10 yr. The secondary standards are relied upon in the intervening years.

Unfortunately photometric secondary standards deteriorate with use and even if unused. This means that maintenance of standards is a continuing problem. Usually additional personnel must be trained to carry on with routine photometry while the primary standard is being used to calibrate secondary standards. There is also a temporary space problem that may only be solved by providing excess space for 9 yr out of 10 or by closing down some calibration services while the primary standard is in use. For the above reasons there is some justification for changing to absolute radiometry and a defined value of K_m, from the primary standard of light, as Rutgers[6] states [in this issue of *Applied Optics*. The space problem could then be eliminated. The absolute radiometer could easily be stored and used in techniques that are fairly routine to a photometrist as opposed to the specialized techniques of high temperature physics and radio frequency oscillators that have been required in using the present Primary Standard of Light.

A recent paper of Quinn and Chandler[7] describes a wire-wound resistance furnace for melting a platinum ingot that eliminates the need for the bulky high power radio frequency induction heater. This, combined with the resultant much improved temperature conditions around the Pt ingot, should make the primary standard much more acceptable in the future.

In applying photometric principles one needs to be reminded occasionally that the spectral sensitivity of the human eye varies from the light to dark adapted state. We have a photopic and a scotopic standard observer adopted by the CIE and a CIE recommendation on how to make visual photometric measurements in the mesopic state between these two levels of adaptation. If we move to a system of absolute radiometry, there would need to be adopted values of K_m and K_m', retention of the scotopic and photopic standard observers, and some agreed method of mesopic photometry.

Cautions

Some photometric specifications state the measuring instrument that must be used. Specific techniques and standards are recommended. If the properties of the instrument are not specified, this can result in insisting on precise measurements with systematic errors, as well as in the users knowing less about photometry than they would if accurate measurements were specified. It can also result in delaying the development of accurate instruments. The expected advantage of consistent measurements from using the same model of instrument is also not always achieved.

The development of new sources of light poses additional photometric problems because of large or small source size, large or small luminous flux or candle power, temporally or spatially odd properties, or spectrally different properties. All these require great care in development and application of techniques, and large and uncertain systematic errors in measurements may result. International or commercial competition eventually results in a difference of opinion on specification and performance, and the problem is presented to one of the international or national committees. How a national or industrial laboratory can best meet this challenge is still to be determined. Probably most laboratories are forced to ignore the problems in some cases, because they are not staffed and financed to develop and test the new measuring equipment and techniques that are required.

Responsibility to Society

The eye is so tolerant of illumination level that in street lighting, for example, we tend to accept lower levels than are really safe except under ideal conditions. With fast heavy traffic, in poor weather, a driver with below normal vision may be in great danger that could be alleviated by more light.

Should the photometrist only measure, or should he press for better illumination? Since relatively few individuals will suffer from accidents caused by poor lighting, most people rely on statistical chance and are silent. However, the entire population suffers from accidents because of the cost to the economy from loss of lives, recovery time, disability, and cost of repairs. Thus all will benefit from good street lighting requirements.

It seems part of the responsibility of the photometrists and vision experts to educate the public and the politicians. We must continue to work with various committees and associations to improve recommendations and to define and obtain measured quantities that correlate more completely with the human performance of the visual task.

References

1. W. E. K. Middleton, Appl. Opt. **10**, 2592 (1971).
2. W. D. Wright, *Photometry and the Eye* (Hatton, London, 1949), p. 9.
3. H. H. Seliger and W. D. McElroy, *Light: Physical and Biological Action*, (Academic, New York, 1965).
4. *International Lighting Vocabulary* (Bureau Central de la CIE, Paris, 1970).
5. *Principles of Light Measurements*, Publication CIE 18 (E 1.2) (Bureau Central de la CIE, Paris, 1970).
6. G. A. W. Rutgers, Appl. Opt. **10**, 2595 (1971).
7. T. J. Quinn and T. R. D. Chandler, "The Freezing Point of Platinum Determined by the NPL Photoelectric Pyrometer," 5th Symposium on Temperature, Its Measurement and Control in Science and Industry, Paper S6-27 (1971).