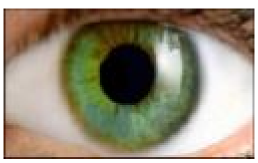
NEW DEVELOPMENTS IN PHOTOMETRY AND RADIOMETRY

Franz Hengstberger
CSIR – National Metrology Laboratory
P O Box 395, 0001 Pretoria, South Africa
Tel +27 12 841-4352, Fax +27 12 841-3382, e-mail fhengstb@csir.co.za

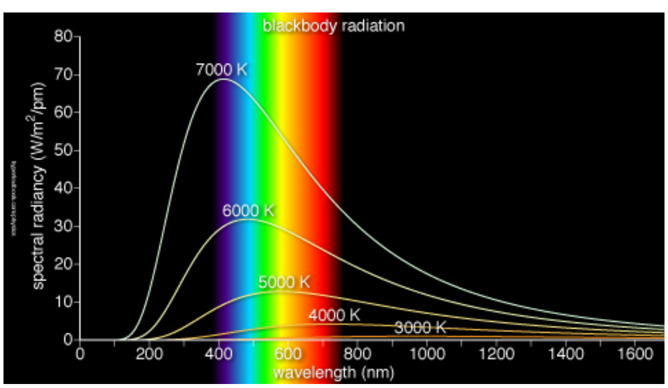
Abstract: The paper reviews the most important developments taking place in the fields of photometry and optical radiometry. It presents an overview of the most significant trends and tries to identify current drivers in photometric and radiometric technologies as well as new developments one can expect in these fields over the short to medium term.

1. INTRODUCTION

Photometry is concerned with the measurement of optical radiation quantities relevant to observation and evaluation by the human eye. Optical radiometry on the other hand deals with the measurement of quantities characterizing optical radiation as a physical quantity, independent of evaluation by a particular observer or detector.



Because of the ready availability of the human eye as a detector of optical radiation in the visible region and the early development of artificial light sources like fire, photometry was one of the most developed fields of measurement when the current SI system emerged during the second half of the 19th century.



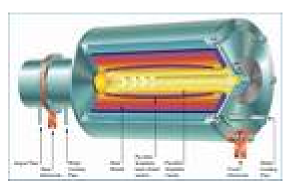
The development of optical radiometry received a boost with the derivation of the optical radiation laws applicable to blackbody radiators (Stefan-Boltzmann law, Planck's law) at the end of the 20th century and has since grown strongly with every new development in detectors, sources and materials. The spurts in the improvements of these components were in turn fueled by demands from fields ranging from semiconductor and integrated circuit production, materials processing, photo-electronics, photonics, lighting, earth sciences, meteorology, space science, military and communications technologies. This continuing evolution of optical radiometry as well as the need to develop ever more efficient light sources for reasons of energy conservation also benefited and drove the further development of photometry over the last few decades.

Another interesting aspect of the developments, when viewed over longer periods of time, is the sequence of improvements in sources and detectors. These often take place at different periods and lead to the perceived temporary dominance of either source-based or detector-based methods in the race to ever higher performance and accuracy.

2. LIGHT AND RADIATION SOURCES

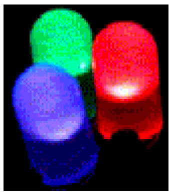
The most important absolute source standards in optical radiometry, with a theoretically predictable output, are

- blackbody radiators and
- electron synchrotrons.



There has been major progress in the design, construction and operation of blackbody radiators, both in terms of the materials used to achieve high temperatures (pyrolytic graphite) and in terms of temperature stability (use of metal eutectics) [1].

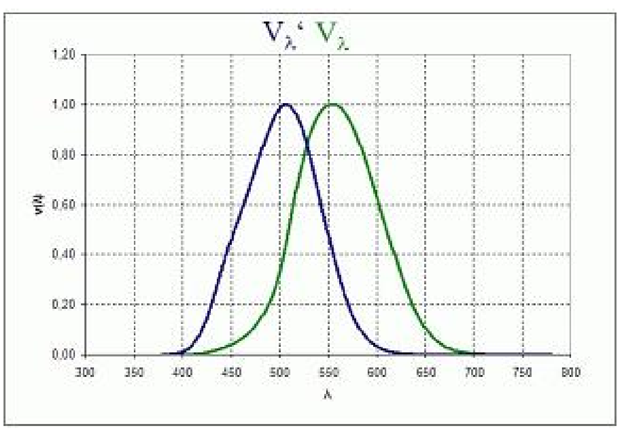
In terms of electron synchrotrons as absolute radiation sources [2], the progress has been characterized less by eye-catching technological breakthroughs and more by a steady, long-term improvement. Electron synchrotrons dominate particularly at shorter wavelengths (UV and VUV regions). They are not only used as calibration sources but also increasingly as radiation sources for the smaller and smaller line widths required by the semiconductor manufacturers.



For applications, the most important developments in radiation sources have been in the area of Light Emitting Diodes (LEDs). These are now having a significant impact on automotive lighting and traffic lights and are capturing their first niches in the mainstream lighting market. Other LED applications include the lighting of mobile phones and other mobile appliances. Metrologists have had to develop new techniques for the proper characterization and calibration of these sources. Because of the increasing variety of dominant wavelengths in which LEDS have become available, they also offer the prospect of spectrally tunable radiation sources, which are able to synthesize source spectra, which are otherwise not easily reproduced artificially, for example daylight and other colorimetric illuminants.

Advances with the generation of correlated pairs of photons by parametric down-conversion inside a non-linear crystal have produced new types of source standards for detector calibrations in the photon-counting regime [3]. Other radiometric applications of correlated photon beams are still under development but can be expected to play a greater role in radiometry in the future.

3. LIGHT AND RADIATION DETECTORS

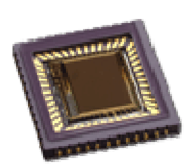


A recommended model for mesopic vision by the International Commission on Illumination (CIE) is expected in the near future. This implies that new light meters/ lux-meters/ photometers will appear on the market soon afterwards, which will not only cover the photopic (light-adapted) range of the human eye as almost all did up to now, but also the scotopic (dark-adapted) and mesopic (in-between) range. These new light meters will need to process at least the output of a photopically and scotopically corrected detector, and possibly even the output of a full set of tristimulous detectors (two more detectors).

Once such a CIE recommendation is accepted by the CCPR and the CIPM (as was the case for photopic and scotopic vision), photometric standards laboratories will have to develop methods and facilities to characterize and calibrate these multi-channel light meters.

An area in radiometry where continued progress is required is in long-term stable UV detectors.

Another such area is the development of high-performance, stable thermal detectors for cryogenic absolute radiometers [4]. Detectors using the transition region from the conducting to the super-conducting state (edge detectors) are currently receiving a lot of attention in this regard. Such detectors, when fully developed, would enable cryogenic absolute radiometers to measure at power levels useful for spectro-radiometry. An increase in the accuracy of spectro-radiometric measurements would qualify spectro-radiometers for many applications, where broadband measurements are currently used because of the higher power levels and the resulting higher accuracy.



The development of CCD and CMOS image sensors is mostly driven by consumer demand for digital cameras and for mobile phones incorporating digital cameras. It can be expected that single detectors will increasingly be superseded by 2D digital image sensors in many photometric and radiometric applications. Their prices are now being driven so low by mass production that the price barrier is no longer as significant as it used to be. This will eventually enable light meters to take into account the whole visual environment and not just the average luminance or illuminance when making a measurement. For photometry laboratories this trend will mean that methods and facilities will have to be developed for the routine calibration of light meters and colorimeters incorporating such sensors.

4. MATERIALS

Electro-optically tunable filters have become commercially available over the last few years, mostly due to improvements in LCD technology. However, many of their optical characteristics still need to be improved before they can replace more conventional filters in many applications. The potential applications for such filters have always been large but the technological progress has been disappointingly slow over the last few decades.

Filters and diffusers with better long-term stability need to be developed for the UV region.

5. TECHNOLOGIES AND FACILITIES

Photometry and radiometry laboratories have over the past few decades benefited greatly from advances in computers, digital and analog electronics, software, sensors, cryogenic technologies, robotics, instrumentation, interfaces and communications technologies.

This has given rise to

- automated optical benches of impressive mechanical and electrical precision and performance [5],
- robotic installations for versatile and precise scanning of light intensity, colorimetric and spectral irradiance distributions [5],
- cryogenic absolute radiometers with unprecedented accuracies for measuring radiant power and irradiance [4],
- eutectic, high-temperature blackbodies with temperature stabilities in the order of 0.01 °C [1],
- synthesized radiation sources with a widely tunable spectral output,
- high-accuracy wavelength standards for fibre-optic applications,
- etc.

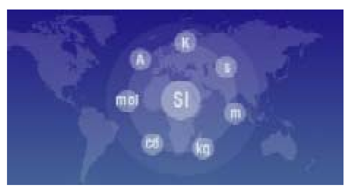
At the same time, NMIs have implemented and documented their laboratory quality systems and vastly improved their capabilities in understanding, analyzing and calculating measurement uncertainties.

6. THEORIES

The general theoretical framework for dealing with measurement uncertainties was to a large extent completed with the publication of the GUM [6]. The application of the GUM methodology in photometry and radiometry has been boosted by the implementation of the CIPM MRA , participation by NMIs in the required key and RMO comparisons and the submission and international scrutiny of their Calibration and Measurement Capabilities (CMCs) for inclusion in the BIPM MRA database. There were also a number of workshops and training courses on this subject organized by the CIE and a comprehensive CIE publication on the subject, with examples from the most important application areas in the field is in preparation.

From the optical side, continued progress is being made with the theory of partial coherence and its implications for the radiometry of partially coherent radiation sources, which is the majority of sources used in the laboratory.

Further progress was made both with the theory and the experimental characterization of integrating spheres, resulting in a new absolute method for deriving the luminous flux scale from a luminous intensity scale.



The SI System is currently going though an important phase in which the definitions of quite a number of base units will be revised within the coming decade. These planned revisions do not involve the definition of the unit of luminous intensity, the candela, at this stage, although a CIE model for mesopic vision may result in a proposal to perhaps change some explanatory references in the SI brochure. There is also an ongoing debate about the optimum number of SI base units and on which fundamental constants to base them.

7. DISCUSSION

It can be conjectured that the CIPM MRA between NMIs [7] has resulted in a much closer coupling of the NMIs (and their measurement scales) to each other, both internationally and within the various Regional Metrology Organizations (RMOs). NMIs are now much more aware of each others' facilities, for example through the scrutiny of other NMIs'

CMCs during the international review process, and there is a much closer interaction amongst metrologists in each field than some decades ago, particularly through the RMOs.

With regard to customers and stakeholders, the MRA database on the world-wide web provides a means for comparing the measurement capabilities of different NMIs on a common basis through the use of agreed service categories in each field. This provides regulators in different countries with an objective basis for the recognition of calibration and test results from trading partners and a means for overcoming Technical Barriers to Trade (TBTs) as well as Sanitary and Phyto-Sanitary (SPS) trade measures.

8. CONCLUSIONS

With the increasing importance of light and optical radiation measurements for both existing and emerging technologies, there can be no doubt that photometry and radiometry will continue to develop and remain important areas of metrology.

REFERENCES

[1] Yamada Y., *Application of Metal (Carbide)-Carbon Eutectic Fixed Points in radiometry*, Proc. NEWRAD, Davos, Switzerland, October 2005.

[2] Richter M., Hollandt J., Kroth U., Paustian W., Rabus H., Thornagel R and Ulm G., *Source and detector calibration in the UV and VUV using Bessy II,* Metrologia 40, S107-S110 (2003)

[3] Ghazi-Bellouati A., Razet A., Bastie J. and Himbert M.E., *Detector calibration at INM using a correlated photons source,* Eur. Phys. J. Appl. Phys. 35, 211-216 (2006)

[4] Houston J., *NIST Reference Cryogenic Radiometer Designed for Versatile Performance*, Proc. NEWRAD, Davos, Switzerland, October 2005.

[5] Sauter G., *Review of New Developments in Photometry*, Proc. NEWRAD, Davos, Switzerland, October 2005.

[6] ISO, *Guide to the Expression of Uncertainty in Measurement,* International Organization for Standardization, Geneva, Switzerland, 1993.

[7] CIPM, *Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes,* International Committee of Weights and Measures, Sevres, France, October 1999.