NOTIZEN

Comparison of Synchrotron Radiation and Hydrogen Continuum Radiation in the Near VUV by Means of a Deuterium Transfer Standard

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(Z. Naturforsch **31 a**, 1131–1132 [1976]; received July 25, 1976)

The spectral radiance of a deuterium lamp has been calibrated by the radiation of an electron synchrotron and by the continuum radiation of a high temperature hydrogen arc. The two measurements allow an indirect comparison of the two radiometric standards in the spectral range from 175 to 340 nm. They agree with each other within less than ±5%.

Introduction

Both the synchrotron radiation and the optically thin continuum radiation of a wall stabilized hydrogen arc are supposed to be reliable in calibrating spectral radiance standards in the uv and near vuv [1–7].

The direct comparison of these two light sources is difficult because of the complexity of the experimental equipment. The purpose of the experiment described in this paper was to perform an indirect comparison by means of a deuterium transfer standard. In this experiment the range of wavelength is limited to the interval between 175 and 340 nm. The lamp had been calibrated at DESY, Hamburg, first, and was brought immediately to Munich in order to perform the hydrogen continuum calibration. Thus no aging effects of the lamp [8] could influence the results.

Calibration by Means of the Synchrotron Radiation

The Schwinger theory [4] tells us the power radiated from a single electron. The total flux emitted from the synchrotron into a given direction is proportional to the number of orbiting electrons. At present this number cannot be accurately determined at DESY by electrical measurements. But an accurate determination of the number of electrons circulating in the electron synchrotron is possible by measuring the visible radiation with a tungsten strip lamp. Then, the total flux of the synchrotron radiation in a given direction as function of uv- and vuv-wavelengths is predictable with adequate accuracy. The experimental set-up at DESY permits a simultaneous measurement of the synchrotron radiation in the visible [photomultiplier current: $i^{\mathrm{Sy}}(\lambda_0)$] and the vuv spectral region ($i^{\mathrm{Sy}}(\lambda)$) by means of two monochromators. One monochromator observes the visible radiation ($i^{\mathrm{Sy}}(\lambda_0)$) in comparison to a tungsten strip lamp ($i^{\mathrm{TSL}}(\lambda_0)$). The second monochromator operates in the vuv and compares the synchrotron radiation ($i^{\mathrm{Sy}}(\lambda)$) with a deuterium lamp ($i^{\mathrm{DL}}(\lambda)$) of unknown spectral radiance. A detailed description of the calibration principle and the pertinent experimental device is given in [9].

The relation between the spectral radiance of the deuterium lamps and the measured photomultiplier current is:

$$L_\lambda^{\mathrm{DL}}(\lambda) = L_\lambda^{\mathrm{TSL}}(\lambda_0) \cdot \frac{i^{\mathrm{DL}}(\lambda)}{i^{\mathrm{TSL}}(\lambda_0)} \cdot \frac{i^{\mathrm{Sy}}(\lambda_0)}{i^{\mathrm{Sy}}(\lambda)} \cdot \frac{1 + p^{\mathrm{Sy}}(\lambda) \cdot p^{\mathrm{Mo}}(\lambda)}{1 + p^{\mathrm{Sy}}(\lambda_0) \cdot p^{\mathrm{Mo}}(\lambda_0)} \cdot \frac{\Phi_\lambda^{\mathrm{Sy}}(\lambda)}{\Phi_\lambda^{\mathrm{Sy}}(\lambda_0)}$$

where L_λ^{TSL} is the spectral radiance of the tungsten strip lamp, $p^{\mathrm{Sy}}(\lambda)$ and $p^{\mathrm{Sy}}(\lambda_0)$ are the degrees of polarization of the synchrotron radiation, $p^{\mathrm{Mo}}(\lambda)$ and $p^{\mathrm{Mo}}(\lambda_0)$ are the degrees of polarization produced by the monochromators, $\Phi_\lambda^{\mathrm{Sy}}(\lambda)/\Phi_\lambda^{\mathrm{Sy}}(\lambda_0)$ is the theoretically predicted ratio of the radiant power of the synchrotron.

The uncertainty of this calibration procedure is ±4% [9] and is essentially the sum of the following individual contributions: Uncertainty of the spectral radiance of the tungsten strip standard lamp, uncertainty of the degree of polarization produced by each monochromator, uncertainty of computing the synchrotron radiant power caused by oscillations of orbiting electrons. In the wavelength region between 260 nm and 340 nm the uncertainty of the calibrated spectral radiance of the deuterium lamps has been checked additionally by comparing the spectral radiance of the deuterium lamp with that of the low current carbon arc [10]. The agreement is within ±5%.

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Calibration by Means of the Hydrogen Arc

The continuum radiation of an almost completely ionized hydrogen plasma which is very close to the state of LTE is calculable to within a few percent [7]. At each particular wavelength the temperature dependence of this continuum shows a broad maximum at $T_{\mathrm{m}}(\lambda)$ which in our case ranges from about 17000 K to 20000 K. These temperatures can easily be reached in the axis of a high power hydrogen cascade arc [11]. Together with the physical length of the plasma and the plasma pressure the continuum radiation then constitutes a primary source of spectral radiance and does not require any plasma diagnostics [7]. The procedure for applying the arc as a radiometric standard reduces simply to adjusting the arc current for maximum signal at the wavelength of interest. The arc is substituted by the light source under investigation, i. e. the deuterium lamp, and the signal is recorded by means of the same optical system and detector. The spectral radiance of the deuterium lamp is then given by the signal ratio vs. wavelength, by the calculated maximum hydrogen emission coefficient and the length of the hydrogen plasma.

For the experiment described above a 1m-McPherson vuv-monochromator has been used with 0.08 nm resolution. In order to ensure sufficient spatial resolution for the hydrogen arc the observed area had to be restricted to $300 \times 150\ \mu\mathrm{m}$ and the aperture had to be limited to 1/200. The calibration procedure was performed then on two consecutive days with a complete realignment of the arc and the optics resulting in a reproducibility of 2%. The accuracy of the hydrogen continuum calibration is mainly limited by an insufficient knowledge of the plasma length which causes an uncertainty of about $\pm 5\%$. However, in case of this experiment, where the deuterium lamp signal is up to a factor of 5000 weaker than the hydrogen intensity, additional uncertainty due to a nonlinearity of the photomultiplier current could not be absolutely excluded.

Results

Figure 1 shows the ratio of the spectral radiance of the deuterium lamp calibrated by the synchrotron radiation and by the hydrogen continuum. If all the theoretical assumptions were correct and no experimental error involved this ratio were equal to one. Due to uncertainties of the two calibration procedures mentioned above the ratio could be insecure within a range of as much as 9%. Figure 1 demonstrates that the result is well inside this estimate (the mean value of the measured ratio between 175 and 340 nm is 1.03). This means that the two radiometric standards are well described by the respective theories. Furthermore the results show that it is not only possible but also practical to do radiometry in the vuv using deuterium lamps [8].

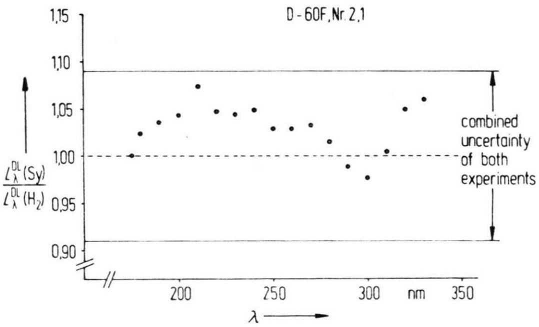

Fig. 1. Ratio of the spectral radiance of a deuterium lamp (D-60 F, Nr. 2,1) calibrated by synchrotron radiation and by hydrogen continuum.

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Nachdruck — auch auszugsweise — nur mit schriftlicher Genehmigung des Verlags
Verantwortlich für den Inhalt: A. Klemm
Satz und Druck: Konrad Triltsch, Würzburg