Temperature Effect on Spectrometer Slit Width and Photomultiplier Sensitivity*

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Variations in intensity measurements at 5100 Å resulting from temperature changes have been recorded using a 0.5 m Ebert scanning spectrometer equipped with a dual unilateral curved jaw slit assembly. Photons were detected by either a S-13 or S-5 photomultiplier. The variations were found to be consistent with an effective change of -0.10 ± 0.02 μ/°C in the width of the spectrometer slits and with sensitivity changes of -0.8 and -0.45%/°C for the S-13 and S-5 tubes, respectively.

INTRODUCTION

In testing the long term stability of the recorded intensity of radiation at 5100 Å from a tungsten–iodide lamp, intensity variations up to 15% were noted under "normal" laboratory conditions. These variations are illustrated in Fig. 1. The intensity is recorded as the photomultiplier current. The measurements were made with a 0.5 m Ebert scanning spectrometer using a slit width setting of 10 μ for the dual unilateral curved jaw slit assembly and an uncooled S-13 photomultiplier tube.

These intensity variations were found to be largely temperature dependent by correlating them with dark current changes and ambient temperature changes. Extensive investigation revealed that they could be attributed neither to changes in output radiation of the tungsten–iodide lamp nor to any of the electronic components of the recording system. Subsequent investigation measured the intensity variations in the temperature region between 21 and 32°C and determined what fractions of the observed variations could be attributed to changes in photomultiplier sensitivity and to changes in slit width.

Changes in photomultiplier tube sensitivity with temperature have been reported by Boileau and Miller.[1] Using S-4 and S-11 photocathodes, they concluded that "(1) a lowering of the temperature usually increases the short wavelength sensitivity and decreases the long wavelength sensitivity, (2) the effect varies between different types of phototubes and between phototubes of the same type, and (3) in the opinion of the authors, the only solution to this problem is temperature control." The crossover between short wavelength sensitivity and long wavelength sensitivity occurred at about 5900 Å.

Temperature control of the photomultiplier tube can be achieved by a thermoelectric cooler. However, with a spectrometer as part of the detecting system, the use of a thermoelectric cooler only partially solves the problem. This paper conclusively shows that slit width variations also have to be considered, and that, when narrow slit

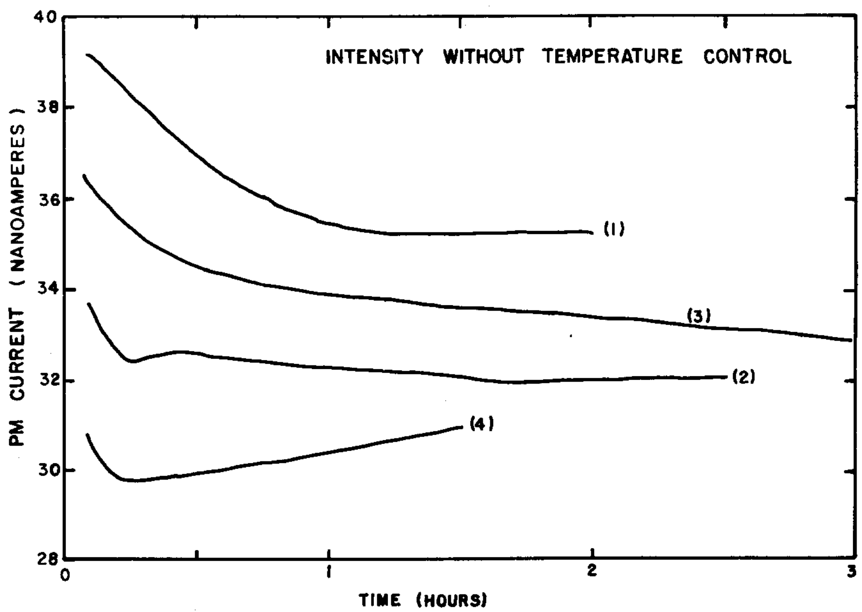

Fig. 1. Typical photomultiplier currents giving intensity from a 1000 W tungsten–iodide lamp using a 0.5 m Ebert spectrometer set at 5100 Å equipped with a dual unilateral curved jaw slit assembly set at 10 μ and equipped with an uncooled S-13 photomultiplier tube. Zero time corresponds to the time when the lamp was turned on. The four curves give the recorded intensity for four runs in the order made when the ambient temperature was uncontrolled.

* The views expressed in this paper are those of the authors and do not express an official position of the Ballistic Research Laboratories or of the Department of the Army.
[1] A. R. Boileau and F. D. Miller, Appl. Opt. 6, 1179 (1967).

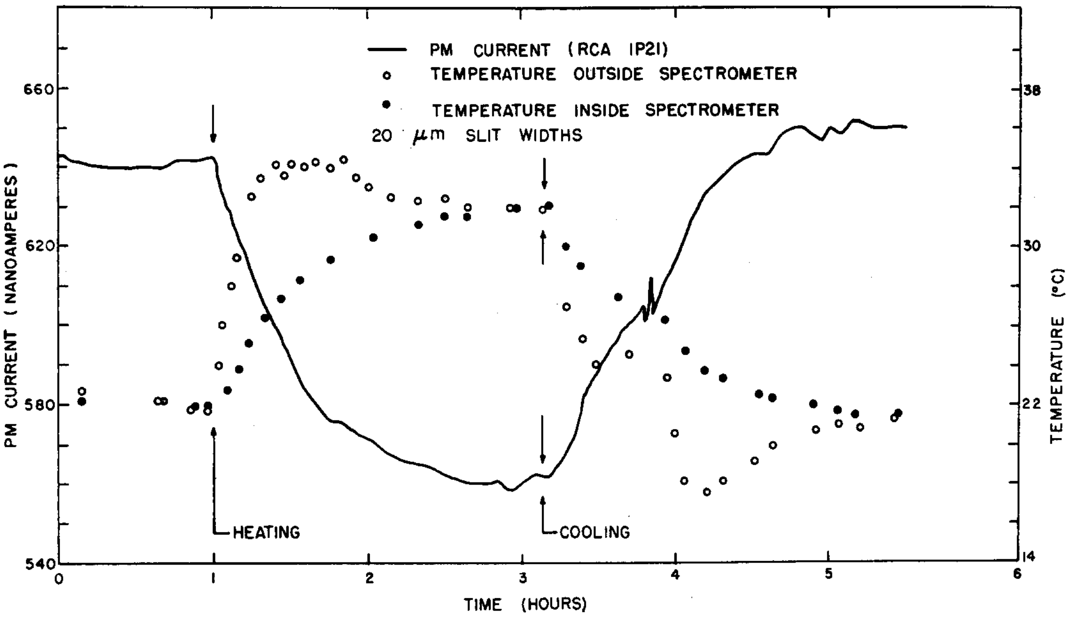

FIG. 2. Ambient temperature cycle showing the temperature outside and inside the spectrometer and the resulting intensity variation. A 0.5 m Ebert spectrometer set at 5100 Å equipped with a dual unilateral curved jaw slit assembly set at 20 μ and equipped with an uncooled S-5 photomultiplier tube was used.

widths are employed, such changes may be large enough to be the dominant source of variation in the recorded intensity.

Since the magnitude of slit width changes can be expected to vary among different types of slit assemblies, our quantitative results apply only to the one slit assembly used by us. However, other slit assemblies will probably have similar responses to temperature variations. For accurate measurements of intensity, each slit assembly should be checked for the change in slit width as a function of temperature.

EXPERIMENTAL PROCEDURE

The experimental arrangement was similar to that employed for making absolute intensity measurements with a spectrometer. The spectral source (General Electric DXW 1000 W tungsten–iodide lamp) was located 50 to 100 cm directly in front of the entrance slit of a 0.5 m Ebert scanning spectrometer (Jarrell–Ash 82-020) equipped with a dual unilateral curved jaw slit assembly (Jarrell–Ash 82-093). Photons were detected by either a S-13 photomultiplier (EMI 6255B) or a S-5 photomultiplier (RCA 1P28). The resulting current was recorded by a Jarrell–Ash 82-110 recording electronics system. When desired, the S-13 tube could be maintained at a constant temperature by a thermoelectric photomultiplier cooler (Jarrell–Ash 83-055). No cooler was available for the S-5 tube.

The current supply for the tungsten–iodide lamp was either a supply built in this laboratory according to the design of Stair *et al.*[2] or an EG&G 590-11A current control unit with an air-cooled lamp housing.

[2] R. Stair, W. E. Schneider, and J. K. Jackson, Appl. Opt. 2, 1151 (1963).

When using the S-5 tube, the spectrometer could be placed inside an environmental chamber through which air at constant temperature could be circulated. (The position of the thermoelectric cooler used with the S-13 tube prevented the spectrometer from being placed inside the chamber when the cooler was attached.)

When the spectrometer with the S-5 phototube was placed inside the environmental chamber and the air temperature controlled, the variations in intensity were quite small. Typically, the changes could be limited to about ±2% for a slit width setting of 10 μ when the environmental temperature was controlled to ±0.5°C. Temperature was monitored by a thermometer outside the spectrometer but inside the chamber.

Intensity variations resulting from lack of temperature control can be caused by changes in the spectral sensitivity of the photomultiplier, by changes in the widths of the entrance and exit slits, by changes in the mirror focus, and by changes in the grating dispersion. Calculations reveal that the latter two changes should be negligible.

To determine experimentally the overall dependence of the system on temperature the following procedure was used. With the intensity being continuously recorded, the spectrometer and photomultiplier were subjected to a complete temperature cycle by bringing them from thermal equilibrium at ambient temperature (about 21°C) to equilibrium at a higher temperature and then back to equilibrium at the initial temperature. The change in temperature was usually about 10 °C. (Thermal equilibrium is defined as the condition wherein the temperature inside the spectrometer housing equals the temperature outside the spectrometer.) Care was taken to ensure that the intensity during a temperature cycle was independent

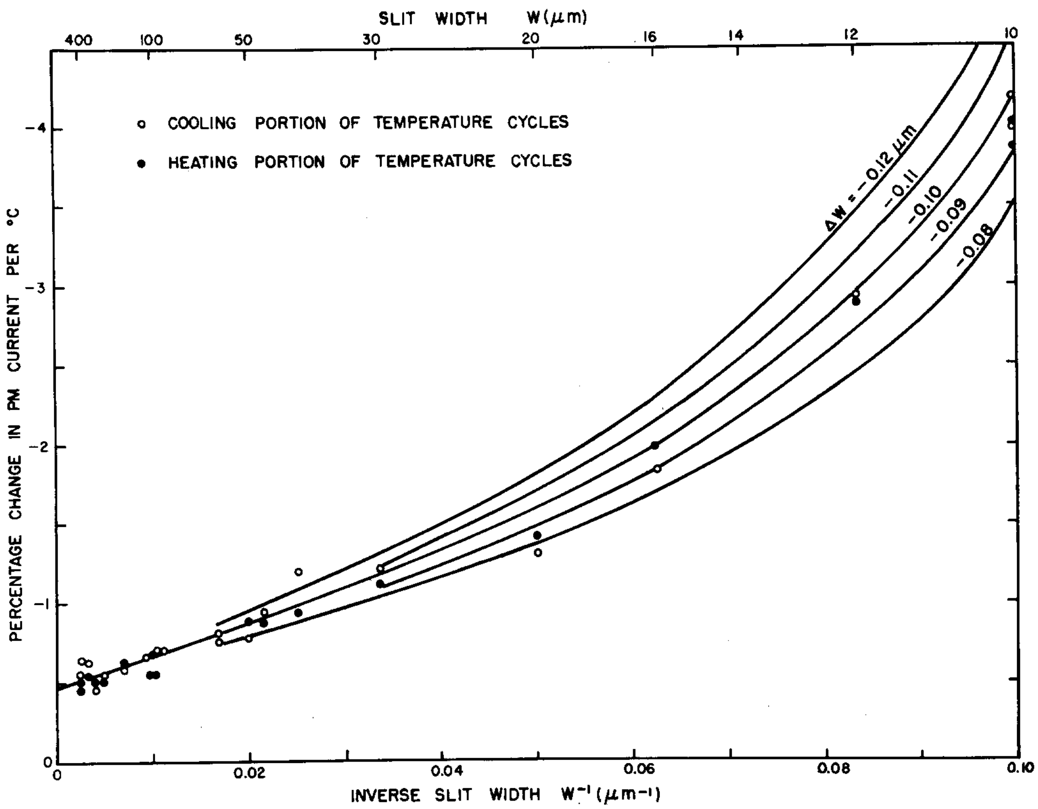

FIG. 3. Percentage change in intensity per degree Centigrade as a function of inverse slit width setting using S-5 photomultiplier tube. The circles represent experimental values obtained from curves similar to that shown in Fig. 2. The solid curves represent an empirical fit to data obtained by manually changing the slit width setting and offsetting the curves by −0.45%/°C.

of the preceding temperature cycle. A typical temperature cycle is illustrated in Fig. 2.

Only two temperature points were used during any single run in order to minimize the cycle time and thereby reduce the chance of recording nontemperature-dependent changes.[3] The obvious drawback of this method is that the linearity of the intensity changes within the temperature interval used is not checked. However, previous investigation which measured the intensity variations caused by small step increases in temperature showed that the intensity changes were approximately linear with temperature changes.

To determine what fraction of the total changes observed could be attributed to slit width changes, the type of data illustrated in Fig. 2 was repeated for different slit width settings ranging from 10 to 400 μ. To avoid the possibility of saturating the photomultiplier over the range of slit widths used, the photomultiplier current was always kept in the vicinity of 5×10^{-7} A by using neutral density filters and/or by changing the lamp current and lamp distance.

RESULTS

A convenient way to present the experimental results is the percentage change in intensity per degree[4] Centigrade as a function of inverse slit width setting. The experimental results are presented in this manner in Fig. 3.

For continuum sources and for a spectrometer whose entrance and exit slit widths are each W, the exit intensity I is proportional to W^2. Therefore

$$dI/I=2dW/W. \quad (1)$$

However, since W is a function of temperature T, this relation needs to be modified to

$$(dI/I)/dT=[2(dW/dT)]/W. \quad (2)$$

Equation (2) indicates that as long as the slit expansion is linear with temperature (a reasonable assumption for moderate temperature changes) the slope of a plot of percentage change in intensity per degree Centigrade vs $1/W$ should be constant and equal to $2\Delta W/°C$, where we have changed from the differential form to the incremental form.

Log–log plots of I vs the dial setting W, where W was changed manually from 10 to 400 μ, showed that for our system I was proportional to W^2 from 20 to 200 μ. This established the interval over which Eq. (2) could be applied. For all practical purposes, however, the deviation above 200 μ proved to be negligible.

Figure 4 shows an expanded section of Fig. 3 from 20 to 400 μm. The data, as expected, are fairly linear. The

[3] Fatigue effects were initially a problem; however, these were reduced by subjecting the system to radiation for several days before making measurements.

[4] The percentage change in intensity per degree Centigrade was determined using the expression $[100 \ln (I_2/I_1)]/(T_2-T_1)$. To the first order, $\ln (I_2/I_1)=2(I_2-I_1)/(I_2+I_1)$.

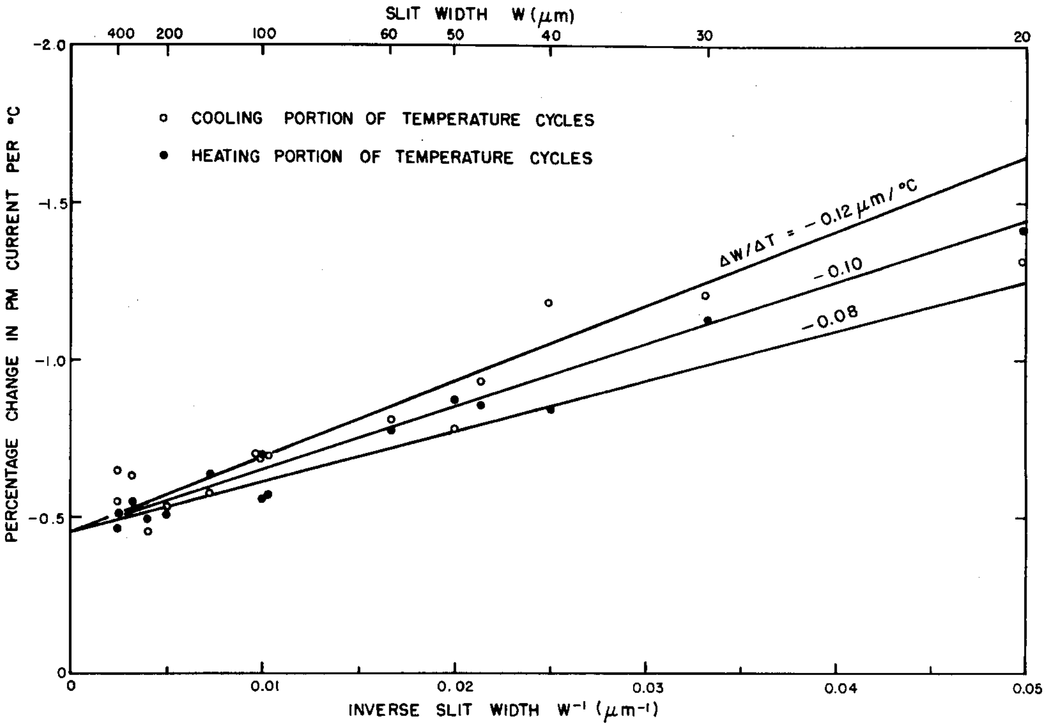

FIG. 4. An expanded section of Fig. 3 between 20 and 400 μ showing linearity of the percentage change in intensity per degree Centigrade with inverse slit width setting.

slope of the center solid straight line, determined by visual inspection as representing the data, leads to the value

$$\Delta W/\Delta T = -0.10 \pm 01\ \mu/°\text{C}. \tag{3}$$

The top and bottom lines, shown for comparison, are what would be expected for -0.12 and $-0.08\ \mu/°$C, respectively.

Another method for obtaining $\Delta W/\Delta T$ allows the use of all of the data points. This method depends on Eq. (1). If the temperature is constant and the slit width setting is changed manually, then the percentage change in intensity can be determined. Plots of percentage change in intensity vs $1/W$ obtained in this manner should be equivalent to plots which reflect only the thermal response of the slit assembly. As will be discussed later, a change in intensity $-0.45\%/°$C can be attributed to the photomultiplier. Offsetting the plots, obtained by manually changing the slit width setting, by $-0.45\%/°$C gives the results shown by the solid lines in Fig. 3 where plots are given for ΔW equal to -0.08, -0.09, -0.10, -0.11, and $-0.12\ \mu$. The ΔW which most closely reproduces the thermal data can then be taken as the appropriate value of $\Delta W/°$C. A value of $-0.10 \pm 0.02\ \mu$ is seen to fit the thermal data reasonably well.

Two earlier attempts were made to measure the widths of the slits without conclusive results. First, an attempt was made to measure the slit width directly by using a microscope. However, the smallest graduation on the dial of the microscope was $1\ \mu$. Thus the slit width could not be measured directly with sufficient accuracy. Second, a He–Ne laser was used to create a diffraction pattern of the entrance slit. At a slit width setting near $50\ \mu$, manual and thermal changes in the width of the diffraction pattern indicated a value for $\Delta W/\Delta T$ equal to $-0.08\ \mu/°\text{C} \pm 60\%$. The large uncertainty made it necessary to try to determine $\Delta W/\Delta T$ by other means.

The presence of the extreme deviation from linearity in Fig. 3 below $20\ \mu$ indicates a sizeable increase in $(\Delta I/I)/°$C over and above that represented by Eq. (2). The origin of the deviation cannot be conclusively determined with the present information about the system, since it can be caused by several factors. However, it is certain that calibration errors in the slit width settings and diffraction losses can contribute to such behavior and would become increasingly important at narrow slit widths. Indeed, values of $\Delta I/I$ determined manually at different wavelengths (4000 to 6000 Å) substantially altered the shape of the curve below $20\ \mu$ and indicated that diffraction losses are probably involved.

In addition to determining $\Delta W/\Delta T$, Fig. 4 also gives us $-0.45\%/°$C as the percentage change of intensity per degree Centigrade associated with something other than slit width changes. This value, which is the residual of $(\Delta I/I)/°$C at $1/W=0$, is believed to represent the temperature dependence of the S-5 photomultiplier that was used. For comparison Boileau and Miller's[1] data yield a value of about $-0.25\%/°$C for a S-4 tube. (The S-4 tube is similar in photocathode characteristics to the S-5 tube.) We determined this value of $-0.25\%/°$C at 5100 Å from Fig. 3 of Ref. 1.

A lower limit of $-0.45\%/°C$ for the tube used in our studies appears to be confirmed by other evidence. An earlier investigation, in which the spectrometer was replaced by a set of interference filters with peak transmission at 5000 Å and halfwidth of 250 Å, gave values for the temperature dependence ranging from -0.45 to as high as $-0.8\%/°C$. However, the higher values may have been associated with fatigue effects in the tube.

During the course of checking intensity variations without employing an environment chamber, both S-5 and S-13 photomultipliers were used. The temperature dependence of the S-13 tube was tested by measuring the intensity change resulting from cooling the tube by a thermoelectric cooling unit. For a temperature drop of 41 °C (+27 to −14°C), as measured by a thermocouple placed near the photocathode inside the cooling jacket, the measured intensity change was +32 or $-0.9\%/°C$. To eliminate errors associated with heating transients caused by the high power output of the source, the lamp was turned on 3 h before cooling. In addition, the room temperature was kept as constant as possible during the cooling time itself.

Our result for the S-13 tube compares favorably with the results of Boileau and Miller.[1] Figure 2 of their paper shows that a change in temperature from 17.2 to 3.3°C produced a change of about +12% at 5100 Å for a phototube with a S-11 response. (The S-11 and S-13 spectral responses are similar in this spectral region.) Their change is therefore about $-0.9\%/°C$. However, it must be kept in mind that a comparison of average values taken over considerably different temperature regions may not necessarily be meaningful since they have pointed out that the sensitivity changes may not be linear with temperature.

For a slit width setting of $10\,\mu$, Fig. 3 shows that a room temperature change of +5 °C will cause a 20% decrease in recorded intensity. Most of the change in recorded intensity will be caused by changes in slit widths. For accurate measurement of absolute or relative intesities, frequent checks with a standard of irradiance will be necessary.