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A UNIVERSAL SPECTROPHOTOMETER FOR THE MEASUREMENT OF THE RELATIVE
SPECTRAL DISTRIBUTION OF THE CARBON ARC SOURCE

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A UNIVERSAL SPECTROPHOTOMETER FOR THE MEASUREMENT OF THE
RELATIVE SPECTRAL ENERGY DISTRIBUTION OF A CARBON ARC SOURCE.

By

Leo J. Krolak
Thomas P. Davis

ABSTRACT

A spectrophotometer, calibrated for a useful range between 0.3μ and 2.6μ , was constructed to be used for determining the relative spectral energy distribution of a 24" high intensity carbon arc, and for ultimate use in reflectance and transmission studies. Several line sources and absorbing media were used to calibrate the wavelength drum scale.

A tungsten ribbon filament lamp and a MacPherson arc were used as sources of known relative spectral energy distribution for the determination of the overall spectral response of the spectrophotometer. Before using the former source, the spectral emissivities of tungsten had to be determined for various operational temperatures. Because of the uncertainty of results with the tungsten ribbon filament lamp, the more reliable and simpler MacPherson arc was finally used to determine the overall spectral response of the spectrophotometer.

Three different types of PbS cells and an evacuated thermocouple were compared; it was found that the thermocouple was the most suitable because of better noise characteristics even though its sensitivity was lower than that of the PbS cells.

NOTE: This study was carried out through the facilities of the University of Rochester Atomic Energy Project, under contract with the U. S. Atomic Energy Commission, and its expenses defrayed under grant from the Quartermaster Corps, U. S. Army.

Various arrangements were devised to measure, by means of the f/5 spectrophotometer, the intense radiation from the f/1.6 condensing system of the 24" carbon arc source. The resulting curve peaked at $.500 \mu$, the maximum of a blackbody at 4800°K although the short and long ends of the carbon arc curve deviated from the ideal blackbody curve. It was found that the relative spectral energy distribution of the 24" carbon arc is independent of the irradiance at the exposure plane.

INTRODUCTION

During the course of various investigations of the effects of different physical factors upon the production of burns in this laboratory, a need has arisen for data concerning the relative spectral energy distribution of the 24" carbon arc (5) employed as a radiation source in these researches (1, 2, 3). Such studies as the influence of wavelength upon the production of burns and the protective effect of fabrics become more meaningful when the spectral distribution of the source is known.

Some of the more important phases in this investigation were the construction of a spectrophotometer which would be sensitive in the wavelength region 0.3 to 2.6μ keeping in mind an ultimate adaptation to reflectance and transmission measurements; the study of suitable calibration standards, particularly a radiant energy source with a known relative spectral energy distribution; and the design of an arrangement appropriate for the measuring of the spectral distribution of the intense radiation from the f/1.6 condensing system of the 24" carbon arc source.

Apparatus and Equipment

A block diagram of the spectrophotometer appears in figure 1 and photographs in figures 2 and 3. Light from the source S was focussed on the entrance slit A of the monochromator by the spherical mirrors M_1 and M_2 and the plane mirror M_3 . At the image of the source S', the beam was interrupted 13 times per second by a small motor-driven light chopper. Within the monochromator, a Perkin-Elmer model 83 universal instrument, the radiation passing through the entrance slit was collimated by an 18° off-axis parabolic mirror M_4 , dispersed by a 60° fused quartz prism, reflected back through the prism by the Littrow mirror M_5 , and focussed

SPECTROPHOTOMETER BLOCK DIAGRAM

FIGURE 1

Figure 2

1. Source
- 2,3. Spherical Mirrors
4. 13 Cycle Chopper
5. Flat Mirror
6. Monochromator Slit
7. Slit Micrometer
8. Wavelength Drum
9. Wavelength Drive
- 10,11. Off-Axis Parabolic Mirrors
12. Swiss Made PbS Cells

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FIGURE 2

Figure 3

1. Model 81 Amplifier
2. Mercury Lamp Power Supply
3. Ribbon Filament Power Supply
4. Ribbon Filament Ammeter
5. Speedomax Recorder
6. Wavelength Drive Control Panel
7. Recorder Balance Control
8. PbS Input

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FIGURE 3

on the exit slit B by the parabolic reflector M_4 and a small diagonal mirror M_6 . The wavelength of the radiation passing through the exit slit could be varied by rotation of the Littrow mirror, which, in turn, was controlled by the wavelength drum C. The latter was directly coupled to a Perkin-Elmer wavelength drive which permitted automatic scanning of the spectrum at exact rates of 1, 2 or 4 minutes per revolution of the wavelength drum.

The monochromatic radiation passing through the exit slit B was focussed on an internal detector D_1 by a plane mirror M_7 and an ellipsoidal mirror M_8 . Rotation of mirror M_7 out of the beam permitted the radiation to pass through a fused quartz window in the monochromator cover where the exit slit could be imaged by the two off-axis parabolic mirrors M_9 and M_{10} on an external detector D_2 . The 13 cycle signal from either D_1 or D_2 , after suitable preamplification, was fed to a Perkin-Elmer model 81 amplifier. After sufficient amplification, the signal was synchronously rectified by cam-operated switches on the light chopper shaft, and resultant pulsating dc passed through a low-pass filter to the recorder. The cut-off frequency of the filter could be in four steps, with response setting 1 corresponding to the highest cut-off, and response setting 4 corresponding to the lowest.

Three different makes of PbS cells and a vacuum thermocouple were used in this investigation. The PbS cells consisted of a 1/4 in. x 3/16 in. Ektron detector made by Eastman Kodak Company, a 0.5 mm x 2.0 mm cell manufactured by Photoswitch Company, and finally a swiss made cell. The latter detector was deposited between the walls of a small Dewar flask. The thermocouple, manufactured by the Perkin-Elmer Company, consisted of a gold leaf blackened target welded to pillers made of the active elements in an evacuated chamber with a fused quartz window.

The two external detector focussing mirrors were identical $f/5$ 15 in. focal length 15° off-axis parabolic mirrors made by the Ferson Optical Company of Biloxi, Miss. The internal focussing mirrors were supplied by the Perkin-Elmer Corporation and consisted of an 80 mm elliptical mirror with focal lengths of 1.32 in. and 7.92 in. and a plane diagonal mirror 20 mm x 30 mm.

The source focussing mirrors were made up of two identical 80 mm diameter 294 mm radius of curvature spherical mirrors and a 38 mm x 50 mm plane mirror all made by the Perkin-Elmer Corporation.

Five light sources were used to calibrate the wavelength scale. These consisted of a Cenco neon gas spectrum tube, an 18 amp 10 v ribbon filament General Electric Corporation spectroscopic lamp, and three General Electric mercury vapor lamps (AH-4, BH-4, S-4). A Bausch and Lomb 5 amp mechanical feed arc lamp was converted for use as a MacPherson Arc (8) to be used as a standard source of known spectral energy distribution. Another standard source used was a General Electric 6 v 36 amp ribbon filament lamp calibrated by the National Bureau of Standards.

The calibration of the wavelength scale was further extended by the use of absorbing media consisting of 1, 2, 4-trichlorobenzene, tetrachloroethane, and pentachloroethane.

METHOD

The emission lines of the AH-4 mercury lamp, with outer jacket removed, were used in the wavelength region $.2967\mu$ - 2.325μ (6, 10, 14). Some difficulty was encountered in identifying the lines in the ultraviolet region of the spectrum. This difficulty was obviated by the use of mercury BH-4 and S-4 lamps. The S-4 lamp emits lines of wavelength $.2967$, $.3022$, and $.3129\mu$ whereas the BH-4 does not. On the other hand, the BH-4 emits

lines of wavelength .4047 and .4358 μ while in fact the S-4 does not emit in this region. The .3341 and .3654 μ lines are emitted by both these lamps. In addition to this, the BH-4 cuts out above .4358 μ . Because of these definite cut-out points, it was a simple matter to identify the mercury lines in the ultraviolet.

Because of the absence of emission lines in the mercury spectrum between .6 and 1.0 μ , other sources must be used in this region. There is an abundance of strong lines in the neon spectrum in this region but, because of their very abundance, it becomes difficult to identify them. Consequently, some asbestos paper was soaked in a solution of potassium chloride and water, dried, and tied around the tip of a bunsen burner (13). The flame gave a very distinctive potassium line at .7682 μ facilitating the identification of a few of the many lines in the neon spectrum (6).

Several absorption bands of 1, 2, 4 - trichlorobenzene (11), tetrachloroethane, and pentachloroethane (16) have been measured with sufficient accuracy for use in the calibration of prism instruments. The first of these compounds gave absorption bands at 1.6606, 2.1526, 2.3126, 2.4030, and 2.4374 μ while the second absorbed at 2.329, 2.496, and 2.634 μ , and the third at 2.368 μ . These liquids were retained in a cell made from two pieces of polished fused quartz 1 mm thick and separated by a distance of about 0.5 mm. The above absorption lines helped to fill in some of the gaps between the mercury lines and also to extend the calibration beyond the last mercury line up to 2.634 μ .

Before finding the overall response curve of the spectrophotometer, it was necessary to determine the input versus output characteristics of the amplifier. Figure 4 is a schematic of the circuit used to do this. The

current in the circuit was changed by means of a variable resistance and read with a Weston model 622 dc milliammeter. The amplifier was set at each of its 19 gain settings and the current across the one ohm resistance adjusted until the Speedomax registered deflections of 1, 2, 3,10 mv for each gain setting. The voltage drop across the standard resistance was plotted against the recorder readings.

At this time the actual noise of the amplifier for a detector of about 10 ohms was compared to the theoretical Johnson noise. The formula for Johnson noise is

$$E^2 = 4kTR\Delta f$$

where

$$E = \text{rms volts}$$

$$k = 1.38 \times 10^{-23} \text{ joule per degree absolute (Boltzman's constant)}$$

$$T = \text{temperature in degrees absolute}$$

$$R = \text{resistance}$$

$$\Delta f = \text{band width}$$

In order to find the theoretical noise of the amplifier with a 10 ohm resistor in place of the detector, it was necessary to determine the band width from the formula

$$\Delta f = \frac{1}{2\pi t}$$

where t is 63% of the time to reach the peak. The time to peak was determined by using the 0.1 μ v test signal on the amplifier and reading the time to reach peak on a model 127 Sanborn Recorder. This was done for the two middle response settings on the amplifier. These two values of the band width were substituted in the Johnson formula above.

The actual noise was found by turning on the 0.1 μ v test signal and

letting the Speedomax Recorder run for a minute or so. An average line was drawn through the trace and a plot made of the square of the deviation from the average against the chart length. These curves were then planimetered and the average height found. Knowing the test signal value, the rms noise was determined by multiplying the average height in mm times the test signal value per mm of chart height.

Now that some of the characteristics of the amplifier were known, a study of the overall response of the system could be made. However, before this could be done, the emissivity of tungsten at different temperatures had to be determined in order that the relative spectral energy distribution of the 36 amp 6 v tungsten ribbon filament lamp could be predicted. Because spectral emissivities in general vary with temperature and wavelength, there is a double infinity of emissivities needed to fully describe the radiation of a non-blackbody such as tungsten.

Weniger and Pfund (15) found that the reflection factor of tungsten is a linear function of temperature up to 2067° K for wavelengths between 0.67μ and 4.0μ . Since the emissivity at any one wavelength for non-transparent radiators is equal to one minus the reflectivity for that particular wavelength, the spectral emissivities also vary linearly with temperatures. Coblentz (4) determined the reflection factors of tungsten at room temperature for wavelengths between 0.5μ and 6.0μ . Combining the work of Coblentz, Weniger and Pfund, it was a simple matter to determine the emissivities of tungsten for various wavelengths at different temperatures up to 2067° K. Worthing (16), in an earlier paper, found that this linear relationship between emissivities and temperature could be extended to 3300° K. Hulburt (7) studied the emissive powers of tungsten in the near infrared, visible, and near ultraviolet down to $.34\mu$. Consequently, the spectral emissivity of tungsten was now known for the wavelengths and temperatures of interest to this study.

Because the voltage supplied to the 6 v 36 amp lamp was made up of a dc component and an ac ripple, it was decided to study this effect upon the output of the lamp. Since the ammeter used to control the output of the lamp indicated the average current and the lamp responded to the rms value, it was necessary to apply a correction factor to the ammeter. Figure 5 is a schematic of the power supply to the lamp (dotted portion) and the circuit used to determine the correction factor to be applied to the ammeter.

Now it can be shown that

$$\frac{I_{\text{effec.}}}{I_{\text{dc}}} = \left(1 + \frac{(\bar{V}_{\text{ac}})^2}{(V_{\text{dc}})^2} \right)^{1/2}$$

where	$I_{\text{effec.}}$	=	the effective heating current
	I_{dc}	=	the dc current component read by the ammeter
	V_{dc}	=	the dc voltage across the lamp
	V_{ac}	=	the ripple voltage across the lamp

The ordinates from one complete cycle, as seen on the cathode ray oscilloscope screen, were squared and plotted against phase angle. The area was planimetered and the mean square voltage $(\bar{V}_{\text{ac}}^2)$ calculated. The correction factor, $I_{\text{effec.}}/I_{\text{dc}}$, was calculated for four settings of the ammeter. The fluctuating output of the lamp was measured with a 925 vacuum photo tube hooked up to a cathode ray oscilloscope. The dc voltage and the peak to peak ac voltage were measured and the per cent variation calculated.

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SCHEMATIC FOR FINDING AMMETER CORRECTION FACTOR

FIGURE 5

Using the Stefan - Boltzmann law, it can be shown that

$$\frac{dT}{T} = \frac{1}{4} \frac{dW}{W}$$

where

dT = variation in temperature in °K

T = temperature in °K

dW = variation in flux per unit area

W = flux per unit area

Since the per cent variation of voltage is the same as the per cent variation of the output $(\frac{dW}{W})$, the per cent variation in the temperature $(\frac{dT}{T})$ can be calculated.

The spectral response of the spectrophotometer could now be determined. The 6 v 36 amp ribbon filament lamp was placed at S in figure 1 and a run through the spectrum from about $.35 \mu$ to 2.6μ was made. This was done for three current settings, and hence brightness temperatures, of the lamp. The true temperature of the filament may be found from

$$\frac{1}{T} - \frac{1}{S} = \frac{\lambda \ln e}{C_2}$$

where

T = the true temperature in °K

S = the brightness temperature in °K

e = the emissivity of tungsten at the effective wavelength λ .

C_2 = $1.4385 \text{ cm } ^\circ\text{K}$

The emissivity at an effective wavelength was supplied by the National Bureau of Standards for each brightness temperature.

Blackbody curves, with temperatures equal to the true temperatures of the tungsten in the above runs, were calculated. A correction for dispersion of the prism and for the emissivity of tungsten was made. These

latter curves and the curves of the spectrophotometer traces were normalized to 100% and plotted. The ordinate ratio at any given wavelength between the actual trace, obtained with the spectrophotometer, and the corrected blackbody curve, gave the value of the response of the system at this particular wavelength. Doing this for all wavelengths, an overall response curve was arrived at for all three brightness temperatures of the lamp.

MacPherson (8) states that a small dc carbon arc, when operated according to stated rules, will produce a source of known absolute spectral energy distribution. For a positive electrode, the arc employed a spectroscopically pure graphite rod of $1/4$ in. diameter and a $1/8$ in. or $3/16$ in. diameter spectroscopically pure carbon rod for the negative. The maximum current that can be forced through the arc without hissing was provided. This varied anywhere from 10 to 12 $1/2$ amperes. Since the steadiness of the arc depends upon the relative position of the negative and positive tips, an enlarged side image of the electrodes was projected on the wall by means of a simple lens. The central portion of the positive crater of this arc was focussed on the entrance slit of the monochromator, as with the ribbon filament lamp, and a run made through the spectrum.

The average true temperature across the crater, the distribution temperature, is known to be 3860° K. A 3860° K blackbody curve, with appropriate corrections for the dispersion of the prism, was calculated; the ratio between the trace and the blackbody normalized curves were found. This again was the overall response of the spectrophotometric system.

Overall response curves were found using four different receivers. The photoswitch PbS cell was mounted internally at the primary focus of the elliptical mirror as was the evacuated thermocouple. The remaining two PbS

cells were located externally with the exit slit focussed on them by the two off-axis parabolic mirrors.

In the arrangement for finding the relative spectral energy distribution of the 24" carbon arc, two chief requirements had to be fulfilled. First of all, the radiant energy at the exposure plane had to be attenuated many fold before being focussed on the exit slit of the monochromator. Secondly, the energy entering the monochromator had to be a representative sample of all of the radiant energy being emitted by the positive crater of the arc and reflected by the elliptical condensing mirror of the arc. Figure 6 depicts two methods which were tried. In the first method, a .005 in. thick sheet of brass smoked with MgO was placed at the exposure plane. A 1/16 in. hole in the sheet passed radiation to the diagonal MgO (12) coated Pyrex plate. Two spherical collecting mirrors focussed the radiation on the exit slit of the monochromator. The main disadvantage of this arrangement was that the second requirement, mentioned previously, was not fulfilled. In the second method, the 13 cycle chopper was coated with MgO (12) and placed at the exposure plane behind a water cooled aperture (9). In addition to fulfilling the above two requirements, this latter set up had another advantage. There was a great deal of scattered radiation, but only that which was diffusely reflected by the chopper and collected by mirror M_1 (fig. 6), was amplified and recorded.

Traces were made for both the highest and a lower irradiance at the exposure plane to see whether or not this made a difference in the spectral quality of the distribution.

FIRST METHOD

SECOND METHOD

SETUPS FOR MEAS. REL. SPEC. DIST. 24" ARC

FIGURE 6

Because a MgO coated surface was used in finding the distribution of the 24" arc and was not used in finding the overall response of the spectrophotometer, it was thought advisable at this time to determine the overall response characteristics using essentially the same set up used with the 24" arc arrangement. This, of course, eliminated any correction for the spectral reflectance of MgO prepared according to the standard method (12). Figure 7 shows the arrangement used to make this redetermination of the overall response characteristics.

RESULTS

Figure 8 is a calibration of the wavelength scale and table 1 a tabulation of the wavelengths used, the state, a description, the substance, and references. The calibration curve is based on a wavelength scale setting of 16.12 for the mercury emission line at $.5461\mu$. The left hand ordinate scale applied to curve 1 and the right hand ordinate to curves 2 and 3. The bottom abscissa refers to curve 1 and the upper portion of the top abscissa applies to curve 2 and the lower portion to curve 3.

Figure 9 shows the input versus output characteristics of the model 81 amplifier plotted on a log log scale. The rms measured noise for response settings of 2 and 3 was $.00074\mu v$ and $.000498\mu v$ respectively, while the Johnson noise for these settings was $.00015\mu v$ and $.000092\mu v$ respectively.

Figure 10 represents the values of the emissivity of tungsten for a true temperature of $2861^{\circ} K$. The dotted line represents the emissivity for a temperature of $2861^{\circ} K$ as found by Forsythe and Adams (17).

SOURCE OPTICS FOR MEAS. OVERALL RESPONSE

FIGURE 7

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Table 1

Wavelength (μ)	State	Description	Substance	Reference
.2967	Emission	BH-4,AH-4(no jack)	mercury	6,14
.3022	"	"	"	"
.3126	"	"	"	"
.3132	"	"	"	"
.3341	"	S-4	"	"
.3650	"	"	"	"
.3663	"	"	"	"
.4047	"	AH-4,BH-4	"	6,10,14
.4078	"	"	"	"
.4358	"	"	"	"
.5461	"	AH-4	"	"
.5770	"	"	"	"
.5791	"	"	"	"
.6402	"	spectrum tube	neon	13
.6507	"	"	"	"
.6907	"	AH-4	mercury	6,10,14
.6929	"	spectrum tube	neon	13
.7032	"	"	"	"
.7209	"	"	"	"
.7489	"	"	"	"
.7682	"	bunsen burner	potassium	"
.8377	"	spectrum tube	neon	"
.8654	"	"	"	"
1.0140	"	AH-4	mercury	6,10
1.1287	"	"	"	"
1.1888	"	"	"	"
1.3570	"	"	"	"
1.3673	"	"	"	"
1.3950	"	"	"	"
1.5295	"	"	"	"
1.6606	liquid absorb	0.5 mm cell	trichlorobenzine	11
1.6921	emission	AH-4	mercury	6,10,11
1.7091	"	"	"	"
1.8130	"	"	"	"
1.9701	"	"	"	"
2.1526	liquid absorb	0.5 mm cell	trichlorobenzine	11
2.2492	emission	AH-4	mercury	6,10,11
2.3126	liquid absorb	0.5 mm cell	trichlorobenzine	11
2.3254	emission	AH-4	mercury	6,10,11
2.3290	liquid absorb	0.5 mm cell	tetrachloroethane	16
2.3680	"	"	pentachloroethane	16
2.4030	"	"	trichlorobenzine	11
2.4374	"	"	"	"
2.4960	"	"	tetrachloroethane	16
2.6340	"	"	"	"

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FIGURE 9

AMPLIFIER CHARACTERISTICS FOR VARIOUS GAIN SETTINGS

FIGURE 10
EMISSIVITY OF TUNGSTEN

The correction factor, $I_{\text{effec.}}/I_{\text{dc}}$, for the various settings of the lamp follow:

Table 2

Lamp Current (amperes)	Correction Factor ($I_{\text{effec.}}/I_{\text{dc}}$)
15.0	1.000027
22.5	1.000044
30.0	1.000054
44.0	1.000140

The variation of the temperature of the ribbon filament, $\frac{dT}{T}$, turned out to be about 0.1%.

The three response curves for the three different current settings of the lamp are found in figure 11. Listed below are the lamp settings used along with the equivalent brightness and true temperatures.

Table 3

Lamp Setting (amperes)	Brightness Temperature (°C)	True Temperature (°K)
44.2	2300	2861
35.7	2000	2487
21.5	1400	1786

The overall response curves using the MacPherson arc as a source appear in figure 12. The various curves represent the different receivers used.

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FIGURE 11
SPECTROPHOTOMETER RESPONSE WITH TUNGSTEN LAMP
AT VARIOUS BRIGHTNESS TEMPERATURES

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OVERALL RESPONSE WITH VARIOUS DETECTORS

FIGURE 12

Figure 13 is a comparison of the Speedomax traces for an irradiance of 31 and 1 cal/cm²-sec. This is also an indirect comparison between the relative spectral energy distributions at the two irradiance levels. Finally, figure 14 shows the relative spectral energy distribution of the 24" arc at full irradiance.

DISCUSSION OF RESULTS

The model 81 amplifier is linear for any gain setting above 6. A full turn of the fine gain control knob is equivalent to about 1-1/2 settings on the coarse control. In determining the linearity, a source impedance of only 1 ohm was used; whereas, the impedance of say the PbS cell was of the order of magnitude of 6 megohms. However, the linearity of the amplifier should not be affected by this difference in resistance.

For either response setting 2 or 3, the actual noise level was about five times that of the theoretical Johnson noise. The noise levels found here are for a receiver impedance of about 10 ohms, which is about the impedance of the evacuated thermocouple. Since the noise is directly proportional to the impedance of the source, the noise would be much greater when the PbS cells are in the circuit.

The emissivities of tungsten at various wavelengths and temperatures compare rather favorably with those values found by Forsythe and Adams (14). In figure 10 the emissivities, found by the method outlined previously, do not vary by more than 8% from those values as found by Forsythe and Adams. The data available does not permit an estimate of the accuracy of the former determination, but the stated accuracy of the latter work by Forsythe and Adams is accurate within 5% to 8% for the entire range.

FIGURE 13

The correction factors for setting the lamp current of the ribbon filament lamp are not significant in this study. If the ammeter used were as accurate as the National Bureau of Standards calibration for this lamp, a correction of + 0.01 amps would have to be made in the 44.21 amp (true temperature of 2861°K) setting.

The 925 photo tube, used in the filament temperature variation study, has a sensitivity peak which falls to the left of the blackbody curve for the lamp set at 44.21 amps. Since the blackbody curve moves back and forth across the sensitivity curve of the 925 photo tube at a point where a slight change in the blackbody curve makes a disproportionately higher change in the output of the tube, the measured 0.1% change in dW/W is probably too high. However, the 0.1% fluctuation results in a filament temperature change of about 3° K. Since the maximum uncertainty in the brightness temperature calibration is 7° K, the ac fluctuation of the tungsten lamp can be neglected.

The overall response curves for the different brightness temperatures of the ribbon filament lamp are in substantial agreement. The greatest deviation is about 13% at 1.10 μ and 15% at 1.87 μ . Beyond the latter wavelength the deviation increases above 15%. The variation could be due to a change in calibration of the lamp since it has been used for a total of about four hours. Most of the lamp's use has been at current settings above the stated value of 36 amps. The emissivity data were arrived at by using freshly polished pieces of tungsten in most instances. The surface of the tungsten ribbon has darkened and become pitted. Because of the uncertainty of these overall response curves, it was decided to utilize the more reliable and simpler MacPherson arc.

The various overall response curves made with the different detectors do not indicate the true relative spectral sensitivity of the detectors, but instead, they represent the relative spectral sensitivity of the whole system (mirrors, windows, prism, detector). The Swiss made PbS cell has a lower signal to noise ratio than the other two PbS cells tested and it also is more sensitive in the visible end of the spectrum. However, the Perkin-Elmer evacuated thermocouple has been incorporated into the final design because of its far superior noise qualities even though its absolute sensitivity is far below that of all three PbS cells.

The Speedomax traces of the radiant output of the arc at two different irradiances, are almost identically alike. It is probably safe to assume that the relative spectral energy distribution of the arc is independent of the irradiance. The spectral distribution of the arc shown in figure 14 has been extrapolated to lower wavelengths below $.3\mu$. The peak of the distribution falls at $.5\mu$, the peak of a blackbody radiating at 5800°K . The distribution of the arc in the far visible and near infrared falls away from the ideal blackbody curve. This may be due to the fact that the cored carbons are not radiating as a black or gray body.

BIBLIOGRAPHY

1. K. M. Berkley, "Study on flash burns: The influence of ultraviolet radiation on the production of cutaneous burns," The University of Rochester Atomic Energy Project Report, UR-335, (1954).
2. K. M. Berkley and T. P. Davis, "Studies on flash burns: The influence of wavelength on the production of cutaneous burns," The University of Rochester Atomic Energy Project Report, UR-283, (1953).
3. K. M. Berkley, T. P. Davis, and H. E. Pearse, "Study of flash burns: The effect of spectral distribution on the production of cutaneous burns," The University of Rochester Atomic Energy Project Report, UR-336, (1954).
4. W. W. Coblentz and W. B. Emerson, "Reflecting power of tungsten and stellite," Bull. Bur. Standards 14,307 (1947).
5. T. P. Davis, L. J. Krolak, and R. M. Blakney, "The modification of the carbon arc searchlight for producing experimental flashburns," J. Opt. Soc. Am. 44, (1954).
6. Handbook of Chemistry and Physics (Chemical Rubber Publishing Co., 33rd edition).
7. E. O. Hulburt, "The emissive power of tungsten for short wavelengths," Astrophys. J. 45 No. 3, 149 (April 1917).
8. H. G. MacPherson, "The carbon arc as a radiation standard," Temperature Its Measurement and Control in Science and Industry (Reinhold Publishing Corporation, New York, 1941), p. 1141.
9. G. Mixter and L. J. Krolak, "Critical energy of fabric as indicated by its persistence time under thermal radiation," The University of Rochester Atomic Energy Project Report, UR-260, (1952).

BIBLIOGRAPHY

10. Perkin-Elmer Corporation, Instruction manual for model 12c infrared spectrometer.
11. E. K. Plyer and C. W. Peters, "Wavelengths for calibration of prism spectrometers," J. Research Natl. Bur. Standards 45, 462 (1950).
12. "Preparation and colorimetric properties of a magnesium oxide reflectance standard," Natl. Bur. Standards, Letter Circular LC547 (1939).
13. J. Strong, Procedures in Experimental Physics (Prentice-Hall, Inc., New York, 1949) pp. 358, 356.
14. C. E. Weitz, General Electric Lamp Bulletin LD-1, May, 1946.
15. W. Weniger and A. H. Pfund, "The reflection factor of tungsten at incandescent temperatures," Phys. Rev. 14, no. 5, 427 (1919).
16. A. G. Worthing, "The true temperature scale of tungsten and its emissive powers at incandescent temperatures," Phys. Rev. 10, 377 (1917).
17. W. E. Forsythe and E. Q. Adams, "Radiating characteristics of tungsten and tungsten lamps," J. Opt. Soc. Am. 35 no. 2, 108 (Feb. 1954).