ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
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INFRARED-EMISSION SPECTRA OF CHROMEL WIRE

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ABSTRACT

This report presents several experimental curves of the intensity of infrared radiation as a function of wavelength. The emitter is Chromel wire heated to nominal temperatures of 525°, 825°, 1125°, 1425°, and 1625°F. Theoretical curves, drawn using the Planck law, are also included. Their suitability for use in the place of experimental curves is discussed.

OBJECT

The object of the experiments reported here is to obtain experimental infrared-emission curves for heated Chromel wire. This knowledge is important in the design of equipment using Chromel wire for heat and is, therefore, of interest to the Hoskins Manufacturing Co.

A. INTRODUCTION

The opacity to infrared radiation may have a wavelength dependence in some materials. In some processes, it is desirable to have the energy absorbed in the outer surface. This would require radiation of a wavelength to which the material is opaque. In other processes, the energy should be absorbed throughout the material. For these latter cases, the radiation must be of the proper wavelength for which the material is partially transparent. Curves have been experimentally drawn to display the required emission spectra so that the proper temperature or wavelength region may be chosen.

B. EXPERIMENTAL PROCEDURE AND APPARATUS

Three problems arise in the determination of the desired infrared spectra. They are (1) heating the wire sample, (2) measuring its temperature, and (3) recording the spectra.

For better temperature determination, wire of as large a diameter as possible must be used, but the larger the wire, the larger the required current. Availability of a high-current source limited the size of the sample. A 100-ampere auto transformer was used, and it was possible to heat a piece of 10-gage Chromel wire to the required temperatures with about 70 amperes, alternating current. Figure 1 shows the electrical setup used.

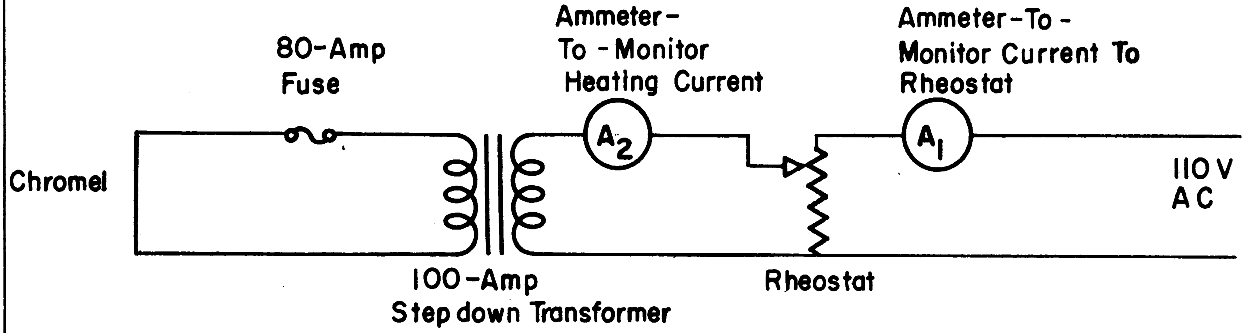


Fig. 1.

A_1 is an ammeter used to monitor the current to the rheostat, which could carry only 5 amperes. The ammeter A_2 monitors the current to the primary of the transformer and is used to maintain temperature during the recording of a spectrum.

The temperature was the most difficult measurement and is probably the least accurate. Tempilstiks[1], which are crayons that melt at or above a given temperature, were used. The 525°F temperature was determined by slowly heating the wire until the 500°F Tempilstik melted and by noting the current in A_2. Then, the current and temperature were increased until the 550°F Tempilstik melted, and again the current was noted. The average of these two currents was taken to be the current required to give 525°F, and this current was maintained during the recording of the spectrum. The temperature was then tested again with the 500°F stick melting and the 550°F stick not melting. The spectra for other temperatures were drawn in a similar manner.

The actual spectra were drawn, using a Perkin-Elmer infrared spectrometer, Model 12B. In normal usage, this instrument utilizes a glowbar for the source of infrared radiation. The glowbar is a carborundum rod 3/16 in. in diameter and which is heated electrically to about 1000°C. The radiation goes through a series of mirrors and slits, finally being dispersed by a rock-salt prism. The prism rotates and thus sends radiation of varying wavelengths to a bismuth—bismuth-tin thermocouple. The resulting potential difference is amplified and recorded by a Leeds and Northrup Speedomax recorder. This potential is then proportional to the intensity of the radiation received for the wavelength under consideration. For infrared spectral work, test absorption cells are placed in the beam and measurements made of the amount of absorption. For this series of experiments, the Chromel wire was used in place of the glowbar and no absorption cells were used.

C. PLANCK AND WIEN DISPLACEMENT LAWS

As the spectra were recorded, a resemblance to a black-body spectrum became evident. If the wire does radiate like a black body, then the spectrum can be calculated and plotted for any temperature, using the Planck law. Also, the wavelength for maximum intensity can be determined with the Wien displacement law. Both these laws are strictly valid only for black-body radiation, but are quite accurate for a material with an emissivity of about one.

[1]Manufactured by Tempil Corp., 132 W. 22nd St., New York, N. Y.

The Planck law[2] is

$$J_\lambda = \frac{C_1\lambda^{-5}}{(e^{C_2/\lambda T} - 1)}$$

where

J_λ = intensity of radiation,

λ = wavelength in microns,

T = temperature in absolute degrees,

C_1 = a constant depending on experimental arrangement, and

C_2 = a constant, 14,320.

The Wien displacement law[3] is

$$\lambda_{max\ energy} = \frac{14,320}{5T} .$$

Planck-law curves were drawn for the experimental temperatures and plotted with the experimental curves. For the higher temperatures, 1425°F and 1625°F, the Planck-law curve and the experimental curve do coincide rather well. For the lower temperatures, the Planck-law curve appears to peak at a longer wavelength than does the experimental curve. This effect may be due to absorption in the air, causing this region to appear less intense than it would in vacuum.

D. ABSORPTION

If radiation has the correct wavelength to furnish energy to some degree of freedom of a medium, then part of the traversing radiation will be

[2] J. M. Cork, Heat. (New York: Wiley, 1924), p. 25

[3] Ibid., p. 34.

absorbed by the medium. The raggedness of the experimental curves is due largely to the absorption of the air. Some molecules absorb very strongly, and these are evident in the large dips in the spectra. The dip at 4.3 microns is due to carbon dioxide, and the dip at 3 microns is due to both carbon dioxide and water vapor. The region around 6 microns has a wide water-vapor absorption band.

E. DISCUSSION OF ACCURACY

The temperature of the wire is the quantity that is measured least accurately. The best that can be done with Tempilstiks is to bracket a temperature within 50°F, because they are made only in 50°F intervals. The manufacturer claims a 1% error for each stick, which would mean 5.5° to 16.5°F. By the method used to control the temperature during a run, this smaller error should be absorbed within the 50°F range. However, for some of the temperature determinations, it was extremely difficult to decide whether the Tempilstiks had melted or not. This human weakness can not be measured quantitatively, but must be in the order of 20° to 30°F. Thus, assuming the worst combination of errors, the error could be as much as 40°-50°F, plus or minus. This would be from near 10% (for 525°F) to around 3% (for 1625°F).

The accuracy of the wavelength determination depends on a prism-setting—wavelength curve. The absorption bands of CO_2 and H_2O vapor are known, and they check the accuracy of the curve used. The wavelength determination is more accurate than the temperature measurement.

F. UTILIZATION OF CURVES

The experimental curves were normalized while being drawn. The slit of the spectrometer was adjusted so that the maximum intensity of radiation went nearly full scale. Thus, the height of the curves can not be compared to give relative intensities of radiation. Following the Stefan-Boltzman law, the hotter wire will give more intense radiation.

One can look at a curve for any of the experimental temperatures and obtain a relative idea of the intensities at various wavelengths. For the temperatures from about 1100°F and up, one can draw a Planck curve for any temperature desired and use it for the required spectrum. The absorption of the atmosphere between the source and the utilization point must be considered. As shown on the experimental curves, an absorbing gas may take a large portion of the radiation, although the gas is present at less than 1%. Other gases will absorb at other wavelengths and an atlas of absorption bands should be consulted.

For temperatures of 825° and 525°F, the experimental curves presented here can give relative intensity values. A Planck curve could be drawn, but due to the absorption in the air at the longer wavelengths, its value would be doubtful.

After trying to correct for the effects of absorption, it is evident that the wavelength of the maximum intensity appears somewhere near the value as determined by the Wien law (see Table I). This is truer for the higher temperatures. Therefore, the wavelength for maximum intensity could be predicted from the Wien law for any temperature. Of course, this again should be tempered with a knowledge of the absorption in the atmosphere between source and utilization point.

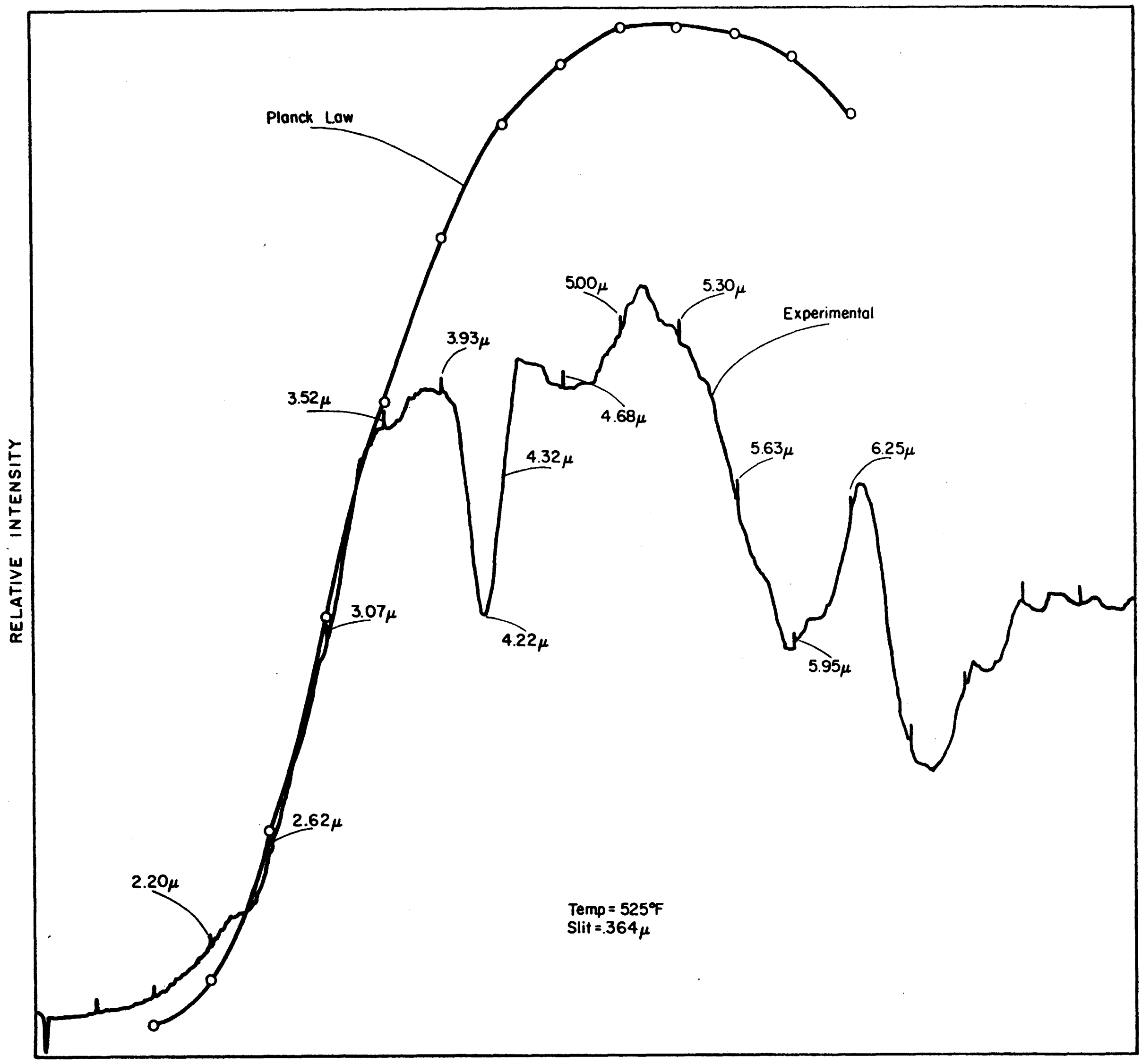
TABLE I

WAVELENGTH OF MAXIMUM INTENSITY AS DETERMINED BY WIEN DISPLACEMENT LAW

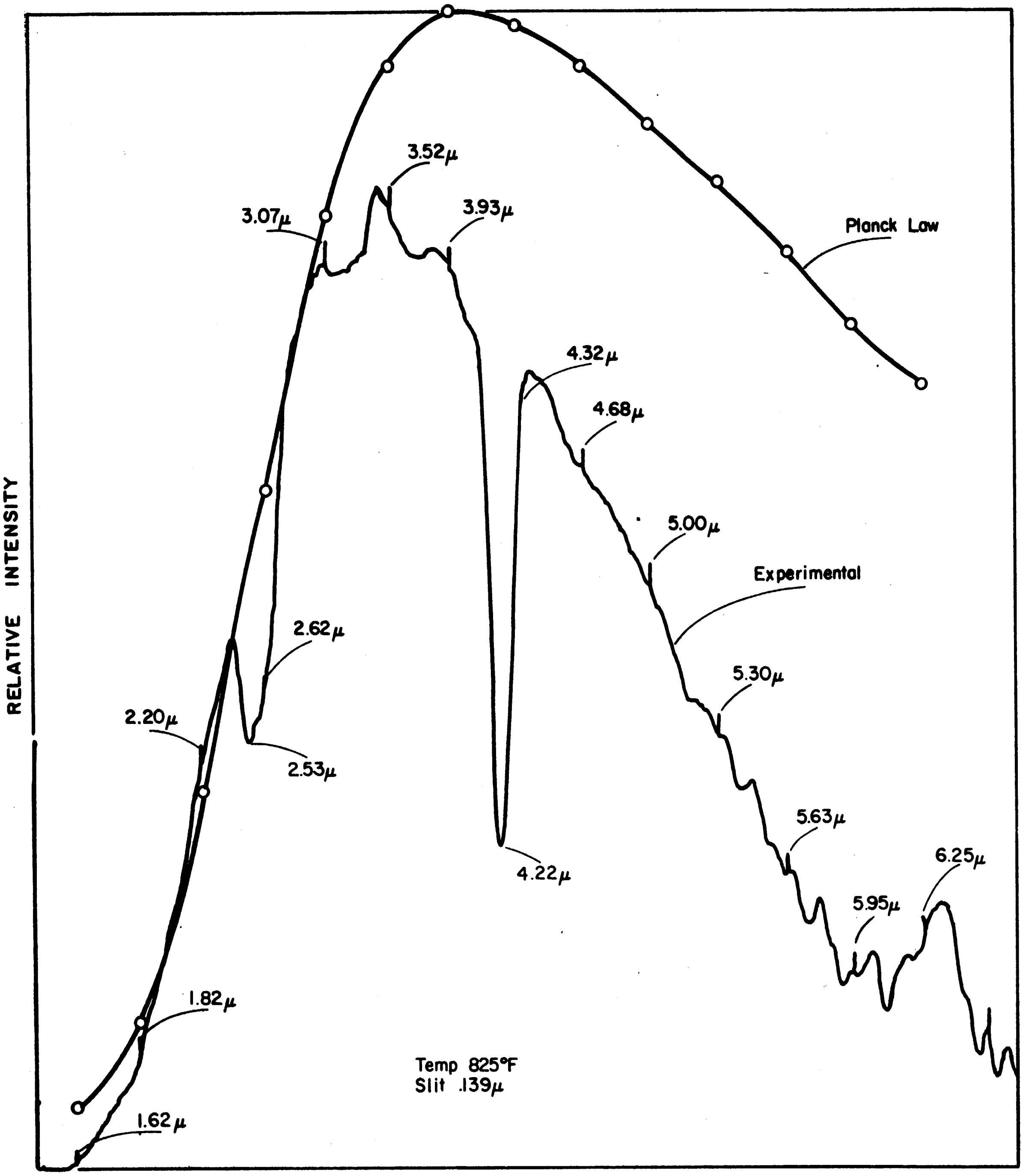
T_λ			λ_{max} intensity
525°F	=	547°K	5.29 μ
825°F	=	714°K	4.06 μ
1125°F	=	880°K	3.29 μ
1425°F	=	1047°K	2.77 μ
1625°F	=	1158°K	2.50 μ

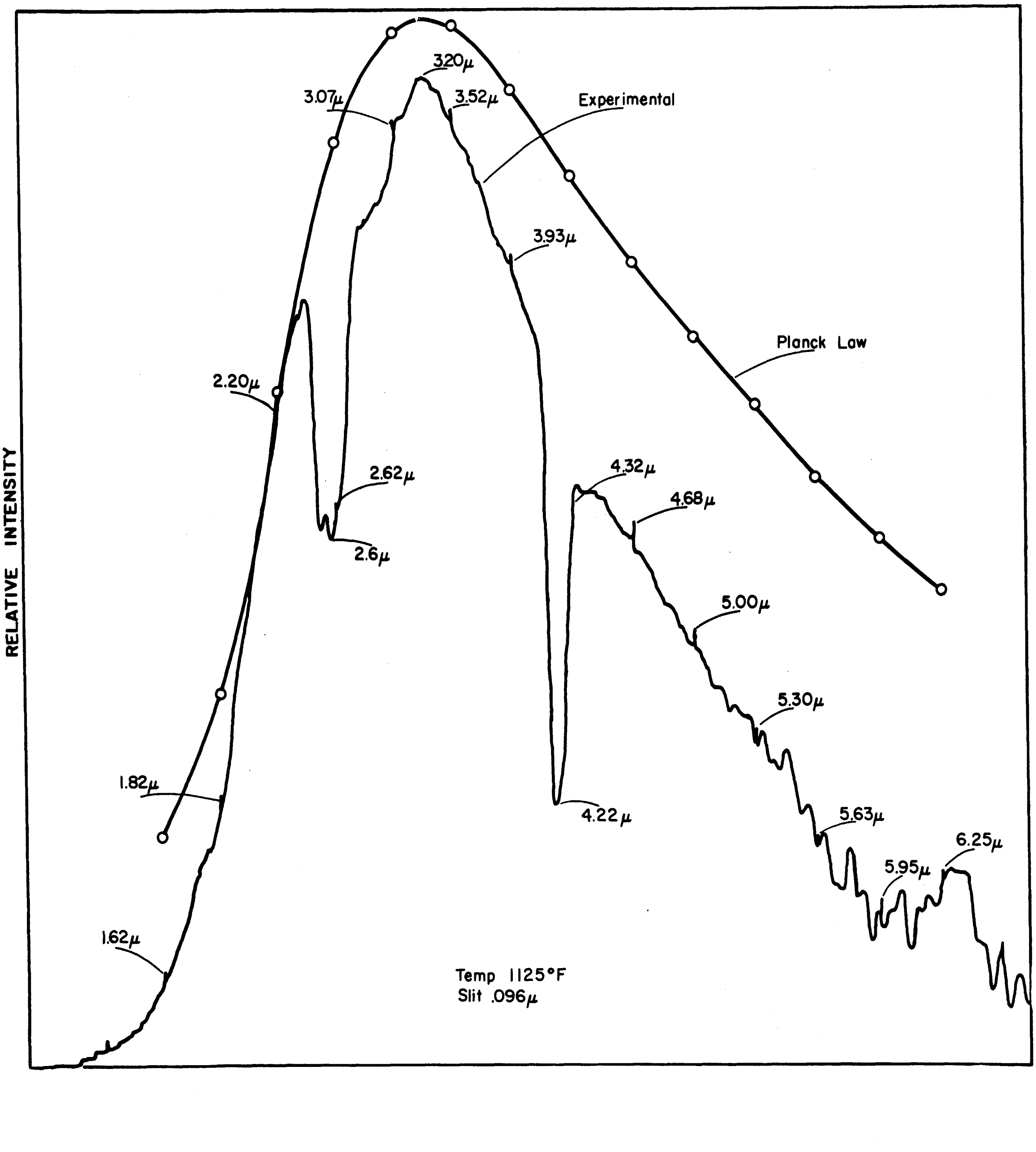
G. EFFECT OF AN OVEN OR FURNACE

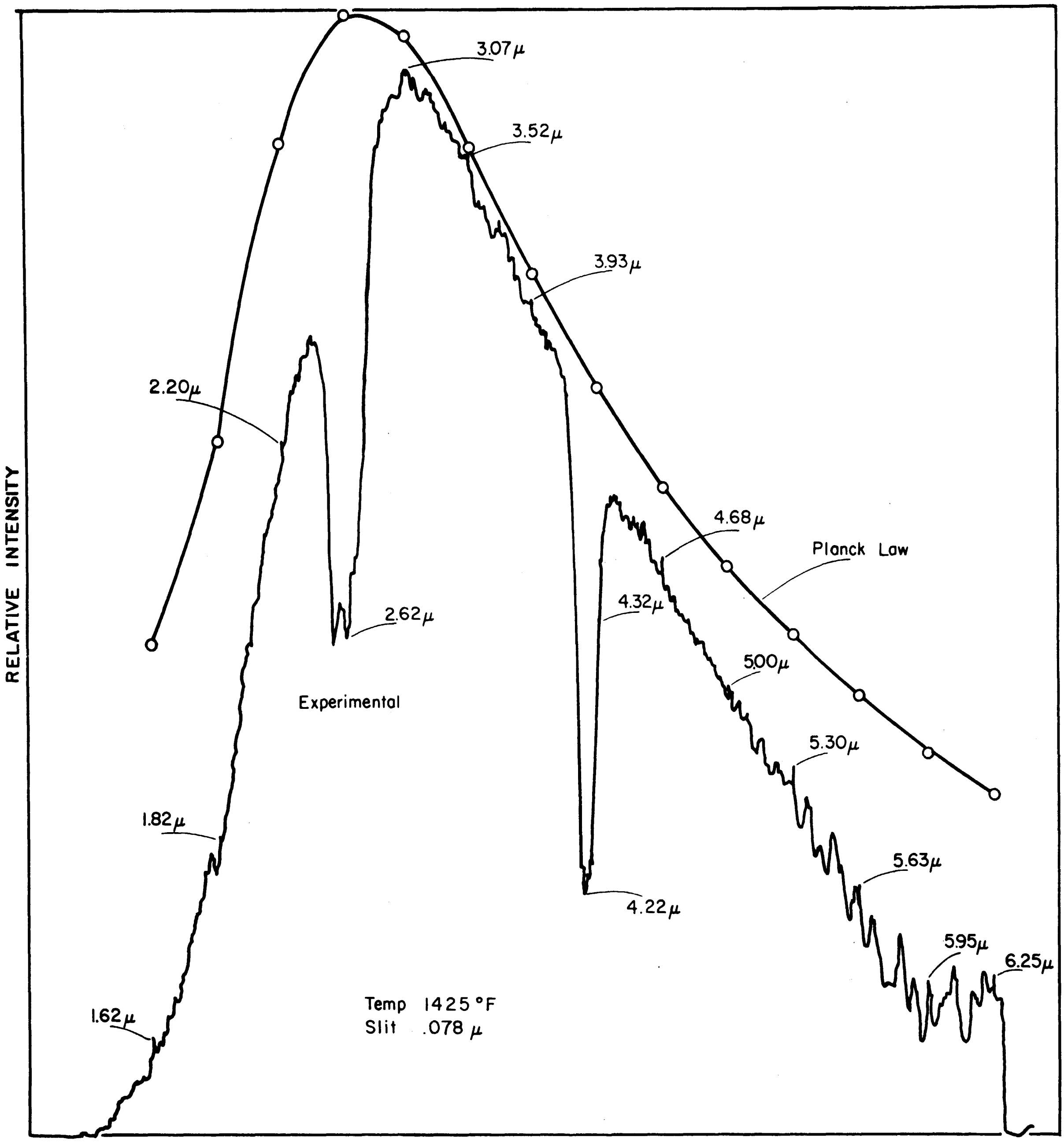
The experimental curves were drawn for a piece of wire in the open air. It is well known that a heated enclosure with only a small hole behaves exactly as a black body. Thus, if the Chromel wire is used in an oven, the infrared spectrum will be almost that of a black body at the temperature of the oven. For this case, the Planck law will give the spectrum curve with very good accuracy.



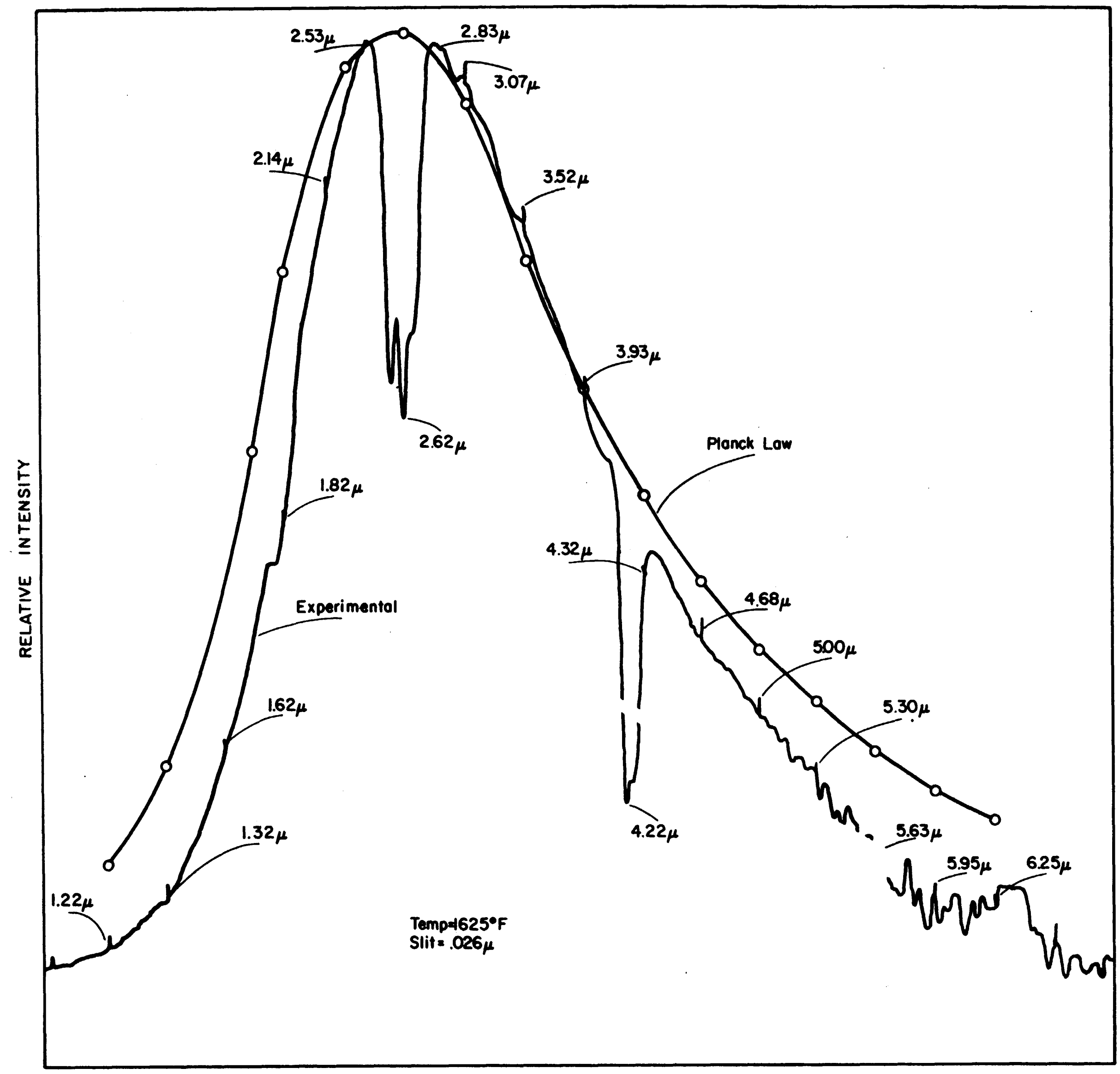
Planck Law
Experimental
RELATIVE INTENSITY
2.20μ
2.62μ
3.07μ
3.52μ
3.93μ
4.22μ
4.32μ
4.68μ
5.00μ
5.30μ
5.63μ
5.95μ
6.25μ
Temp = 525°F
Slit = .364μ


RELATIVE INTENSITY
Planck Law
Experimental
3.52μ
3.07μ
3.93μ
4.32μ
4.68μ
5.00μ
2.62μ
2.20μ
2.53μ
5.30μ
5.63μ
4.22μ
6.25μ
5.95μ
1.82μ
1.62μ
Temp 825°F
Slit .139μ


3.20μ
3.07μ
3.52μ
Experimental
3.93μ
Planck Law
2.20μ
2.62μ
2.6μ
4.32μ
4.68μ
RELATIVE INTENSITY
5.00μ
5.30μ
1.82μ
4.22μ
5.63μ
6.25μ
5.95μ
1.62μ
Temp 1125°F
Slit .096μ



RELATIVE INTENSITY
3.07μ
3.52μ
3.93μ
2.20μ
4.68μ
Planck Law
4.32μ
2.62μ
5.00μ
Experimental
5.30μ
1.82μ
5.63μ
4.22μ
5.95μ
6.25μ
1.62μ
Temp 1425 °F
Slit .078 μ


2.53μ
2.83μ
3.07μ
2.14μ
3.52μ
3.93μ
2.62μ
Planck Law
RELATIVE INTENSITY
1.82μ
4.32μ
4.68μ
Experimental
5.00μ
1.62μ
5.30μ
1.32μ
4.22μ
5.63μ
5.95μ
6.25μ
1.22μ
Temp=1625°F
Slit= .026μ